Assessing the Feasibility of a Pedestrian and Bicycle Count Program in Virginia

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PETER B. OHLMS, AICP
Research Scientist

LANCE E. DOUGALD
Senior Research Scientist

HANNAH E. MacKNIGHT
Research Assistant

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VIRGINIA TRANSPORTATION RESEARCH COUNCIL
530 Edgemont Road, Charlottesville, VA 22903-2454

vtrc.virginiadot.org

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Based on discussions with staff of VDOT's Transportation and Mobility Planning Division and Traffic Engineering Division, no formal approach or program had been established to collect or incorporate count data for bicycle and pedestrian modes throughout Virginia, thus making it difficult to plan projects, prioritize improvements, and justify investments. The purpose of this study was to identify ways to plan and implement a nonmotorized count program in Virginia including an understanding of whom such a program would serve and how frequently data would need to be collected and for what purposes.

The study tasks included (1) reviewing existing national-level guidance and examples from other state departments of transportation to determine effective ways to implement bicycle and pedestrian counting programs; (2) obtaining Virginia-specific information from localities and organizations including data collection locations and methods; and (3) developing a framework for VDOT to initiate a pilot count program in Virginia.

The study found a large volume of recent research on the topic of nonmotorized travel monitoring; several states were developing count programs and had begun putting their data to use. In Virginia, many localities were interested in some level of pedestrian and bicycle volume data collection, although relatively few already engaged in the practice. To assist with counting efforts, localities in VDOT's Salem and Northern Virginia districts expressed a high level of interest in partnering with VDOT using partnership models currently employed by the North Carolina Department of Transportation and/or the Minnesota Department of Transportation.

The study recommends that VDOT's Transportation and Mobility Planning Division, with assistance from the Virginia Transportation Research Council, establish a pilot nonmotorized count program in one or more VDOT districts. Recommended program elements include purchasing and installing count equipment; identifying opportunities for training and outreach; and working with VDOT's Traffic Engineering Division to identify an acceptable data storage mechanism. The study also recommends that the Virginia Transportation Research Council assist in evaluating the pilot program and documenting lessons learned. Providing count data that could be of use to localities and VDOT as described in this report and incrementally expanding VDOT's capabilities in this area will inform future actions including maximizing the value of efforts (by using compatible data formats and methodologies), simplifying data analysis and use, and facilitating reporting of such data to the federal data repository.

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FINAL REPORT

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Peter B. Ohlms, AICP
Research Scientist

Lance E. Dougald
Senior Research Scientist

Hannah E. MacKnight
Research Assistant

In Cooperation with the U.S. Department of Transportation
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(A partnership of the Virginia Department of Transportation
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ABSTRACT

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ABBREVIATIONS AND ACRONYMS

AADBT	Annual average daily bicycle traffic
AADPT	Annual average daily pedestrian traffic
ATC	Appalachian Trail Conservancy
CCS	Continuous count station
CDOT	Colorado Department of Transportation
DOT	Department of Transportation
FHWA	Federal Highway Administration
IP address	Internet Protocol address
ITRE	Institute for Transportation Research and Education
MnDOT	Minnesota Department of Transportation
MPO	Metropolitan Planning Organization
NCDOT	North Carolina Department of Transportation
NCHRP	National Cooperative Highway Research Program
NRVRC	New River Valley Regional Commission
NVRPA	Northern Virginia Regional Park Authority
PDC	Planning District Commission
RVARC	Roanoke Valley-Alleghany Regional Commission
RVGC	Roanoke Valley Greenway Commission
SDC	Short-duration count
TED	Virginia Department of Transportation’s Traffic Engineering Division
TJF	Thomas Jefferson Foundation
TMG	*Traffic Monitoring Guide*
TMAS	Travel Monitoring Analysis System
TMPD	Virginia Department of Transportation’s Transportation and Mobility Planning Division
TRP	Technical Review Panel
VDOT	Virginia Department of Transportation
VTRC	Virginia Transportation Research Council

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INTRODUCTION

Most state departments of transportation (DOTs) have minimal capabilities for quantifying total pedestrian and bicycle travel. Surveys provide some data; U.S. Census data showed that nearly 1 million more people reported walking or biking to work in 2013 than in 2005 (U.S. Government Accountability Office, 2015). Facilities for walking and bicycling are key elements of a multimodal transportation system, and research has provided growing evidence that cities with higher walking and bicycling rates have better road safety records. For example, one study found a lower risk of fatal crashes for all road users in “bike-oriented” cities vs. other cities based on 11 years of road safety data in California (Marshall and Garrick, 2011). However, although overall traffic fatalities nationwide steadily declined from 2004 through 2013, recorded pedestrian and bicycle fatalities increased, both in absolute numbers and as a proportion of all traffic deaths (U.S. Government Accountability Office, 2015). The Virginia Department of Transportation (VDOT) documented an increase in Virginia bicycle fatalities in recent years and a continuing increase in the proportion of pedestrian deaths among total highway deaths (VDOT, 2017a). The picture is incomplete because of a lack of data on how many people are walking and biking, along with where and when.

A 2016 nationwide survey of bicycle and pedestrian coordinators and transportation planners at state, regional, and local agencies that received 133 responses (19% response rate) found that 20% of respondents had at least one permanent bicycle count site (i.e., a location equipped with automated bicycle count equipment), with 40% having at least one annual temporary bicycle count site. One-third of respondents did not collect any bicycle or pedestrian count data. Although respondents thought safety was important, they often did not have the studies or data to support their decisions (Grossman and Watkins, 2017).

In order to assess exposure hazards for pedestrians and bicyclists, there is a need to understand better spatial and temporal patterns of nonmotorized traffic volumes (Hankey et al., 2016). One of the challenges for transportation agencies is the lack of documentation on pedestrian and bicycle usage and demand. Without such data, it is difficult to determine whether increases in the number of pedestrian and bicycle crashes are attributable to issues with transportation facility designs or to increased rates of walking and bicycling. It is also difficult to measure the positive results of investments in these modes and to calculate performance measures, which are comparatively better established for motorized travel modes. In 2015, the Federal Highway Administration (FHWA) released its *Guidebook for Developing Pedestrian and Bicycle Performance Measures* (Semler et al., 2016), which is intended to help communities fully integrate pedestrian and bicycle considerations into ongoing performance management activities, including how measures can be tracked and what data are required.

In recent years, there has been a paradigm shift within transportation agencies to account for and incorporate nonmotorized travel in business and strategic highway safety plans. VDOT's FY16 Business Plan included "delivering a safe and reliable multi-modal transportation system" as a component of its five key performance areas: Plan, Deliver, Operate, Maintain, and Support (VDOT, 2015). In addition, DOTs are required under FHWA's Highway Safety Improvement Program to provide a framework for reducing fatalities and serious injuries on all public roads. As of September 2017, VDOT had committed about 15% ($75 million) of its available funds under the Highway Safety Improvement Program to bicycle and pedestrian safety projects that were planned or ongoing (Cole, 2017).

Several recent federal initiatives have been developed to encourage the creation of safer, more comfortable, and more connected bicycling and walking environments. The Safer People, Safer Streets Initiative, launched in 2014, is focused on strengthening partnerships among DOTs, local officials, safety experts, planners, engineers, advocacy groups, the public, and other stakeholders (Milne and Melin, 2016). One of the highlights of the initiative includes data collection. In 2015, FHWA and the National Highway Traffic Safety Administration initiated the Bicycle-Pedestrian Count Technology Pilot Project to collect more accurate data on pedestrian and bicyclist activity to support planning and investment decisions and targeted safety improvements (Baas et al., 2016). Further, the 2013 update of FHWA's *Traffic Monitoring Guide* (TMG) was the first edition to include a chapter on nonmotorized traffic, comprising information on monitoring pedestrians, bicyclists, and other nonmotorized road and trail users (FHWA, 2013). The TMG includes the data format requirements for the Travel Monitoring Analysis System (TMAS), a national traffic volume database maintained by FHWA.

As the number of federal pedestrian and bicycle initiatives has increased, so has research activity with respect to developing and executing successful nonmotorized count programs, and with advancements in research, state-administered count programs began to emerge. Several states have initiated count programs to evaluate the utility of new facilities, identify frequently used routes, and calculate mode share. Many more local and regional agencies have established data collection programs of varying scopes and with varying data collection methods. Some local governments and other organizations have implemented automatic counting equipment that provides short-duration count (SDC) or continuous count data. With some exceptions in urban areas and on major off-street trails, VDOT has not typically collected or made use of these data, which vary in terms of quality and availability.

In 2017, VDOT's Maintenance Division approved an updated Instructional and Informational Memorandum regarding paved shoulders for bicycle use (VDOT, 2017b). One criterion for including a minimum 2-foot paved shoulder on roadway sections that are part of a paving schedule was that "the roadway has a significant enough bicycle volume that providing a paved shoulder, or additional paved shoulder width, would help reduce conflicts with motor vehicles and thus promote safety." It did not specify how bicycle volumes were to be determined.

In September 2015, VDOT installed seven permanent automatic counters on the Virginia Capital Trail east of Richmond and investigated how to use the data being collected. However, based on discussions with staff of VDOT's Transportation and Mobility Planning Division (TMPD) and Traffic Engineering Division (TED), no formal approach or program had been established to collect or incorporate count data for bicycle and pedestrian modes throughout Virginia, thus making it difficult to plan projects, prioritize improvements, and justify investments. The TMPD requested research on developing a statewide nonmotorized count program, which ranked as the number one priority at the spring 2016 meeting of the Virginia Transportation Research Council's (VTRC) Transportation Planning Research Advisory Committee.

PURPOSE AND SCOPE

The purpose of this study was to identify ways to plan and implement a nonmotorized count program in Virginia including an understanding of whom such a program would serve and how frequently data would need to be collected and for what purposes.

The scope included reviewing existing national-level guidance and examples from other state DOTs to determine the most effective ways of implementing a nonmotorized (bicycle and pedestrian) count program in Virginia in terms of counting method(s) that could be used (manual and/or automated); options for data warehousing; and count site selection, duration, and frequency. A primary consideration was how a state-level counting program could be incorporated into VDOT's routine business activities. A detailed system design for a potential count program was outside the scope of this study but could be included in future efforts, along with the development of guidance on specific data quality control measures and data management and/or an investigation of performance measures for bicycle and pedestrian transportation that would use the count data.

METHODS

Four tasks were undertaken to achieve the study objectives:

1. Conduct a literature review of relevant information regarding nonmotorized travel monitoring programs, practices, and technologies.

2. Obtain information from other states with regard to their nonmotorized count programs.

3. Obtain Virginia-specific information on ongoing nonmotorized counting efforts including data collection locations and methods.

4. Develop a framework for a pilot nonmotorized count program in Virginia.

Conducting the Literature Review

A review of the literature was undertaken to obtain relevant information regarding nonmotorized travel monitoring programs, practices, and technologies. Of particular interest were studies containing guidance on how to establish and maintain a nonmotorized data collection program and literature describing efforts in other states or in specific regions. Other literature was also reviewed that pertained to the following topics:

- *Evaluations of the accuracy and practicality of specific technologies for site-based nonmotorized data collection.* This included computer vision/video evaluations but excluded studies that simply summarized detailed algorithms for video image processing optimization.

- *Studies of route-tracking smartphone applications (apps) and crowdsourcing data.*

- *Studies outlining methods for count* adjustments (e.g., for weather conditions and seasonality), factoring, or quality assurance.

- *Descriptions of data warehouses and archives for nonmotorized count data.*

- *Studies primarily describing how counts are used.* Although such studies are of limited usefulness for developing a count program, they give examples of the benefits of doing so.

- *Older studies that may be of historical interest.*

The VDOT Research Library conducted a broad search using subscription databases and freely accessible search tools (Winter and Anglada, 2016).

Obtaining Information From Other States

This task involved gathering information from other states with nonmotorized count programs. The dual focus areas of this task were to identify those states that have taken steps to collect count data for walking and bicycling and to document their methods, scope, costs, and successes and challenges in collecting and managing data.

Three states (Colorado, Minnesota, and North Carolina) were identified by a review of literature describing efforts in other states and through an informational interview with Jeremy Raw, Community Planner, FHWA Office of Planning. Information about each state’s efforts was obtained from the literature and through semi-structured interviews of public agency staff and/or researchers involved in each state's program (interview questions are provided in Appendix A). Where available, websites for state-administered counting programs in these and other states were also reviewed.

Obtaining Virginia-Specific Information Including Data Collection Locations and Methods

Ongoing Efforts

Information about ongoing nonmotorized counting efforts in Virginia was obtained through informational interviews with David Patton, Bicycle and Pedestrian Planner, Arlington County; Steve Hankey, Assistant Professor, Virginia Tech; staff of VDOT's TED and TMPD; and representatives of the crowdsourced data firms Strava and StreetLight.

Inventory of Data Collection Locations and Methods

This task involved creating and deploying a survey to gather information from counties, towns, cities, and metropolitan planning organizations (MPOs) in Virginia. The survey was designed to document the extent to which nonmotorized count data were collected in Virginia, the methods and technologies used, how data were shared and stored, how or if data quality was addressed, and the benefits of collecting these data.

Developing the Survey Instrument

An initial draft of survey questions was developed and shared with the study's technical review panel (TRP), which included members with experience in traditional travel monitoring and/or pedestrian and bicycle planning in Virginia. Collectively, the TRP noted several suggestions such as simplifying questions; restructuring to avoid double-barreled questions; replacing subjective quantities (e.g., the terms "several" and "many") with numeric quantities or ranges; elaborating on questions so respondents could give more informed answers; and reformatting answer choices to enable more concise analyses. Based on comments from the TRP, the survey was revised, uploaded to the cloud-based SurveyMonkey platform, and subsequently pilot-tested by the TRP and staff of the City of Charlottesville and Arlington County. Upon receiving feedback from the pilot-test participants, additional revisions were made and a final pilot-test was conducted by staff of the Richmond Regional Planning District Commission.

The general form of the final survey instrument is shown in the flowchart in Figure 1. Based on answers to questions, skip logic (also known as "conditional branching" or "branch logic") was developed, allowing a path through the survey that varies based on a respondent's answers. Appendix B lists questions in the survey; because of the skip logic feature, some questions appear as duplicates in the list but would not have appeared so to an individual respondent.

Figure 1. General Form of Survey Instrument. NC = North Carolina.

Conducting the Survey

When the survey was distributed, the objective was to provide an opportunity for input from every county, city, town, MPO, and planning district commission (PDC) in Virginia. To meet this objective, the first step was to obtain or develop a list of initial contacts, including a telephone number and email address, for each locality (i.e., city, county, or town), MPO, and PDC. VDOT's Local Assistance Division provided an initial list of email addresses for county administrators and city and town managers, and the researchers reviewed locality websites to obtain contacts in departments of planning, economic development, or parks and recreation. In cases where specific department listings were not found, the contact points remained the administrators and managers. The list of initial contacts was populated for all 95 counties; 39 cities; 112 of 190 towns (some of Virginia's towns are very small and had not had contact with the Local Assistance Division or lacked email addresses); and all 25 MPOs and PDCs operating in Virginia. In addition, contacts were created for other organizations known to operate pedestrian and/or bicycle trails or counting equipment, including the Northern Virginia Regional Park Authority (NVRPA), Bike Walk RVA, the Roanoke Valley Greenway Commission (RVGC), the Appalachian Trail Conservancy (ATC), and the Thomas Jefferson Foundation (TJF).

Because it was anticipated that a survey instrument distributed solely by email would have a low response rate, telephone calls were made to every contact. If a direct connection was made (telephone was answered), an introduction to the project was given followed by the question of who would be the most appropriate person to complete the survey for the organization. In most cases, the initial contact was the appropriate person. If not, he or she provided another contact's telephone number and email address, and the process was repeated. In cases where the contact person did not answer the telephone (approximately 50% of the time), a message was left on voicemail. Immediately after discussing the project and introducing the survey with each contact (either directly or by voicemail), the researcher sent a link to the survey via email.

Analyzing the Survey

As discussed in the "Results" section, an assumption was made that counting was not performed by localities and organizations that did not respond to the survey. Although the researchers acknowledge that some non-responders may have conducted counts, this assumption was deemed prudent for a more complete, big-picture analysis.

The process for analyzing the survey essentially mimicked the flowchart in Figure 1. The first step was to filter responses from localities and organizations that had counted at any time since 2010 and those that had not counted. Once this was accomplished, analyses were conducted for each group using the following outline:

I. Respondents who conducted only sporadic (as-needed) counts
   A. Methods of counting (manual/automatic)
   B. Purpose of counting
   C. Frequency of counting

II. Respondents with continuous or periodic (recurring) count programs
    A. Methods of counting (manual/automatic)
    B. Purpose of counting
    C. Frequency of counting
    D. Number of counting locations
    E. Automated counting technologies
    F. Data storage and services
    G. Data validation and quality assessment
    H. Data sharing
    I. Program funding
    J. Program oversight

III. Interest in counting (non-counters and both categories of counters outlined previously)
    A. Beneficial locations
    B. Interest in partnering with VDOT using the North Carolina DOT (NCDOT) program model
    C. Interest in partnering with VDOT using the Minnesota DOT (MnDOT) program model
    D. Overall interest.

To perform analyses on these topics, several survey housekeeping tasks first needed to be addressed. These involved the following:

- *Combining questions that were duplicated along different paths in the survey logic to allow for a more thorough analysis of each question.*

- *Analyzing incomplete responses.* Because the question requesting the name of the respondent's locality or organization occurred toward the end of the survey, responses that were incomplete were analyzed in one of three ways using the respondent metadata provided by SurveyMonkey:

    1. If an incomplete response had a duplicate Internet Protocol address (IP address) and the other response was more complete and contained the same answers (for questions that were answered on the incomplete one), the less complete duplicate response was deleted.

    2. If an incomplete response had answers that provided insight as to what locality it was (beyond a reasonable doubt), the locality name was added to the response and the response was further analyzed.

    3. If an incomplete response was almost complete but still did not contain any identifying information *and* had a duplicate IP address, the IP address was run through an IP address search engine. If the search engine produced a locality result, that locality name was added to the response. If that locality had already provided a complete response, the incomplete duplicate was deleted.

Any incomplete responses that were not identified as duplicates were analyzed for the questions that had been answered (e.g., if a survey response contained only a response to Question 1, that response was added into the analysis of Question 1 only).

- *Analyzing duplicate responses.* Responses for localities that had duplicate responses (whether from multiple individuals/departments or the same person) were merged to reflect properly the quantities of localities responding and to ensure the most accurate data were being used (for example, if one department conducted counts and another did not, the locality was deemed to be conducting counts and the response from the counting department was used). Alleghany County, Roanoke County, Spotsylvania County, and the Town of Vienna had duplicate responses.

- *Sorting responses by organization and locality type (i.e., county, city, or town).* Population, land area, and population density estimates based on the 2010 Census (U.S. Census Bureau, 2016) were evaluated for trends in responses to certain questions.

- *Sorting responses by VDOT district to determine counting status and trends within each district.*

- *Conducting statistical hypothesis testing on interest ratings for the NCDOT and MnDOT programs.* These included the Wilcoxon signed-rank test to determine statistical significance of interest ratings (on a scale of 1 to 5) within each VDOT district and the Mann-Whitney U test to determine if one type of partnership was favored over the other within each VDOT district.

Developing a Framework for a Pilot Nonmotorized Count Program in Virginia

A framework for a pilot nonmotorized count program in Virginia was developed based on the researchers' understanding of the state of the practice as informed by the literature and information obtained from other states. Survey results indicating the interests of Virginia localities were also considered, along with feedback from the study's TRP and other VDOT stakeholders.

RESULTS AND DISCUSSION

Literature Review

The results of the literature review are organized into the following general topic categories:

- guidance on how to establish and maintain a nonmotorized data collection program

- summaries of efforts in other states or in specific regions

- evaluations of the accuracy and practicality of specific technologies for site-based nonmotorized data collection (this included computer vision/video evaluations but excluded studies that simply summarized detailed algorithms for video image processing optimization)

- studies of route-tracking smartphone apps and crowdsourcing data

- studies outlining methods for count adjustments (e.g., for weather conditions and seasonality), factoring, or quality assurance

- descriptions of data warehouses and archives for nonmotorized count data

- studies primarily describing how counts are used (although these studies are of limited usefulness for developing a count program, they give examples of the benefits of doing so)

- older studies that may be of historical interest (excluded from this report but available from the authors).

A more detailed summary of the literature including its sources is provided in Appendix C.

Program Guidance

In the area of general program guidance, the literature and conversations with experts revealed that two key resources for this topic were the *Traffic Monitoring Guide* (FHWA, 2016) and National Cooperative Highway Research Program (NCHRP) Report 797, *Guidebook on Pedestrian and Bicycle Volume Data Collection* (Ryus et al., 2014a). These comprehensive guides summarized current methods for nonmotorized traffic data collection, including site selection and technology options for automated counters. Other studies provided recommendations on implementation of a coordinated nonmotorized data collection program based on the experiences of individual states or regions. Some of these were broad and wide-ranging (e.g., North Central Texas Council of Governments et al., 2013), and others outlined specifics related to a topic such as site selection (Jackson et al., 2015) or multi-use trail networks (Lindsey et al., 2017). One recurring theme in studies with general program guidance was that planners and engineers should recognize the differences between motor vehicles and bicycles and pedestrians in terms of scale, distribution, variability, and trip lengths and the resulting differences in designing a monitoring program.

Efforts in Other States and Specific Regions

More than 20 studies were reviewed that summarized nonmotorized data collection efforts in other states, including Colorado, Minnesota, Oregon, and Washington, or in specific regions. These studies documented a nascent but quickly evolving field of transportation engineering and planning with various approaches to collecting data; state/local cooperation; data analysis, storage, and use; and program institutionalization. No state had a fully complete picture of nonmotorized travel, but a combination of travel survey data, short- and long-term sample-based count data, and travel models provided useful estimates. Data collection recommendations included integrating short-term and long-term counts, having at least five to seven continuous counters per factor group (a set of sites with similar volume patterns), counting bicycles and pedestrians separately, and having at least 7 days of counts. Several studies recommended scaling SDCs to yearly volumes, which requires adjustment factors that are generally location dependent and cannot be applied statewide. Data quality assurance can require substantial effort.

States and regions found that technology applicability was location specific. Although automated counters are becoming more common, manual counts remain an important element of many state and regional programs and can provide a large number of SDCs that are supported by a relatively smaller number of continuous counts. Manual counts are labor intensive but reasonably accurate and can collect user information beyond volumes (e.g., behaviors). Statewide coordination of counts and/or integration into existing motor vehicle count databases can support data standardization and easier analysis.

Technology Evaluations

More than 30 studies that evaluated automated count technologies were reviewed. Two key resources in this area were efforts related to NCHRP Report 797 in which multiple automated count technologies in different settings, including weather and traffic conditions, were evaluated to determine accuracy and reliability (Ryus et al., 2014b; Ryus et al., 2016). Correction factors were given for the following types of tested automated count technologies: passive infrared, active infrared, pneumatic tube, radio beam, inductive loop, piezoelectric strip, radar, and thermal imaging sensors, but the authors noted that it is critical for practitioners to calibrate and evaluate the effectiveness of the counters they install at specific sites, which could include developing site-specific correction factors. Calibration requires site-specific baseline data, which can be time-consuming to collect or reduce from video footage. Many studies found that technologies that worked adequately in a controlled environment had more difficulty under real-world conditions. Factors affecting the accuracy of automated count technology included presence of mixed traffic, facility width, device placement and installation, calibration, classification schemes, and arrival patterns (e.g., occlusion from bicyclists riding side by side or people walking in groups). Evaluations often revealed that products undercounted pedestrians and bicyclists because of occlusion. In more recent studies, weather and temperature did not affect most technologies. Table 1 lists the number of studies that covered each technology and summarizes key findings.

Table 1. Key Findings for Each Technology From the Literature

Technology (Description)	No. of Studies	Key Findings
Passive infrared (detects infrared radiation given off by pedestrians and bicyclists passing the sensor)	8	Satisfactory results in pedestrian-only environments when volumes were low and the counter was properly located; successful at an intersection in 1 study; easier to deploy than a thermal sensor but undercounted substantially at high-volume sites; not affected by rain or snow; nonparametric statistical method was recommended for calibrating raw data; detection algorithm modifications can improve accuracy.
Active infrared (detects users breaking an infrared light beam from transmitter to receiver)	4	One study was affected by a bird that kept flying in front of the device; rain did not appear to affect the device, but some uncertainty remained; acceptable for on-road use.

Pneumatic tubes (detect pulses of air generated when tires pass over the tubes—includes standard pneumatic tubes and bicycle-specific versions)	8	Accurate bicycle counting technology for mixed traffic conditions; low cost; more accurate with bicycle-specific vehicle classification schemes when counting bicycle traffic within a shorter distance (4 or 10 ft from counting device, depending on the study) and when using bicycle-specific tubes; high undercount errors when cyclists ride side by side or in groups; accuracy decreased as bicycle and auto traffic increased; details of equipment and installation matter; avoid using tubes across multiple lanes to count bicycles, although it is possible to count both sides of a 2-lane road no wider than 27 ft using bicycle-specific tubes; substantial validation and calibration were required. One 2014 study found them to be inaccurate.
Radio beam (detects users breaking a radio beam from emitter to receiver)	2	Relatively high error.
Inductive loops (electric current running through a loop embedded in the pavement or placed on top of the pavement produces a magnetic field that detects magnetic objects including bicycles)	9	Relatively low error; loops at intersection approaches in mixed traffic were not recommended for counting purposes, although at least 1 product could differentiate bikes from autos; suitable for off-road paths and separated bike routes, but if bike volumes exceed 200/hr or 50/15 min, occlusion becomes an issue; placement away from electrical interference is vital; installation, settings, and maintenance matter; loops in off-street paths can function well for 10 years with little or no maintenance.
Piezoelectric strips (emit electrical signals when deformed as bicycle wheels pass over them)	4	Varying error; suitable for off-road paths and separated bike routes; some devices acceptable for on-road use.
Radar (detects users based on reflected electromagnetic pulses)	2	Moderate error; will not count during rain.
Thermal cameras (combination of overhead passive infrared detection and automated imaging technology)	5	Not recommended for counting purposes at intersection approaches in mixed traffic; produced less error than passive infrared in 1 study; not affected by rain or snow; children may not be counted because of their height; setup and calibration are important.
Computer vision / automated video (visual algorithms detect and classify users from video frames)	6	Evolving quickly but not reliable enough for practical deployment as of 2013; algorithms were not well suited for video quality and could not classify objects reliably as of 2014. By 2015, feasible and accurate for multiple-direction counts, especially with more separation of users (e.g., cycle track vs. mixed traffic); complex intersection movements could reduce accuracy; combinations of specialized equipment such as stereo cameras and laser scanners can count pedestrians walking in groups.
Bluetooth and Wi-Fi (detectors record unique identifiers of enabled devices passing by)	2	Using Bluetooth alone was not feasible as of 2016; Wi-Fi had comparatively high detection rates (but still only 26.4%); double-counting and user classification were challenges, although an algorithm could eliminate the former.
Laser scanners (detect users based on reflected laser pulses)	2	Can determine height and width of humans and their position, direction, and velocity; can count people walking in groups; oblique mounting may be a challenge.
Depth cameras (dot matrix of infrared light captured by a receptor creates a 3-dimensional image of a scene)	1	Acceptable counting performance in low to moderate volumes, including in low-light conditions that thwart computer vision; occlusion was a limitation.
Ultrasonic sensors (transmits an ultrasound wave of a set duration and uses the echo to measure distance)	1	Appropriate for wide sidewalks without walls, a condition that challenges infrared-based systems; very high energy consumption (battery life of only a few days).
Signal controllers (logging of pedestrian phase calls from pushbutton presses and bicycle calls, typically from inductive loops)	3	Pedestrian-pushbutton phase logging using signal controllers may be a cost-effective method to estimate pedestrian activity if correction factors can be calculated and the signal is not on pedestrian recall; counts from bike detection loops in mixed traffic were not useful.
Manual counts (humans equipped with clipboards and paper or mechanical clickers)	2	Manual counts with either paper or clickers systematically undercounted pedestrians; error rates were greater at the beginning and end of the observation period, possibly because of the observer's lack of familiarity with the tasks or fatigue, but this could be overshadowed by unreliability because of the infrequent, short-duration nature of most volunteer count programs; video recordings should be used for studies when count accuracy is the main concern.

Route-Tracking Tools

Five studies looked at crowdsourced route data or “big data” solutions collected from smartphone apps such as Cycle Atlanta, CycleTracks, and Strava. Such apps can help with data collection on infrastructure preferences of bicyclists by tracking routes in a more ongoing way than surveys can (i.e., by using smartphone location data to record paths of travel for each trip). Crowdsourced data can also improve the prediction capabilities of travel demand models by incorporating factors such as slopes, traffic speeds, and on-street parking (where such data exist). It is not necessary for cities to develop their own apps from scratch; rather, existing apps can be modified or extended. Limitations include a biased user group of only those with smartphones that may not be representative of the overall community but may possibly be representative of the cycling community (e.g., one dataset was dominated by white male cyclists aged 25 to 44; another indicated a skew toward male fitness cyclists). In addition, the small numbers of trips on some links might not reach statistically significant levels.

Count Adjustments, Factoring, and Quality Assurance

Factoring transforms SDCs into annual average volumes to be used for planning. Continuous count sites are organized by travel characteristics or factor groups, which informs seasonal correction factors. Six studies looked at aspects of estimating annual average daily bicycle traffic (AADBT). Beitel et al. (2017) evaluated the quality of AADBT figures that were extrapolated from short-term counts and found an average absolute relative error from 3% to 13.5%. El Esawey (2016) and Hankey et al. (2014) compared various methods for obtaining AADBT and found that a day-of-year method was more accurate than others, such as day of week or month of year. This method requires a full year of daily bike volume data and is not temporally transferable for forecasting or backcasting; rather, it is useful only for estimating AADBT for other short-term count sites in the same year. El Esawey et al. (2013) developed daily adjustment factors and suggested transferring daily factors spatially from other stations, even if they belong to a different road class, rather than using factors of similar stations of a different year. Beitel and Miranda-Moreno (2016) recommended applying disaggregated factor methods with filtering to long-term counting sites from various regions over multiple years to continue improving AADBT estimation.

Six studies applied various tools (e.g., a negative binomial model) to estimate variations in bicycle or total trail traffic volumes based on various factors. Factors affecting counts from these studies included weather (alternatively modeled as temperature, precipitation / rain / rain in the past 3 hours, humidity, and/or clearness), season, holidays, day of week, sociodemographics, built environment characteristics, and street type. These models are not necessarily transferrable from one city to another. Wang et al. (2016) found that their models could not be applied successfully to other cities and were suitable for planning but not for engineering studies. Hankey et al. (2012) found that 1-hour counts were highly correlated with 12-hour counts. Count sites are often classified contextually, although classification schemes vary; one uses five clusters (utilitarian, mixed-utilitarian, mixed-recreational, recreational, and non-urban–recreational).

El Esawey and Mosa (2015) addressed K factors (the proportion of annual average daily traffic occurring in 1 hour) for bicycle traffic and recommended (1) using local data to calculate K factors while realizing that such data could vary greatly from one location to another, and (2) calculating different K values for weekdays versus weekends and using them with hourly bicycle volume data collected during a summer weekday.

Turner and Lasley (2013) looked at data quality procedures for nonmotorized traffic count data and identified three key principles: (1) quality assurance starts before data are collected; (2) acceptable quality is determined by the data's use; and (3) measures can quantify varying quality dimensions. Automated processes can help with identifying poor-quality data, but manual review may still be necessary.

Data Warehouses and Archives

Four studies summarized efforts to establish regional or national nonmotorized count data clearinghouses for data aggregation, sharing, and reporting. Huff and Brozen (2014) and Tischler et al. (2014) described bicycle-only databases; Zhang et al. (2014) described a pedestrian-only database; and Nordback et al. (2015) described a database that was to include both. Typical components included the ability to import data, evaluate data quality, produce visualizations, and download data. Other potential capabilities could include AADBT or annual average daily pedestrian traffic (AADPT) estimation and safety analysis. Challenges to establishing and maintaining data archives included funding, data standardization, institutionalization, integration with existing archives of motor vehicle volume information, and completion of the underlying data on bicycle and pedestrian facilities. Huff and Brozen (2014) pointed out that without a standard count methodology, "as more and more agencies conduct counts, the set that results from compiling these data together is frustratingly incomplete for the purposes of identifying general use trends and factors as well as regional patterns."

Applications of Nonmotorized Count Data

Studies in this category serve as examples of how nonmotorized count data can be applied, illustrating some potential benefits of data collection. Ten studies applied count data to answer planning and engineering questions. In synthesizing methods to estimate exposure to risk, Turner et al. (2017) found that facility-specific exposure analyses tend to use counts in combination with models and that geographic scale is a key parameter in determining methods for exposure estimation. Rasmussen et al. (2013) and Fields et al. (2014) aggregated count data collected as part of the federal Nonmotorized Transportation Pilot Program to estimate mode share changes and other measures, finding (for example) that increased bicycling and walking activities in pilot communities between 2007 and 2011 were equivalent to 3 million gallons of gas saved or that the length of the bike network near a count location was associated with increases in the rate of change in its counts over time. Wadud (2014) used a negative binomial model, developed with automated bicycle count data, to estimate how climate change would affect bicycle flows in London.

Four studies developed models for volume estimation based on count data. Factors affecting bicycle and/or pedestrian volumes in these models included presence of bicycle facilities, hills, number of jobs, nearby commercial properties, population, origin-destination centrality, transit stops, presence of a median, number of lanes, and number of intersection legs or approaches. Each model had different limitations, such as being based on count hours that were inconsistent, ignoring weather effects, using small sample sizes of counts as inputs, using buffer distances rather than network distances, being based on data from a limited geographic area, and requiring data and computational power that might be unavailable for some localities. Such models can be useful for planning, prioritization, and safety analysis, but actual counts rather than models should be used for site-level analyses.

Strydom and Mavroulidou (2009) found that automated and manual counts could give differing results on the necessity of a pedestrian crossing, with the automated count being more advantageous because it identified the actual peak hours. They noted that if several counts or studies were to be conducted, automatic counting equipment was desirable and that manual counts should be used only for validating the automatic count equipment.

Kingsley et al. (2013) summarized several tools for estimating the benefits of bicycle travel as related to a regional travel demand model. They pointed out various applications of bicycle count data including enhancements to travel models, scenario planning, public health assessments, and emissions calculations.

Information From Other States

Count programs in Colorado, Minnesota, and North Carolina, three states with relatively well-established bicycle and pedestrian count programs, are described in detail here based on semi-structured interviews (the interview questions are provided in Appendix A). In addition to these states, the literature search and follow-up internet searches identified bicycle and pedestrian counting efforts, guidelines, plans, and research in progress by state DOTs in Florida, Idaho, Louisiana, New Hampshire, Oregon, Texas, Washington, Utah, and Vermont, and discussions with colleagues indicated that efforts were also underway in California, Michigan, North Dakota, and Ohio (Figure 2). This study did not closely investigate these efforts, but peer states may have useful information to share. In addition, many local governments and regional agencies around the United States have initiated count programs.

An overview of available data warehouses and archives follows the detailed descriptions of programs in Colorado, Minnesota, and North Carolina; a summary of additional considerations that were not necessarily unique to one of those three states is also provided.

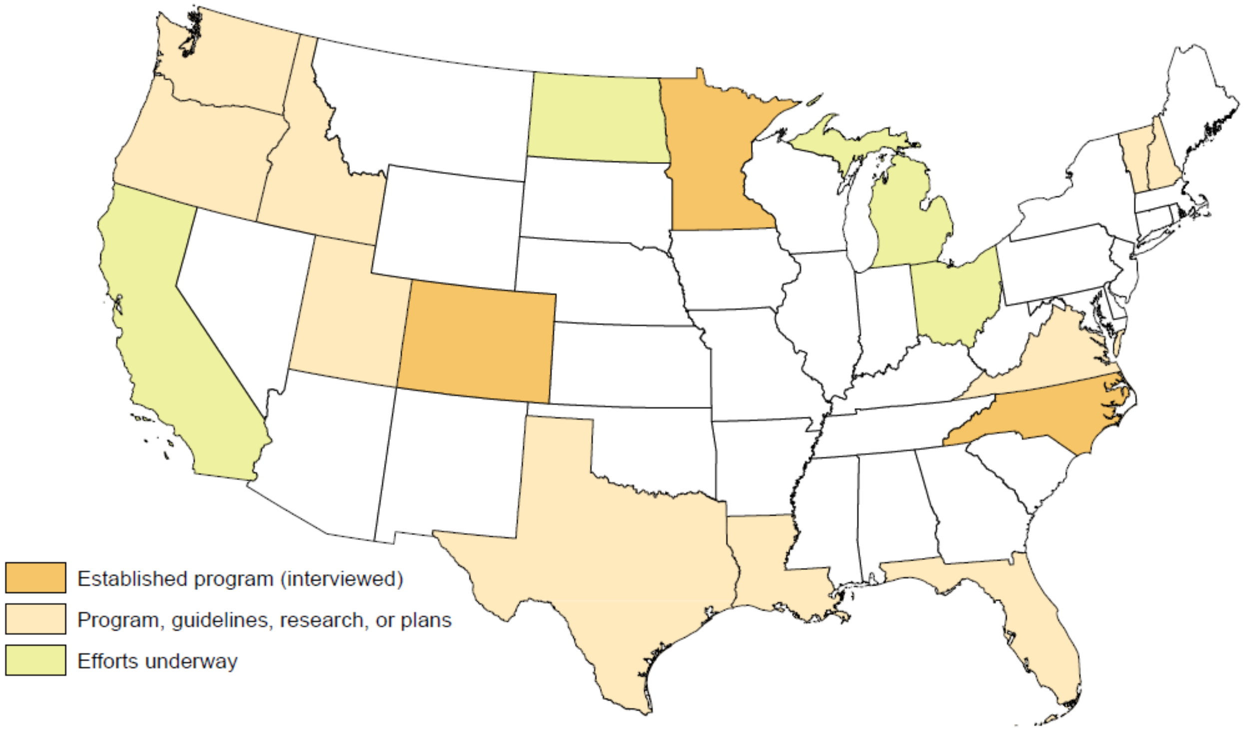

Figure 2. Status of Nonmotorized Traffic Monitoring Programs in Other States

Colorado: A Centralized Approach

Ken Brubaker, Bike and Pedestrian Engineer, Colorado Department of Transportation (CDOT), was interviewed for this study. In addition, Elizabeth Stolz of Digital Traffic Systems, formerly with CDOT, was interviewed.

Program Overview

In 2009, Colorado was the first state to initiate a state-administered nonmotorized travel monitoring program, which occurred in response to a lack of needed data. Initial funding was via a grant from Kaiser Permanente to purchase equipment for five continuous count stations (CCSs), which CDOT installed.

After dedicated program funding was identified in the form of federal State Planning and Research funds, a strategic plan for the count program to install CCSs in locations such that their data could be used to annualize SDCs was completed in 2016 (CDOT and Toole Design Group, 2016). The five main goals of the plan were as follows:

1. Formalize and develop a strategic approach to collect data, as opposed to the previous request-based approach of count site selection.

2. Improve data quality control and quality assurance processes to eliminate data gaps.

3. Expand the count program.

4. Share data beyond CDOT, such as by including it in the online platform used to disseminate traditional data from motorized counts.

5. Use big data such as Strava data to supplement counts.

As of early 2017, CDOT had 26 CCSs. Around 100 additional SDCs (in warm-weather months) were conducted by CDOT or contractors annually using two sets of equipment to fill in gaps and to evaluate potential continuous count sites. CDOT assists local agencies in conducting counts, especially on state highways.

The count program is supported by strategic documents such as CDOT's bicycle and pedestrian plan, which mentions the lack of data on bicycle and pedestrian travel, and the state's Strategic Highway Safety Plan, which notes that such data would be beneficial for supporting decision-making.

Methods for Site Selection and Data Collection

Initially, without dedicated funding, budget realities dictated the scope of Colorado's program, which did not have an organized method for selecting count sites other than by responding to requests. This provided a snapshot of data, but it was not particularly suitable for drawing conclusions (e.g., because there were insufficient numbers of sites for a given type of road).

As of 2017, CCSs are classified as either urban or rural and as primarily commuting, primarily recreation, or mixed commuting/recreation. Most CCSs consist of Eco-Counter passive infrared equipment for pedestrian detection and in-pavement loop detectors for bicycles. Some localities have installed equipment from other vendors, including JAMAR.

The state has typically paid for installation of CCSs in localities, with the intention of having those localities assist with maintenance tasks such as battery replacement, visual inspection, and pest removal. This arrangement has worked for localities with substantial staff resources, but for others, maintenance of the count equipment was not a high priority, and data quality suffered as a consequence. In some cases, localities mistakenly assumed there would be no costs other than data transmission fees after the initial installation. CDOT flags counters for potential relocation if localities are unable to maintain them.

Data Storage, Quality Control, and Usage

Data warehousing is an evolving process, with the eventual goal of transmitting it to TMAS in the proper format. CDOT encourages localities, some of which have their own data warehouses, to submit locally collected data to the state; having these additional datasets can help develop factor groups. Such datasets, if in the proper usable electronic format, undergo quality checks and receive a unique identifier to flag them as originating with outside agencies. Data dissemination is an emerging focus, and it appears that as awareness of count data grows, additional requests for project-specific counts are likely to emerge.

Remote data transmission features of the count equipment allow CDOT to perform simple quality checks weekly (looking for gaps of more than 5 days, directional splits more skewed than 70/30, maximum value of interquartile range, and consecutive zeros of more than 48 hours). CDOT notifies a locality if equipment in its jurisdiction appears to be malfunctioning.

CDOT has conducted stakeholder interviews to learn about potential uses of nonmotorized count data (CDOT and Toole Design Group, 2016). Top data applications for CDOT engineers and planners were exposure data for safety and establishment of a metric using bicycle miles traveled, whereas local agencies planned to use the data to justify physical improvements such as bicycle facilities and pedestrian crossing treatments. Before-after comparisons evaluating whether improvements were associated with an increased level of use were also potential uses for some stakeholders.

Challenges and Lessons Learned

CDOT's SDCs have typically collected data for 24 to 48 hours. As newer guidance has emerged suggesting that SDCs using automatic counters be a minimum of 7 days in duration (e.g., FHWA, 2016), this has raised issues about data quality.

Major challenges have included data dissemination and data quality control related to equipment maintenance. When equipment issues lead to large gaps in data, analysis suffers (i.e., in creation of factor groups and annualizing SDCs). Staffing has also been an issue; the program has no dedicated staff but rather is a collaborative effort of CDOT's traffic analysis and bicycle/pedestrian groups, who often have other priorities when equipment maintenance concerns arise. As such, CDOT has found it important to delineate roles and responsibilities clearly, especially for equipment maintenance. Going forward, localities requesting CCSs must be willing and able to maintain them—and also willing to request CDOT's assistance when needed.

Other advice was to place initial CCSs in locations with high levels of pedestrian/bicycle activity. Although the eventual program should be representative of sites with both high and low levels of activity, those first sites should be at high-volume areas so the volumes of the initial sites are regular enough to allow for learning experiences with installation, maintenance, and data management before lower-volume sites are equipped. In addition, SDCs can help determine whether sites are suitable for CCSs. Site selection for CCSs should be a strategic, intentional process.

Minnesota: Empowering Localities

Greg Lindsey, Professor, University of Minnesota's Humphrey School of Public Affairs, was interviewed for this study. In addition, Steven Hankey, Assistant Professor of Urban Affairs and Planning, Virginia Tech's School of Public and International Affairs, formerly with the University of Minnesota, was interviewed.

Program Overview

MnDOT developed its state-coordinated program to monitor bicycle and pedestrian travel with the assistance of University of Minnesota researchers, and as of spring 2017, the program was becoming institutionalized.

The program's genesis came when a nonmotorized count program was initiated in Minneapolis, one of the four U.S. communities in the federal Nonmotorized Transportation Pilot Program. MnDOT adapted the methodology of the National Bicycle and Pedestrian Documentation Project (Jones and Cheng, 2006) and added some automated infrared trail counters. A series of research studies was focused on developing consistent methodologies for counts, and MnDOT's transit division invested $250,000 in several types of automated counters from Eco-Counter.

The program's strategy was not to cover the state systematically; instead, MnDOT's role has been to demonstrate the feasibility of counting, inform and support local and regional agencies, encourage counts to be done at the local level, and make use of local counts as possible to show trends.

As of winter 2017, there were 26 MnDOT nonmotorized count stations, called "index sites," some of which used multiple counting devices, in both urban and rural areas. Localities were involved by way of training sessions showing how data could be used and analyzed, and several jurisdictions had created their own count programs. An annual motorized counting training session for all jurisdictions was modified to include an add-on half-day course on nonmotorized counting fundamentals.

In recognition that illustrating the commitment to nonmotorized travel monitoring in as many places as possible can help it become institutionalized, an intentional effort has been made to acknowledge, in multiple documents and plans, the need to count bicycle and pedestrian traffic. Multiple statewide plans and policies do so, from the statewide long-range transportation plan, which has a performance indicator that will be fed by data from the state's index sites, to the statewide complete streets policy. Nonmotorized count data can also provide exposure rates for assessing MnDOT's progress in its Toward Zero Deaths initiative.

Methods for Site Selection and Data Collection

MnDOT officials thought it would be infeasible (particularly in terms of funding) to obtain systematic coverage across all eight of the state's regions. Whereas NCDOT was attempting to cover all types of factor groups, MnDOT was being more opportunistic, adding counters where stakeholders were interested in having them, such as on key trails. In each region, a trail CCS and a road CCS provided illustrative count information and made the concept of counting nonmotorized traffic more accessible.

A loan program for counting equipment was intended to make localities and MPOs familiar with counting. Although technical limitations may persist, it was still useful from a practical perspective for localities to become familiar with how to conduct counts, as doing so remained primarily a local activity, with the CCSs providing reference volumes and patterns. As an example, Hennepin County (the county containing Minneapolis) has invested in 60 on-street tube counters.

MnDOT oversees equipment installation, data collection, and data management for its counters. For CCSs, MnDOT selected Eco-Counter products. Some MPOs and researchers in Minnesota were looking at using Strava data to analyze bicyclist route choice, but not necessarily for estimating total demand, because certain user types are overrepresented in such data. A promising innovation on the horizon may be automated video processing from existing MnDOT traffic cameras, but if new cameras are required for such an initiative, it would likely be decades before this data source would be active statewide.

Data Storage, Quality Control, and Usage

The web interface of Eco-Counter's Eco-Visio data storage tool can allow for MPOs to be granted access to data. MnDOT plans to integrate its nonmotorized traffic data with other traffic engineering data (i.e., vehicular counts) in the TMAS format using the Jackalope analysis and storage system by High Desert Traffic. In the near future, an interactive map will improve public data accessibility by displaying the location of each monitoring station linked to downloadable data such as counter installation drawings and count reports.

A longer-term goal that depends on funding is to integrate local and MPO count programs into a statewide database. Until then, local and regional organizations will operate their count programs independently but collaborate with MnDOT and share data as needed.

A newer component of the annual training for localities is quality control, mostly by way of showing examples of data outputs. A systematic quality assurance process for nonmotorized counts is not yet implemented.

Prioritizing funding for nonmotorized infrastructure does not always require count data, but if localities provide counts, MnDOT considers the data, which can help projects advance. The counts have also been used in traffic engineering, e.g., to justify the installation of marked crosswalks and at intersections of shared-use paths and roads where path user volumes were higher than auto volumes, to remove STOP signs from the path and place them on the intersecting roads instead (Minge et al., 2017).

Challenges and Lessons Learned

Lessons from MnDOT include the need for champions to encourage others to change standard operating procedures and prioritization practices. Innovators must be able to show the benefits of nonmotorized data collection to those who may not be innovators but simply want to do their jobs well. Small successes can illustrate ways to meet needs with modest investments.

North Carolina: Systematic Statewide Deployment With Local Partnerships

Sarah O'Brien, Bicycle & Pedestrian Program Manager, North Carolina State University's Institute for Transportation Research and Education (ITRE), was interviewed for this study.

Program Overview

As part of efforts to make objective, data-driven decisions in North Carolina, estimates of AADPT and AADBT were desired for project prioritization and funding, planning decisions, implementation of a complete streets policy, and operations and maintenance. The state's ultimate goal was to use nonmotorized counts as a way to measure performance and assist in project prioritization and planning, but this was not yet possible as of winter 2017. ITRE was contracted to assist NCDOT in the creation and refinement of its count program, which used federal planning funds in coordination with NCDOT's Transportation Planning Branch.

The count program began in fall 2014 in NCDOT's Piedmont Triad Division (a geographic region similar to a VDOT district). This division was chosen because at the time, it had the most comprehensive data in the state's Pedestrian and Bicycle Infrastructure Network, a geodatabase that was developed as an inventory of all known existing and planned bicycle and pedestrian facilities in North Carolina (NCDOT, n.d.). As of winter 2017, 13 CCSs in urbanized areas across two NCDOT divisions were equipped with 22 units of counting equipment and 2 years of data had been collected. Other divisions were to follow in future phases, with the next phase expanding the program to four additional divisions and up to 30 CCSs. This focus on CCSs was to enable ITRE and NCDOT to develop adjustment factors and groups, recognizing that these are essential elements of a credible program with useful data.

When the program began, a few localities were already collecting data but were typically not validating the data. Some had purchased portable equipment, and one had installed CCSs on shared-use paths. There were no issues or objections from those localities when the state became involved and built a program around local agency partnerships, with NCDOT retaining control over data quality. Localities get equipment; technical assistance and training; and access to validated, cleaned data. NCDOT gets critical local knowledge, installation assistance, and monitoring/maintenance assistance.

NCDOT's Division of Bicycle and Pedestrian Transportation oversees localities' installation and maintenance of equipment, which NCDOT owns for 2 years, during which time local agencies are encouraged to participate in maintenance activities for training purposes. The hardware then reverts to locality ownership under a signed agreement (O'Brien et al., 2016). NCDOT (through ITRE) continues to manage the data and coordinate with localities regarding equipment maintenance needs.

An SDC arm of the program similar to NCDOT's short-duration auto count program was to be added in 3 to 5 years and would likely include rural locations. Equipment would be loaned to localities as long as counting was done at certain times each year.

The motivation behind NCDOT's efforts included the fact that statewide policies and plans such as NCDOT's complete streets policy and its statewide bicycle and pedestrian plan included generic language for nonmotorized transportation performance benchmarks, which the agency could not measure without collecting volume data. Increasing walking and bicycling and decreasing crashes were statewide goals, and quantifying nonmotorized crash rates was less meaningful without volume data. Emphasis areas for improved analysis included crash data and a statewide inventory of nonmotorized transportation facilities.

Methods for Site Selection and Data Collection

Even a single NCDOT division is a very large geographic area, and initially, ITRE used a non-systematic approach for site selection. This method was then refined to include (1) site selection guidelines and a webinar provided to local agencies in the division; (2) a survey of local agencies asking where they would count and collecting basic site characteristics (expected volume ranges, existing bicycle/pedestrian facilities, and context); and (3) a virtual audit for feasibility, likely volume ranges, and the likely split between bicycle and pedestrian usage.

Initial CCS sites did not include any rural two-lane roads such as would be used by recreational cyclists and bike tourists, so NCDOT was seeking to add some of those locations in future phases to allow exploration of weekend/weekday and seasonality effects. Similarly, additional locations near schools were sought in order to identify school-related travel patterns.

Because NCDOT purchased the equipment, there was some "back-and-forth" between the state agency and localities about priority locations for data collection. Some sites required multiple counters, multiple data loggers, or more complicated setups. When selecting count sites on behalf of NCDOT, before taking cost estimates into consideration ITRE attempted to identify the best sites using a spreadsheet tool based on population densities, experience, and judgment. Local knowledge was also critical; for example, at one site, local input that sidewalk bicycling was common led ITRE to recommend equipping the sidewalks with bicycle counters and providing count equipment in the roadway.

Eco-Counter was selected as NCDOT's equipment vendor primarily because it was the only vendor at the time with the capability of providing continuous differentiated bicycle and pedestrian counts with acceptable accuracy and precision along with warehousing and analysis software. Video-based technology was considered but was too expensive. The state remained open to using different systems as research and practice evolved.

Data Storage, Quality Control, and Usage

Preliminary data were provided to local agencies on a quarterly basis for the first year after equipment installation at each count site, and an annual report was published after data were cleaned and correction factors were applied. Ultimately, a statewide database was anticipated in order to provide data access for everyone.

Initial installations of equipment in this program always included short-term video data collection to develop site-specific correction factors; this was also done if sensor damage or adjustments required re-validation. ITRE students assisted with post-processing and data monitoring, and a full-time data technician was dedicated to the project. There was an anticipated need for additional staffing as the program grew unless automated data management became possible.

NCDOT recognized the importance of data quality for a database containing submittals from multiple localities, so the state continued handling data monitoring and quality control, even after equipment ownership reverted to localities. In part to identify maintenance issues before they imperiled data validity for an entire quarter, data were inspected and managed on a weekly basis using Eco-Counter tools. This required 1 or 2 hours of staff time per week for 22 units of equipment. As with Colorado's weekly checks, NCDOT searched for data gaps, consecutive zeros, skewed directional splits, and unusual ranges.

Continuous counts were used for traffic monitoring, developing adjustment factors, and being able to extrapolate SDCs, not necessarily for project-based analysis. Local agencies were often more interested in the latter, but valid comparisons between SDCs for that purpose could not be made unless adjustment factors were developed using CCS data.

North Carolina's "Watch for Me NC" pedestrian and bicycle injury prevention program was looking to measure return on investment and changes in crash rates, which would require reliable population-level measures of changes in bicycle and pedestrian exposure data (L. Sandt, unpublished data).

Challenges and Lessons Learned

NCDOT's program was described as a hybrid of Colorado's centralized program and the program in Minnesota, where the state takes a more passive role. NCDOT retains control over site selection but requires local partners. O'Brien suggested that if Virginia has many local agencies that have already established nonmotorized travel monitoring programs, a centralized program such as Colorado's may not be the best fit, because those localities should be key partners in a statewide effort.

O'Brien noted that a state's nonmotorized count program should be integrated into operations of a state's traditional automotive count program. Incremental improvements are to be expected, rather than large changes all at once, and there may be no single, generalizable path for institutionalizing nonmotorized volume data collection within a traditional count program.

NCDOT found that it was easier to make the case for counting equipment to larger cities and MPOs than to smaller jurisdictions. Small towns, especially in rural areas, were typically less interested or did not perceive a benefit to participating in the program. For example, the Town of Nashville's planning staff was interested in a pedestrian count station, but the town council declined to sign NCDOT's agreement because of the ongoing cost of the equipment over an 8-year timeframe.

To protect data integrity, it was important for the state to have thresholds in place for acceptable data quality and formats for its statewide database. NCDOT also recommended providing localities with data collection protocols.

Factor grouping was an ongoing issue. Simply applying the "standard" motor vehicle factor groups was likely to be inappropriate for nonmotorized travel patterns; because the distances traveled are so different from motor vehicle travel distances, the volumes are much more sensitive to specific local context and land use. For example, for a university-area CCS in North Carolina, instead of exhibiting a typical weekday commute pattern, its commute pattern had discernable differences between Tuesday/Thursday and Monday/Wednesday. Class schedules, such as when certain courses were offered, likely influenced this commute pattern. Several years of data may be required before strong conclusions may be drawn, and this could affect factor group definition.

A related question was the number of count stations required per factor group. Although the rule of thumb from the TMG specified three to five CCSs per factor group in order to develop adjustment factors, the greater site-specific variability for nonmotorized travel may necessitate more count stations than this per factor group (FHWA, 2016). For SDCs, it was unclear how many stations were needed to understand each region and to account for seasonality.

Data Warehouses and Archives

Several options exist outside Colorado, Minnesota, and North Carolina for archiving bicycle and pedestrian count data at the state or national level. With data from eight states, the Bike-Ped Portal maintained by Portland State University stated that it was "the national archive for bicycle and pedestrian count data" (Portland State University, 2017). As of spring 2016, it had the capability to link to Eco-Counter data from some localities automatically after a setup process, but most jurisdictions' data were loaded manually onto the portal, either by university staff (for funding partners and university research sites) or by those affiliated with each jurisdiction (Nordback, 2016). A similar data warehouse based in Los Angeles attempted to compile regional bicycle count data and develop standards for methods (Huff and Brozen, 2014).

FHWA's TMAS database began testing inclusion of nonmotorized volume data in 2017, having previously contained only motorized traffic volume data. The Philadelphia region was the first entity to submit bicycle count data (S. Brady, personal communication, October 19, 2017). Jeremy Raw, Community Planner with the FHWA Office of Planning, provided an overview of TMAS during an informational interview. The motor vehicle data in TMAS eventually drive decisions on funding, a well-established institutional arrangement. Mainstreaming bicycle and pedestrian data into TMAS was part of FHWA's effort to bring data-driven decision making for bicycle and pedestrian planning to the same level as that used for motorized traffic data. TMAS submissions must be in the TMG format and require extensive quality checks, making it preferable for localities and MPOs not to submit data directly; from the federal perspective, ideally states would integrate their nonmotorized and motorized counting and reporting programs, compiling data from their localities and submitting them to TMAS. This implies that each state would maintain its own statewide database, but another interviewee reported that a challenge in this area occurred when a database vendor went out of business despite interest from several states (S. Hankey, unpublished data). A related challenge could be data integration from multiple technology vendors; Minnesota was examining techniques for integrating multi-platform data into a state platform, which could, in turn, feed data to TMAS.

Additional Considerations

The following considerations were not necessarily unique to any of the states profiled but were identified by experts in conference sessions, webinars, and interviews.

Program Design

A representative of Eco-Counter suggested several keys to success for a state-managed count program: define the objectives, install equipment carefully, calibrate equipment and verify its functionality, understand the data, document everything, allocate field resources across the state, schedule maintenance, challenge equipment vendors if something is unclear, and manage internal organizational knowledge (J. Rheault, unpublished data).

A count program is much more than just equipment, but it is possible to begin a program with a relatively low budget of a few thousand dollars and scale up as funding permits; however, at any scale, there will be some cost in terms of both dollars and staff time for ongoing equipment maintenance. One expert estimated the staffing requirement in a major city at one full-time-equivalent staff member per 15 counters (S. Brady, unpublished data).

One risk of investing in count equipment (including for motorized counts) is that such investments could prove unnecessary if emerging technologies including big data can provide the same information at a lower cost or with less effort. Although the big data approach is promising, it appears that such data will continue to require some means of validation, typically provided by traditional CCSs.

Methods for Site Selection and Data Collection

A network including both permanent CCSs and SDC sites is ideal. In the selection of count sites, screenline counts (i.e., counts along a road segment tallying road users by direction) may be the simplest option. Intersection counts are useful if they include turning movements (essentially providing multiple sets of screenline counts) but are not useful if they count only one direction per leg (K. Nordback, unpublished data). A best practice is to conduct a trial SDC at a site before installing a CCS. SDCs should be 7 days at minimum, ideally in higher-volume months, and cover sites with differing travel patterns, such as commute, school, and recreation.

Data Storage, Quality Control, and Usage

In developing a program, a state DOT should take data quality very seriously without being overly critical, recognizing that the state of the practice is evolving (T. Tang, unpublished data). Ideally, any data quality element of a state-administered program would enable quick identification and resolution of the causes of invalid data. From time to time, special events may affect data; rather than being discarded, affected data should be flagged and included or excluded depending on the use of the data. Data management should include automatic flagging of questionable data without abandonment of local knowledge.

Validation is comparing manual counts to automated counts to obtain an error rate and evaluate equipment accuracy, ultimately producing a site-specific correction factor. It should be done separately for each mode at sites that count bicycles and pedestrians, and validation should be performed when equipment is new and when it is maintained or annually if no maintenance is required in a year. Changing a battery or clearing an obstruction without moving the sensor would not normally require re-validation (S. O'Brien, unpublished data).

In recognition that quality targets may vary depending on the intended use of the data and that local knowledge can often explain anomalies flagged by automated rules, the following measures (typically automated rules) appear to be commonly accepted means of defining the limits of plausible count data (S. Turner, unpublished data):

- maximum deviation from typical or average hourly or daily volume
- maximum hourly or daily value (typically no minimum for nonmotorized counts)
- volume of zero or an identical repeating value for more than a threshold value of time
- maximum directional split for shared-use paths
- maximum ratio of hourly to daily volume.

Temporal issues ranging from daylight saving time to bad time stamps can affect data quality. Bin sizes also matter, with 15-minute bins the typical standard; Budowski et al. (2017) found that using 2-hour counts (such as those performed under the National Bicycle and Pedestrian Documentation Project) to estimate seasonal average daily bicyclist volumes led to 50% error rates.

Network-level safety analysis is one possible beneficiary of improved nonmotorized volume data after multiple years of data have been collected, but samples at a few sites may not represent data at a statewide or network level particularly well. Surrogate measures could include proportions of total crashes; land use / built environment measures; vehicle volumes; trip counts, distance, or times; or survey data (L. Sandt, unpublished data).

Ongoing Efforts in Virginia

Pedestrian and/or bicycle count data are collected at various locations in Virginia. Some of these were revealed through the survey and are addressed later; others were known previously or discussed in informational interviews. Data vary by site and technology, with some sites differentiating between pedestrians and bicycles, some counting only pedestrians or bicycles, and some counting both without differentiating between the two.

VDOT Efforts

VDOT has nonmotorized count programs and efforts underway in some parts of the state. For several years, the Northern Virginia District has partnered with the Metropolitan Washington Council of Governments, which houses the region's MPO, to obtain video-based (Miovision) counts for trails and paths. Such counts are typically 24 to 72 hours in duration. Spatial and tabular data are publicly available in the Regional Transportation Data Clearinghouse (National Capital Region Transportation Planning Board, 2017). By using count equipment that differentiated between bicyclists and pedestrians, the district learned that nonmotorized use of the 14th Street Bridge connecting Virginia to Washington, D.C., was composed of 85% to 90% bicyclists, which is useful information when winter maintenance activities are considered or connecting facilities are planned. Upcoming work on the I-66 corridor will be accompanied by the installation of six additional permanent automatic bicycle/pedestrian counters on shared-use paths and on-street facilities; the equipment will be maintained by VDOT's Northern Virginia District.

VDOT's Hampton Roads District has used a mobile passive infrared counter at several locations for VDOT studies; a previous unit was loaned to other organizations but was vandalized. One permanent passive infrared counter was installed in Hampton Roads on the Virginia Capital Trail near Greenspring Road, and a second was planned for a similar trail on the Eastern Shore east of U.S. 13 near Seaside Road. Data and reports are available by request from the district transportation planner.

The Richmond District has also installed automated counters on the Virginia Capital Trail east of Richmond. Rough costs were under $50,000, including an ongoing monthly fee for data service. Data from these counters were being added to VDOT's Traffic Monitoring System as sensors that could then be associated with links in the road and trail network. Data quality checks included replacing days with missing data using average counts from other days. In spring 2017, VDOT's TED used automated video counting devices on the Virginia Capital Trail to validate the existing infrared / loop combination counters and investigate rates of occlusion. Equipment maintenance—primarily pest management and battery replacement—has been handled by the Ashland Residency. Counter locations and cumulative bicycle and/or pedestrian counts are publicly available online (VDOT, 2018); other data are available by request from VDOT's TMPD and TED.

The Salem District has automated count equipment on U.S. 11 in Roanoke with inductive loop detectors in both bicycle lanes and on an adjacent shared-use path, which was also equipped with a passive infrared detector. Installed as part of an effort to repair an existing auto count station, the equipment has undergone a series of validation efforts including manual counts and automated video (Miovision) to evaluate its limitations. Data are available by request from VDOT's TED.

VDOT's TED has substantial experience performing quality analysis and factoring for motorized counts, and its staff review such data daily to identify errors and problem counters, which sometimes report their error status automatically. VDOT maintains a network of auto CCSs, including on roads in independent cities and some counties (e.g., Arlington County) that typically maintain their own roads. Walking and bicycling tend to be more common in cities and urban counties than in rural areas, so such places might also be suitable for the installation of nonmotorized CCSs.

Existing VDOT TED business practices that could contribute to a nonmotorized data collection program include (1) adding quality-checked (i.e., not raw) nonmotorized count data to the existing count data repository, and (2) including bicycle/pedestrian counts in the VDOT Traffic Monitoring System team's automated review processes. The latter could incorporate information about likely fluctuations because of weather conditions and would need easily accessible information on equipment maintenance responsibility if counting equipment is maintained by non-VDOT entities. However, incorporation of nonmotorized data in existing business practices would need to be prioritized against pre-existing initiatives such as development of automated data review tools and imputation formulas. For non-traditional data such as route traces via apps such as Strava; surrogate volumes from pedestrian signal phase calls (i.e., how often pushbuttons are pressed to activate pedestrian signals) and deployments of bike racks on buses; and bikeshare system statistics, the path to data integration is less clear.

VDOT obtained sample Strava Metro data in 2017, and one or more local or regional organizations had purchased such data previously; if VDOT were to purchase statewide Strava Metro data, localities, MPOs, and others would be able to access the data. Begun as a tool for athletes to track activity leading up to races, Strava has evolved into a social platform that includes various activities such as running and bicycling, and Metro is its big data product providing spatial, anonymized route data including commutes. The platform logged 2.5 million activities in Virginia in 2016 by 110,000 users. Because Strava does not provide a base map, VDOT would need to develop and maintain one with all streets, roads, trails, paths, and other key bike/walk links in the network. Strava data can be combined with traditional nonmotorized counts to develop multipliers that can be used to estimate AADBT, to estimate relative exposure levels for bicycle crashes, and to examine intersection wait and crossing times for bicyclists.

A key limitation of Strava data is user bias. Use of Strava requires a smartphone with data service; the tool was initially used primarily for recreational rides, and more than three-fourths of cycling users are male. Strava representatives advised that as of 2017, users in rural areas tend to skew more toward recreational bicyclists, whereas users in urban areas may be more evenly split between bicyclists on utilitarian and recreational trips. One key for applying Strava data is first establishing that people using bicycles without using Strava generally take the same routes as those who do use it. Having traditional counters, therefore, makes Strava data more useful, and having Strava data can make data from traditional counters more useful by allowing extrapolation of other users (e.g., joggers) at a bicycle-only count station. Strava representatives advised that after corridors that are represented relatively well by Strava data are identified, traditional count equipment can be re-deployed to corridors that are not.

VDOT makes use of StreetLight Data, another provider of big data. In 2017, StreetLight began incorporating bicycle and pedestrian trip metrics into its offerings. Its capabilities include origin-destination studies and zone activity analyses; in both cases, results would allow comparisons of relative volumes that would not necessarily represent AADBT or AADPT without additional calibration (a future capability). As with Strava data, having traditional counters makes StreetLight data more useful, and with a suitable distribution of traditional sensors, applying StreetLight data could reduce the quantity of sensors required to get a relatively complete picture of the network.

Efforts by Localities and Regional Commissions

Most of the count locations in Virginia are within local jurisdictions on facilities that are not maintained by VDOT. Some examples include the cities of Alexandria, Richmond, Charlottesville, Blacksburg, Harrisonburg, Roanoke, and Virginia Beach, some of which have followed the methodology of the National Bicycle and Pedestrian Documentation Project (Jones and Cheng, 2006). Most have made data available publicly in tabular formats or reports.

The Roanoke Valley-Alleghany Regional Commission (RVARC) and the New River Valley Regional Commission (NRVRC) maintain permanent automated counters on several shared-use paths in their respective study areas. The RVARC automated count program, initiated in 2010, involves regional partnerships with the cities of Roanoke and Salem, the counties of Roanoke and Botetourt, the Town of Vinton, RVGC, and the Roanoke Appalachian Trail Club. Its counters were purchased with a combination of federal funds through the MPO and local funds from localities and RVGC, and the TRAFx DataNet platform was used for data storage and analysis.

Arlington County (which maintains its own secondary roads) has a well-developed count program, and Fairfax County (where all public roads are VDOT-maintained) is beginning to conduct counts. The number of count locations in each jurisdiction and the methods and technologies used to collect the data vary.

Arlington County is considered a national leader in nonmotorized data collection. Data from its 38 permanent count stations, 11 of them in bicycle lanes, are publicly available in tabular and web services formats via an online dashboard (Arlington County, 2018), and the same site also hosts count data from nearby jurisdictions including Alexandria. Their oldest counting device has been in place more than 7 years, and the county has used historical trends, such as an annualized 3.56% increase in bicycle volumes, to forecast future conditions and inform the planning process. A portable counting device has allowed the county to conduct SDCs that can then be expanded and adjusted to project bicycle volumes with and without the addition of a bicycle lane. The bike count infrastructure was useful when service on the regional rail system was curtailed for maintenance, as there was clear evidence that bicycle volumes increased in response. Even simple seasonal and weekday/weekend patterns are effective for those who have never seen them before and may be more valuable than detailed statistical analysis in work with decision-makers.

Arlington County has been successful with interagency partnerships. The county has placed counting equipment on facilities owned and maintained by the National Park Service, the District of Columbia DOT, VDOT, and NVRPA. The county has handled procurement and installation of these devices and has found that ongoing maintenance including pest removal is important in order to obtain reliable data that justify the program's continuation.

Data quality management in Arlington County was primarily driven by local knowledge, with no automated flags for data quality issues. In cases where data were missing or invalid, Arlington County has accepted the practice of reconstructing data to fill the gaps based on historical trends (with the data flagged as "synthetic").

Information Obtained Through Research Studies and by Other Agencies

As part of a research study, the Town of Blacksburg (Virginia) was blanketed with count equipment in 2015, including four permanent reference sites and 97 SDCs of about 1 week each, covering about 10% of the town's transportation network (Hankey et al., 2016). The 40,000 hours of data collected enabled researchers to investigate seasonal, daily, and hourly traffic patterns for bicycle and pedestrian activity and to develop and use day-of-year scaling factors to create AADBT and AADPT estimates from SDCs. Validation and correction factors were developed for each type of counter rather than for each individual installation. The project also provides a data point related to theft of counting equipment, as two of 30 counters were stolen during the study.

The Virginia Department of Conservation and Recreation collects visitor counts for two rail-trail parks. These are not necessarily bicycle/pedestrian counts, but trail volumes are likely related to these counts; in 2016, High Bridge Trail State Park had 239,622 visits, and New River Trail State Park had 1,232,561 visits (Wampler, 2017).

Two U.S. bicycle routes, the Atlantic Coast Bicycle Route and the TransAmerica Trail, cross Virginia. The Adventure Cycling Association, which leads the effort to complete the U.S. Bicycle Route System, does not track usage data other than anecdotally (e.g., map sales and visits to the organization's office in Montana along the TransAmerica Trail) (Milyko, 2017, as cited in Deviney, 2017).

Inventory of Data Collection Locations and Methods in Virginia

Of the 276 surveys distributed, 188 responses were received, for a response rate of 68%. Of the 188 responses, 178 were complete, with all questions answered and locality information obtainable (either from a survey answer or by tracing of IP addresses). Ten were incomplete or were missing locality information; however, completed answers from these were included in non–locality-specific analyses.

Tables 2 through 5 show the counties, cities, towns, and MPOs/PDCs that received surveys. Respondents are indicated and included 50 counties (53% response rate), 29 cities (74% response rate), 75 towns (67% response rate), and 19 MPOs/PDCs (76% response rate). Responses were also received from the five other organizations that were known to operate pedestrian and/or bicycle trails or counting equipment.

As noted earlier, in some cases, a single, coordinated regional count program may include multiple jurisdictions. In such cases, it is possible that multiple survey responses referred to the same program. In other cases (e.g., Arlington County and City of Alexandria), each locality conducts counts independently but data sharing is accomplished collaboratively.

Table 2. Survey Distribution List of Counties

Counties That Responded to Survey	Counties That Did Not Respond to Survey
• Albemarle	• Accomack
• Alleghany	• Bedford
• Amelia	• Buchanan
• Amherst	• Buckingham
• Appomattox	• Caroline
• Arlington	• Carroll
• Augusta	• Charles City
• Bath	• Chesterfield
• Bland	• Craig
• Botetourt	• Cumberland
• Brunswick	• Dickenson
• Campbell	• Dinwiddie
• Charlotte	• Essex
• Clark	• Floyd
• Culpeper	• Franklin
• Fairfax	• Frederick
• Fauquier	• Greene
• Fluvanna	• Greensville
• Giles	• Halifax
• Gloucester	• Hanover
• Goochland	• Henrico
• Grayson	• Highland
• Henry	• King William
• Isle of Wight	• Lancaster
• James City	• Madison
• King and Queen	• Matthews
• King George	• Mecklenburg
• Lee	• Middlesex
• Loudoun	• Nelson
• Louisa	• Northampton
• Lunenburg	• Nottoway
• Montgomery	• Patrick
• New Kent	• Pittsylvania
• Northumberland	• Prince Edward
• Orange	• Rappahannock
• Page	• Richmond
• Powhatan	• Russell
• Prince George	• Smyth
• Prince William	• Southampton
• Pulaski	• Surry
• Roanoke	• Sussex
• Rockbridge	• Warren
• Rockingham	• Washington
• Scott	• Wise
• Shenandoah	• York
• Spotsylvania	
• Stafford	
• Tazewell	
• Westmoreland	
• Wythe	

Table 3. Survey Distribution List of Cities

Cities That Responded to Survey	Cities That Did Not Respond to Survey
• Alexandria • Bristol • Buena Vista • Charlottesville • Chesapeake • Colonial Heights • Emporia • Franklin • Fredericksburg • Galax • Hampton • Harrisonburg • Hopewell • Lexington • Lynchburg • Manassas • Martinsville • Newport News • Norfolk • Norton • Poquoson • Portsmouth • Richmond • Roanoke • Salem • Virginia Beach • Waynesboro • Williamsburg • Winchester	• Bedford • Covington • Danville • Fairfax • Falls Church • Manassas Park • Petersburg • Radford • Staunton • Suffolk

Table 4. Survey Distribution List of Towns

Towns That Responded to Survey	Towns That Did Not Respond to Survey
• Altavista • Amherst • Appomattox • Ashland • Berryville • Blacksburg • Blackstone • Boones Mill • Bowling Green • Bridgewater • Broadway • Brookneal • Cape Charles • Chincoteague • Clarksville • Clintwood • Colonial Beach • Culpeper • Damascus • Dublin • Dumfries • Edinburg • Elkton • Farmville • Floyd • Front Royal • Gate City • Glen Lyn • Gordonsville • Gretna • Grundy • Halifax • Herndon • Hillsville • Hurt • Independence • Irvington • Kilmarnock • La Crosse • Lebanon • Louisa • Luray • Madison • Marion • Middleburg • Mount Jackson • Narrows • New Market • Nickelsville • Occoquan • Orange • Pearisburg • Pulaski • Purcellville • Remington	• Alberta • Appalachia • Bedford • Big Stone Gap • Bluefield • Cedar Bluff • Chase City • Chilhowie • Christiansburg • Clifton Forge • Coeburn • Crewe • Dayton • Fries • Glade Spring • Glasgow • Grottoes • Lawrenceville • Leesburg • Mineral • Onancock • Painter • Pennington Gap • Pocahontas • Rocky Mount • Rural Retreat • Saltville • Saxis • Smithfield • St. Charles • Stephens City • Stuart • Troutdale • Victoria • Wachapreague • Warrenton • White Stone

Richlands Round Hill Scottsville Shenandoah South Boston South Hill Stanley Strasburg Tangier Tappahannock Tazewell Timberville Urbanna Vienna Vinton West Point Windsor Wise Woodstock Wytheville	

Table 5. Survey Distribution List of Metropolitan Planning Organizations (MPOs) and Planning District Commissions (PDCs)

MPOs and PDCs That Responded to Survey	MPOs and PDCs That Did Not Respond to Survey
Accomack-Northampton PDC Central Shenandoah PDC / Harrisonburg-Rockingham MPO / Staunton-Augusta-Waynesboro MPO Crater PDC / Tri-Cities Area MPO Cumberland Plateau PDC George Washington Regional Commission / Fredericksburg Area MPO Hampton Roads TPO Mount Rogers PDC New River Valley Regional Commission Northern Neck PDC Northern Shenandoah Valley Regional Commission / WinFred MPO Northern Virginia Regional Commission Rappahannock-Rapidan Regional Commission Region 2000 Local Government Council / Central Virginia MPO Richmond Regional PDC/TPO Roanoke Valley-Alleghany Regional Commission / Roanoke Valley TPO Southside PDC Thomas Jefferson PDC / Charlottesville-Albemarle MPO West Piedmont PDC / Danville MPO Kingsport [Tennessee] MPO	Commonwealth Regional Council Lenowisco PDC Middle Peninsula PDC New River Valley MPO Bristol, Tennessee MPO Metropolitan Washington Council of Governments / National Capital Region TPB

TPO = transportation planning organization.

When the survey results were analyzed, the first step was to sort responses based on the first question, which identified localities and organizations that have counted pedestrian and/or bicycle volumes on street segments, intersections, or paths at any time from 2010 to the present. Of 188 responses received, 40 respondents indicated "yes" to counting since 2010. These 40 respondents do not represent 40 count programs, however, because many of them did not conduct recurring counts (and some who did were part of regional count programs). Based on the assumption that all 88 non-responders to the survey would have answered "no" to this question, the total rate of counting in Virginia for all localities, MPOs/PDCs, and other organizations contacted would be 14.5%.

Responses received from localities only (i.e., counties, cities, and towns) were filtered, and Figure 3 shows the spatial context of Virginia localities that have counted since 2010. To understand counting by locality type better, the data were tabulated by VDOT district. Figure 4 shows the number of localities that had performed counts by VDOT district and locality type. As shown in the figure, 9 counties, 11 cities, and 7 towns had performed counting in Virginia. Of the counties that counted, the Northern Virginia District had the highest number, with 3; of the cities that counted, the Salem District had the highest number, also 3; and of the towns that counted, the Staunton District had the highest number, again 3. Overall, the Staunton, Salem, and Northern Virginia districts had the most localities that counted, with 5 each. Localities within the Lynchburg District either did not conduct counts or did not respond to the survey and thus were assumed not to conduct counts.

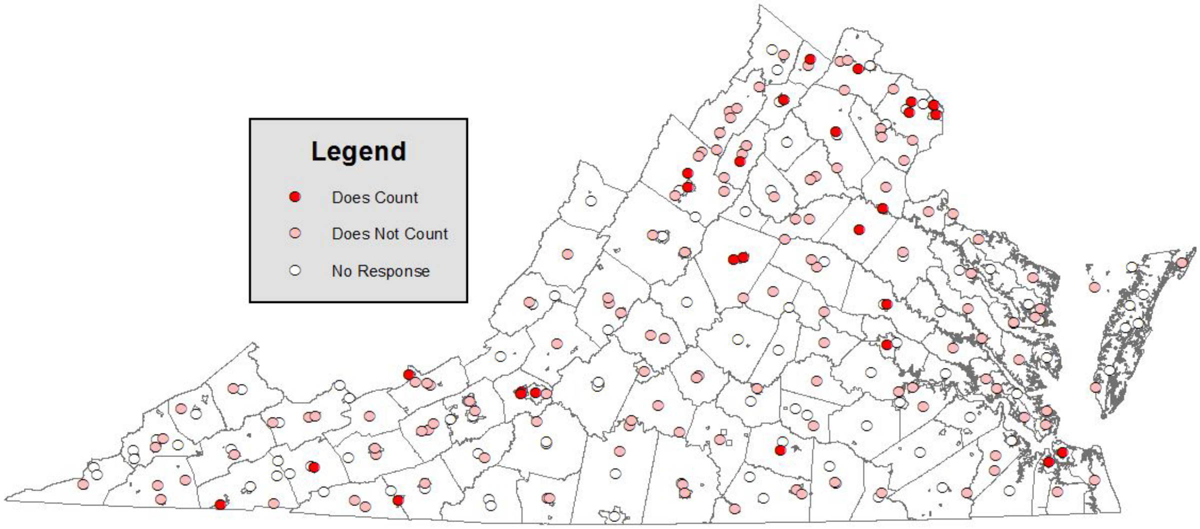

Figure 3. Virginia Localities Surveyed and Whether Each Locality Had Performed Counts Since 2010

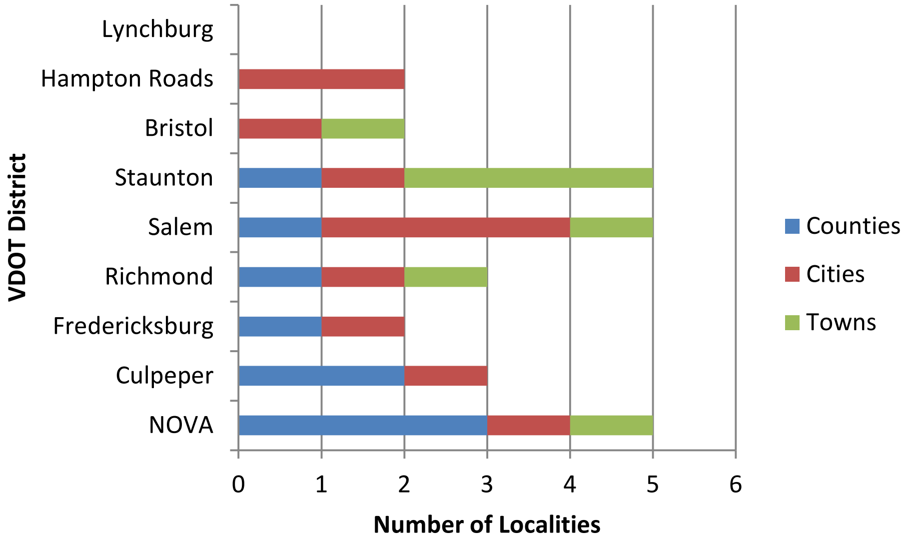

Figure 4. Number of Responding Localities That Performed Counts by VDOT District. NOVA = Northern Virginia District.

Cities represented the highest percentage of localities that had counted (as shown in Figure 5); approximately 28% of cities had counted, followed by counties and towns, at 10% and 6%, respectively. These percentages were calculated by dividing the number of localities that had counted by the total number of that type of locality in Virginia. For example, there were 11 cities that had conducted counts of a total of 39 cities in Virginia; therefore, the percentage of cities that had counted was 28.2%.

When the population of localities was considered, Table 6 shows that a higher percentage of localities had counted as population increased. Tables D1 through D3 in Appendix D provide population, land area, and population density for each locality. These tables were referenced for analyses of potential trends related to localities and population.

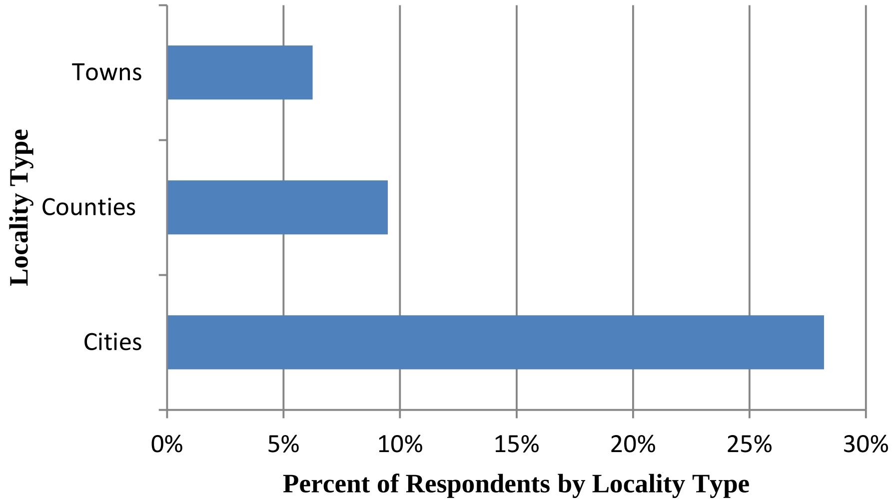

Figure 5. Percentage of Localities That Had Conducted Counts

Table 6. Locality Population and Counting Percentages

Locality Population	Survey Response to Counting	No. of Responses	% Counting
Less than 5,000	Yes	3	3.3
	No	88	
5,000 to 20,000	Yes	7	9.6
	No	66	
20,000 to 100,000	Yes	10	15.6
	No	54	
Over 100,000	Yes	7	38.9
	No	11	

In addition to counting by localities, six MPOs/PDCs indicated that bicycle and/or pedestrian counting had been performed since 2010. With the assumption that counting had not been performed by the seven MPOs/PDCs that did not respond to the survey, the rate of counting among all MPOs/PDCs was approximately 24%. In addition, the five other organizations known to have bicycle and/or pedestrian infrastructure all conducted counts.

The next step in the analysis was to filter responses by type of counting as either sporadic or continuous/periodic. Sporadic counting typically comprises a unique data gathering event at a specific location with no program or schedule to re-visit the site for additional counts. Continuous/periodic counting comprises counting at a particular site or set of sites, whether via continuously operating equipment or periodic (i.e., weekly, monthly, or yearly) SDCs; these would be considered "count programs." Table 7 shows the localities and organizations within each VDOT district that reported counting since 2010 and the type of counting reported. Less than 1% of towns (1 of 112), approximately 15% of cities (6 of 39), and 5% of counties (5 of 95) counted continuously or periodically. In addition, approximately 12% of MPOs/PDCs (3 of 25) counted continuously or periodically. All five of the other organizations surveyed also counted.

Respondents With Sporadic Counting Only

Methods of Counting

Manual counting was the primary method used by localities and organizations that did not have a continuous/periodic count program. As shown in Figure 6, 72% had conducted counts using manual methods only, 11% had used automated methods only, and 17% had used a combination of manual and automated methods.

Purpose of Counting

Figure 7 shows the purposes for counting among sporadic counters. Respondents were given the option to provide more than one purpose; based on the results, the majority of these respondents indicated that they were counting to obtain baseline data. Examples of preparing a planning document include the Thomas Jefferson Planning District Commission's use of count data to incorporate in their long-range transportation plan and the City of Galax's counting for the development of a school zone traffic control plan.

Table 7. Survey Respondents That Had Conducted Pedestrian and/or Bicycle Counts

VDOT District	County	City	Town	MPO/PDC	Other
Northern Virginia	Arlington[a] Fairfax[a] Loudoun	Alexandria[a]	Vienna	-	Northern Virginia Regional Park Authority[a]
Culpeper	Albemarle Fauquier[a]	Charlottesville[a]	-	Thomas Jefferson PDC	Thomas Jefferson Foundation[a]
Staunton	Rockingham[a]	Harrisonburg[a]	Berryville Front Royal Stanley	-	Appalachian Trail Conservancy[a]
Richmond	Lunenburg	Richmond[a]	Ashland	Southside PDC[a] Richmond Regional PDC	Bike Walk RVA[a]
Salem	Roanoke[a]	Galax Roanoke[a] Salem[a]	Glen Lyn[a]	New River Valley Regional Commission[a] Roanoke Valley-Alleghany Regional Commission[a]	Roanoke Valley Greenway Commission[a] Appalachian Trail Conservancy[a]
Bristol	-	Bristol	Marion	Kingsport MPO	Appalachian Trail Conservancy[a]
Hampton Roads	-	Norfolk Portsmouth	-	-	-
Fredericksburg	Spotsylvania	Fredericksburg	-	-	-

MPO = metropolitan planning organization; PDC = planning district commission; - = none.

[a] Conducts counts continuously or periodically at a specific location or set of locations.

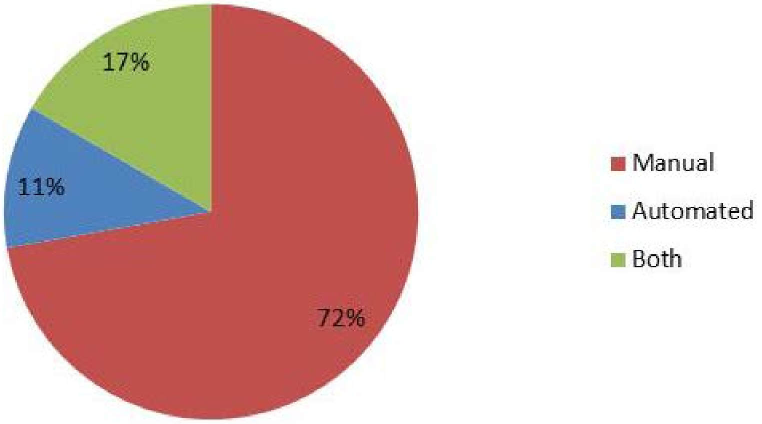

Figure 6. Count Methods for Respondents With Sporadic Counting Efforts

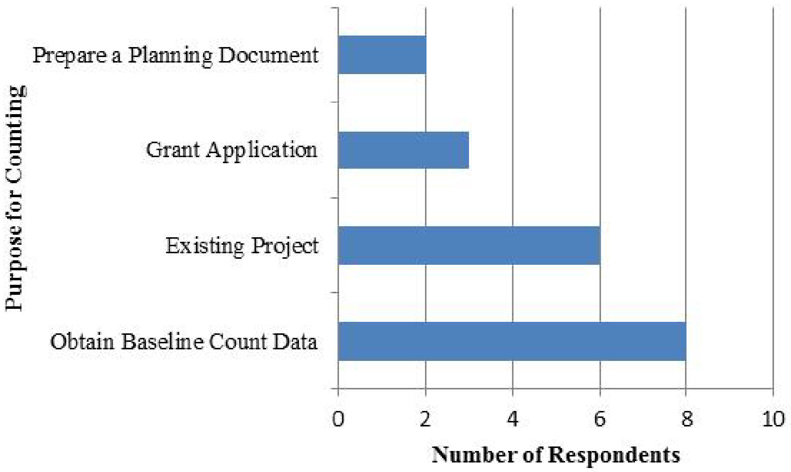

Figure 7. Purpose for Counting Among Respondents With Sporadic Counting Efforts

Three localities (the towns of Berryville and Stanley and the City of Bristol) conducted counts for grant applications; the towns of Berryville and Stanley elaborated that counts were conducted for Safe Routes to School grants. Existing projects included intersection improvements (City of Portsmouth, Loudoun County), a traffic calming study (Town of Vienna), and a streetscape project (Town of Front Royal). The rest of the localities/organizations that counted sporadically did so to obtain baseline data for potential pedestrian and/or bicycle infrastructure projects. For example, the Richmond Regional PDC reported counting at two locations ahead of implementation of bicycle and pedestrian improvements, with the goal of seeing if the improvements resulted in more bicycle and pedestrian traffic. The agency intended to conduct post-improvement counts at the same two locations with the aid of an FHWA bike and pedestrian counting grant it had received.

Frequency of Counting

Table 8 shows the years in which respondents with sporadic counting efforts had conducted counts. With the exception of the City of Portsmouth and the Town of Stanley, the majority of localities or organizations that had counted since 2010 had done so at least once since 2013, suggesting a positive trend of counting in recent years.

Respondents With Continuous or Periodic Counting Programs

Methods of Counting

The majority of Virginia localities and organizations (11 of 20) that counted continuously or periodically at one or more unique locations (i.e., with what would typically be termed a count program) used both manual and automated methods, whereas 5 of 20 used manual methods only and 4 of 20 used automated methods only. Figure 8 shows the relative percentages. When all localities and organizations surveyed were considered, approximately 7% (20 of 276) conducted continuous or periodic counts and approximately 5% (15 of 276) conducted counts via automated methods. Although there was no clear dominant method of counting among cities and regional organizations, towns were more likely to use manual counting and counties appeared to favor automated counting.

Table 8. Years of Counting Among Respondents With Sporadic Counting Efforts

Locality	Year of Counting							Total
	2010	2011	2012	2013	2014	2015	2016	
Town of Berryville				x	x			2
Spotsylvania County	x	x	x	x				4
Thomas Jefferson PDC		x		x		x		3
City of Portsmouth			x					1
Loudoun County					x	x	x	3
Town of Marion								NK
Lunenburg County				x	x			2
City of Bristol, Virginia							x	1
City of Galax				x		x		2
City of Fredericksburg								NK
Town of Vienna						x		1
Town of Stanley	x							1
Albemarle County								NK
Town of Front Royal						x		1
Kingsport MPO					x			1
Richmond Regional PDC						x	x	2
Town of Ashland						x		1
City of Norfolk							x	1

PDC = planning district commission; NK = not known; MPO = metropolitan planning organization.

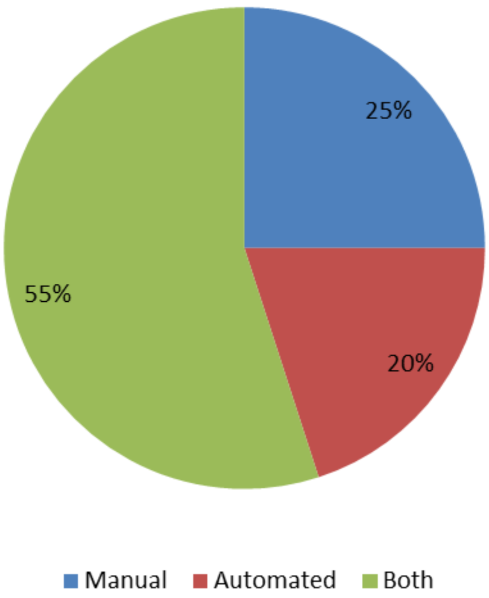

Figure 8. Percentage of Localities and Organizations With Continuous or Periodic Counting Programs Using Manual and/or Automated Count Methods

A locality's choice of count method differed by population size of the locality. For localities with a population under 20,000, 7 of 9 used only manual counts. For localities with a population over 500,000, both methods were used. Mid-sized localities used a mix, with an even distribution between manual only and both manual and automated; only 3 of these localities used automated counts alone.

The majority of manual counts were conducted over 2-hour periods; some respondents mentioned the National Bicycle and Pedestrian Documentation Project as the reason for conducting 2-hour counts. Figure 9 shows labor sources for manual counting done as part of a periodic count program. The majority of such programs relied on staff or volunteers (each 41% of respondents) to complete counts. Some large, dense localities used paid consultants to complete some counts (12% of respondents). The localities that used paid consultants for counting performed both methods of counting and relied on additional parties to complete some of the counts. (To be clear, not all large and dense localities used paid consultants, but all localities reporting the use of paid consultants were large and dense.) Six percent of respondents indicated "other" and reported the use of students and/or researchers.

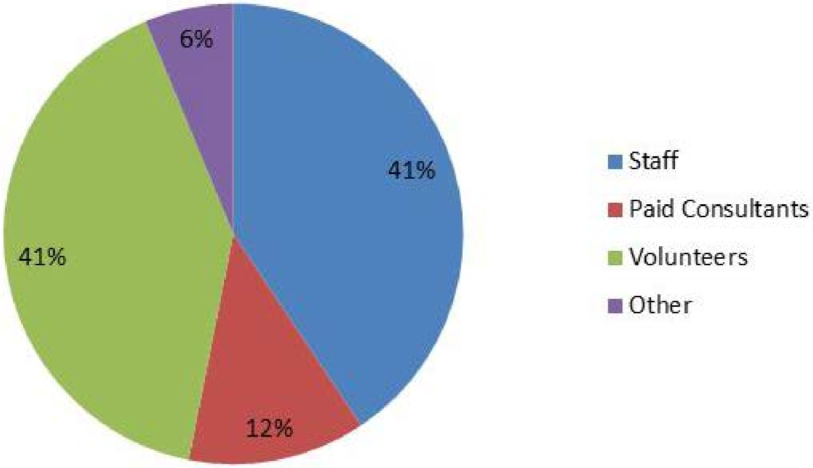

Figure 9. Labor for Manual Periodic Counts

Purpose of Counting

The localities and organizations that counted continuously or periodically did so for a wide range of reasons. The most common response was to show pedestrian and bicycle usage of facilities (e.g., trails, bike lanes, and sidewalks). Usage was documented for informational purposes only (NRVRC) and to help justify budget requests and trail program expansion (Fauquier County). Other responses included the following (presented verbatim):

- *City of Richmond:* Before/after volumes when projects are implemented. Demonstrate park visitor volumes. Economic development impacts.

- *City of Roanoke:* Establishing trends in bicycling and walking.

- *City of Alexandria:* We use count data for the following: Promoting bicycling [and] intersection and corridor studies.

- *City of Charlottesville:* One example is counting trail use at a local reservoir to figure out which trails are most popular and what times/day are most popular and to get a feel for overall use of the park.

- *Arlington County:* Lots of uses. Project planning and evaluation. Safety studies. Studies of resilience in face of Metro disruptions. Data helped make case for clearing snow from shared-use paths. Making the case that bike + walk are significant modes for transportation.

- *Roanoke County:* Grant Applications, Updates for Governing Bodies and Advisory Commissions, Maintenance, Strategic Decisions on where to direct planning for new trail projects.

- *Fairfax County:* Support projects in other areas, measure growth of usage, determine what type of facility to design and construct based on counts at nearby locations.

- *Rockingham County:* The counts had not been conducted for enough years, or the counts sizable enough, to see growth trends.

- *Town of Glen Lyn:* We use the number of walkers to determine additional efforts to improve the trails.

- *RVGC:* Board and Council reports.

- *RVARC:* Yearly performance measures reporting.

- *Bike Walk RVA:* Narrative, before and after bike infrastructure installation.

- *ATC:* Count data assist with understanding visitor use patterns and planning for Appalachian Trail management, including locations/capacities of parking areas and camping facilities.

- *TJF:* Work scheduling around days of the week with lower visitation.

- *NVRPA:* To determine cost per visitor to our parks by dividing the number of visitors per month by monthly maintenance cost.

Frequency of Counting

Most localities/organizations that performed manual periodic counts did so annually. Bike Walk RVA and the City of Alexandria counted semi-annually; the Southside Planning District Commission counted quarterly, and the Town of Glen Lyn conducted monthly counts. The number of manual counts performed each year did not differ by locality size. The duration of counting at locations varied little across localities, with most being 2-hour studies either once or twice on a weekday and again on a weekend. The City of Richmond and Bike Walk RVA counted over a course of 3 days (Tuesday, Wednesday, and Thursday), typically during the P.M. peak period hours of 5 to 7.

Figure 10 shows that one-half of localities and organizations that conducted automated counts did so continuously (50%), followed by on an as-needed basis (28%), and then periodically (22%). Those that counted continuously included the following:

- City of Harrisonburg
- City of Alexandria
- City of Richmond
- Arlington County
- Roanoke County (conducted via the RVARC count program)
- ATC
- TJF
- RVGC (conducted via the RVARC count program)
- NVRPA.

Those that counted periodically using automated methods included the following:

- City of Salem (conducted via the RVARC count program)
- Fauquier County
- Fairfax County
- Arlington County.

Those that counted on an as-needed basis using automated methods included the following:

- City of Charlottesville
- City of Roanoke (conducted via the RVARC count program)
- City of Richmond
- Arlington County
- NRVRC.

The frequency of automated counts did not differ by type of locality. Continuous counts were more common as locality population increased; however, with the small sample size, there was not enough evidence to accept this as a general rule. It is evident that the majority of localities and organizations performing automated counts conducted continuous counts at at least some of their count locations.

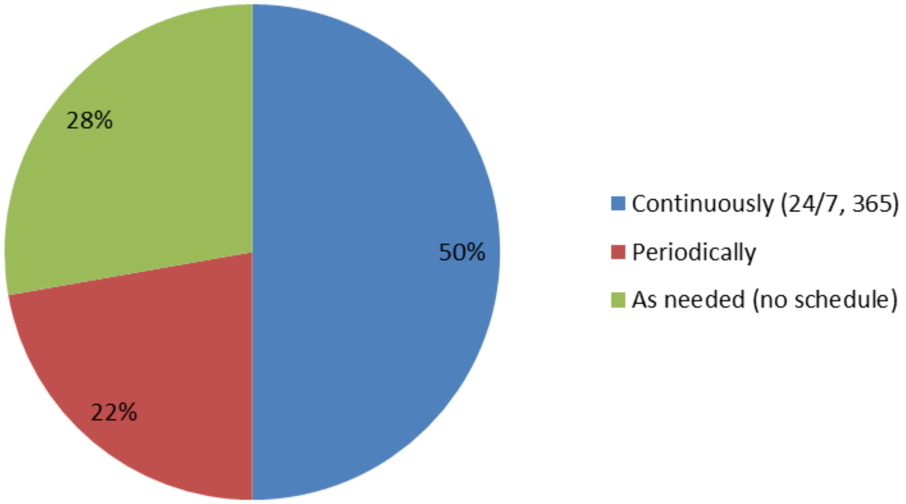

Figure 10. Frequency of Automated Counts

The timeframe for SDCs among localities and organizations that used automated methods varied from 3 days (City of Alexandria) to several weeks (Fairfax County and NRVRC). The City of Richmond and Arlington County used a 5- to 7-day timeframe. It appears that as the land area of the locality increased (see Appendix D), there was more time spent on SDCs; however, the sample size was very small.

Number of Counting Locations

Table 9 shows the localities/organizations that manually counted at 2 through 10 locations, 11 through 20 locations, and more than 20 locations. The majority counted at 11 or more locations (63%). Localities with smaller populations did not have more than 10 counting locations. The number of manual counting locations did not differ based on locality type.

Table 9. Number of Manual Counting Locations

No.	Locality/Organization
2-10	Town of Glen Lyn City of Alexandria City of Charlottesville Roanoke County Southside Planning District Commission Appalachian Trail Conservancy
11-20	City of Roanoke[a] Rockingham County Roanoke Valley-Alleghany Regional Commission Northern Virginia Regional Park Authority Roanoke Valley Greenway Commission
More than 20	City of Harrisonburg City of Richmond Fairfax County Arlington County Bike Walk RVA

[a] Conducted via the Roanoke Valley-Alleghany Regional Commission count program.

Twelve continuous counting localities/organizations used permanent automated counters. These were as follows, along with the number of permanent (i.e., continuous) counting locations:

1. Fauquier County: 9
2. Arlington County: 38
3. Roanoke County: 12 (conducted via the RVARC count program)
4. Fairfax County: 11
5. City of Richmond: 1
6. City of Roanoke: 1 (conducted by VDOT)
7. City of Alexandria: 7
8. City of Harrisonburg: 1
9. RVGC: 8 (conducted via the RVARC count program)
10. TJF: 4
11. ATC: 1
12. NVRPA: 60.

The survey questions did not differentiate between counters on shared-use paths and counters on streets and sidewalks, but survey comments and follow-up communications indicated that there was a mix, with automated count equipment more common on paths than on streets. There was not a trend regarding the size, area, or density of the locality and how many permanent count locations they had, although extremely dense localities (Arlington County and City of Alexandria) had more than other localities of comparable geographic sizes.

Automated Counting Technologies

Passive infrared was the most commonly used technology for automated counts. As shown in Figure 11, passive infrared was used by12 localities/organizations and all other technologies combined were used by 12 localities/organizations. Passive infrared was used regardless of the duration of the study; localities/organizations with long-duration automated count studies, with the exception of NRVRC, used several types of equipment to collect data. Multiple technologies were used by the City of Richmond (pneumatic tubes, inductive loops, and passive infrared); Arlington County (pneumatic tubes, inductive loops, passive infrared, and piezo bicycle counters); and Fairfax County (pneumatic tubes, passive infrared, and automated video). The City of Salem used only active infrared, the City Alexandria used only automated video, and the City of Roanoke used only inductive loops. The rest of the localities/ organizations used only passive infrared. No respondents indicated the use of thermal imaging, radar, or pressure pads.

The most common brand-name technologies were TRAFx and Eco-Counter, with TRAFx used by seven localities/organizations and Eco-Counter used by six. Multiple Eco-Counter products were used by Arlington County (Combo, Multi, PyroBox, and Totem) and the City of Richmond (PyroBox and Zelt). Depending on the type of technology used, other brand names included MioVision (City of Alexandria), MetroCount Piezo (Arlington County), and SenSource (NVRPA).

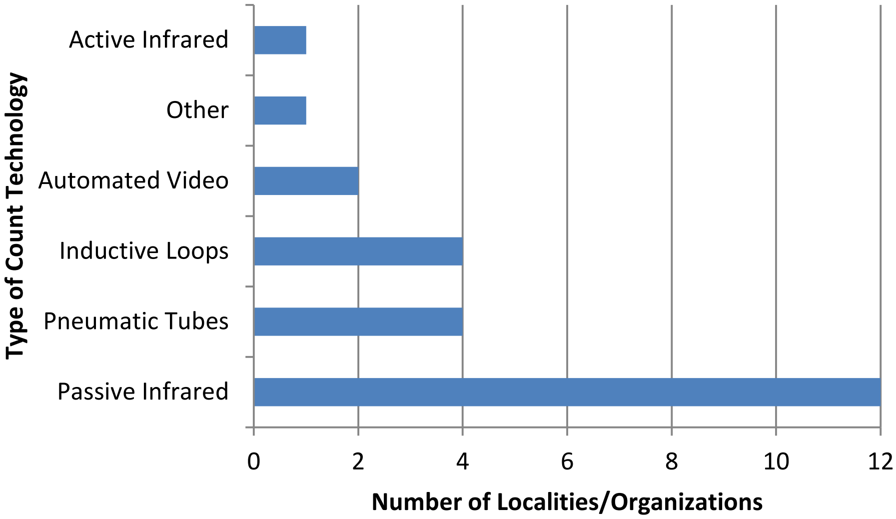

Figure 11. Use of Counting Technologies

Data Storage and Services

Approximately one-half of the localities/organizations that stored count data used a combination of methods; however, the most common was computerized data storage in a tabular format, as indicated in Figure 12. All localities or organizations used computerized, tabular storage with the exception of the cities of Alexandria and Charlottesville, which used a computerized, non-tabular method via a third party vendor (i.e., Eco-Visio or TRAFx DataNet). Other localities/organizations that used a third party vendor included the cities of Richmond and Harrisonburg and the counties of Arlington, Roanoke, and Fairfax. Arlington County and NRVRC were the only two entities that used computerized storage in a spatial data format. Paper files were used by five localities/organizations: Arlington County, Fairfax County, City of Charlottesville, RVARC, and ATC. Arlington County elaborated that field notes and tally sheets from volunteer counts were stored on paper and that it had a data entry backlog that was “significant for little expected benefit.” Other data storage methods included website databases (Arlington County and NRVRC) and smartphone counting apps (Arlington County).

Figure 13 shows the types of data services used by localities. The majority of localities/organizations (12 of 20) responded that data services were not used. The primary data service used was automatic data transmission (cities of Richmond, Alexandria, and Charlottesville; counties of Arlington and Fairfax; and NVRPA). Arlington County, the City of Alexandria, NVRPA, and RVARC also used data service tools to identify irregular data and reconstruct missing data.

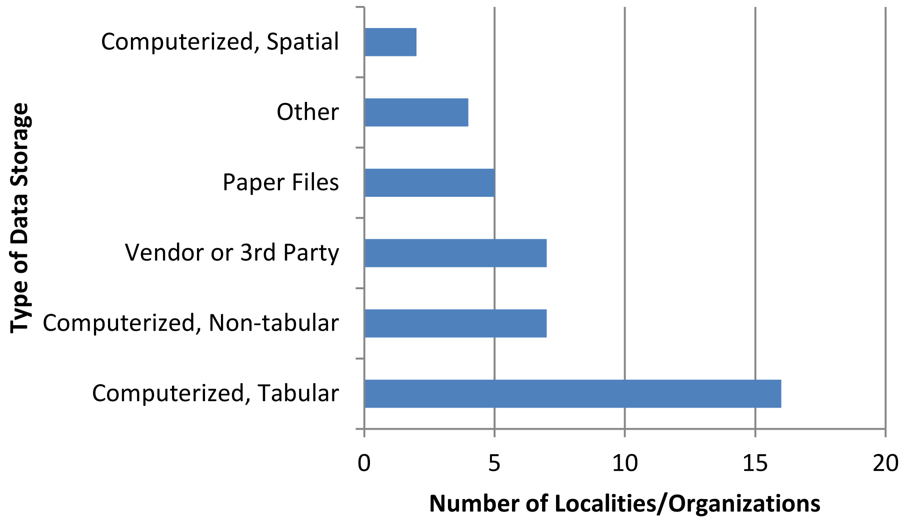

Figure 12. Data Storage Methods

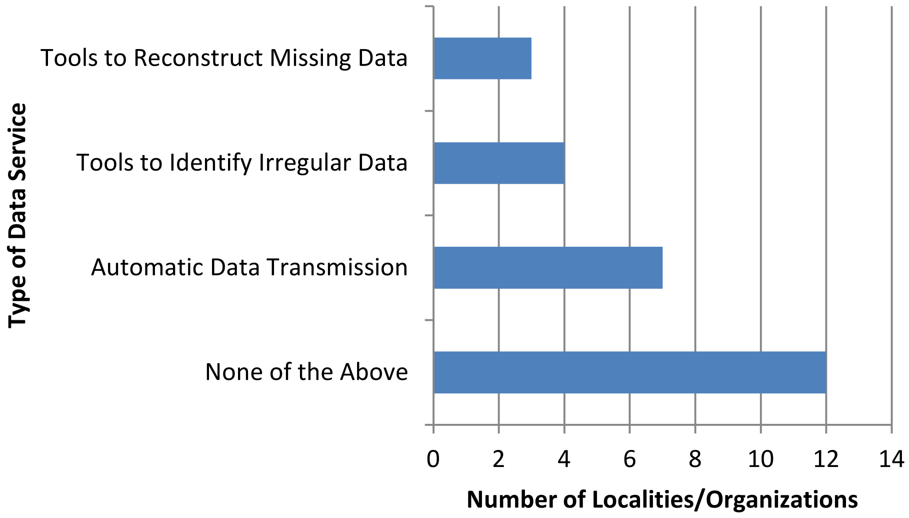

Figure 13. Use of Data Services

Data Validation and Quality Assessment

Very few localities/organizations validated counts (5 of 20), and none did so on a regular basis. The localities that indicated validation of data included the cities of Charlottesville and Roanoke and Arlington County. Organizations that validated data included RVARC and TJF. The methods that were used to validate data as reported by two localities included video (City of Roanoke) and emulating counters via automated devices (Arlington County).

As with validation, a limited number of localities/organizations (8 of 20) assessed data quality. The majority of those indicated that they did so to monitor trends and identify irregular data. Arlington County reported having a contract for premium support with Eco-Counter under which they received bulk checks for data quality (e.g., outliers and anomalies) along with help reconstructing missing data as required. The respondent elaborated further:

> This is an ongoing area of development. Sometimes Eco-Counter catches a problem; sometimes the county catches a problem; sometimes [a] remote public user catches a problem. We are almost a beta test site for getting better at this.

The other localities/organizations that assessed data quality included Fauquier County, Roanoke County, City of Salem, City of Roanoke, City of Charlottesville, NRVRC, and RVGC.

Data Sharing

With the exception of the Town of Glen Lyn and TJF, all localities released data to government agencies, stakeholders, and/or the general public (see Figure 14). It was most common for localities/organizations to release data to government planning partners and stakeholders rather than to the general public. Eleven of 14 localities that released data to government planning partners also released data to stakeholders. Six localities released their information to the general public, government planners, and stakeholders.

Figure 14. Data Sharing

Program Funding

Figure 15 shows the funding sources for continuous count programs. A local budget was the most common source of funding for count programs. NRVRC and ATC were the only two organizations using federal, state, and local funding, and Southside PDC used both state and local funding. The remaining used local budgets (or general budgets, for nonprofit organizations) to fund their programs. Local funding was derived from capital maintenance programs (Roanoke County), vehicle registration fees (Arlington County), rural transportation work programs (Southside PDC), and operational or general department budgets (Fauquier County and RVGC). Other sources of funding included volunteer donations (monetary or time contributions).

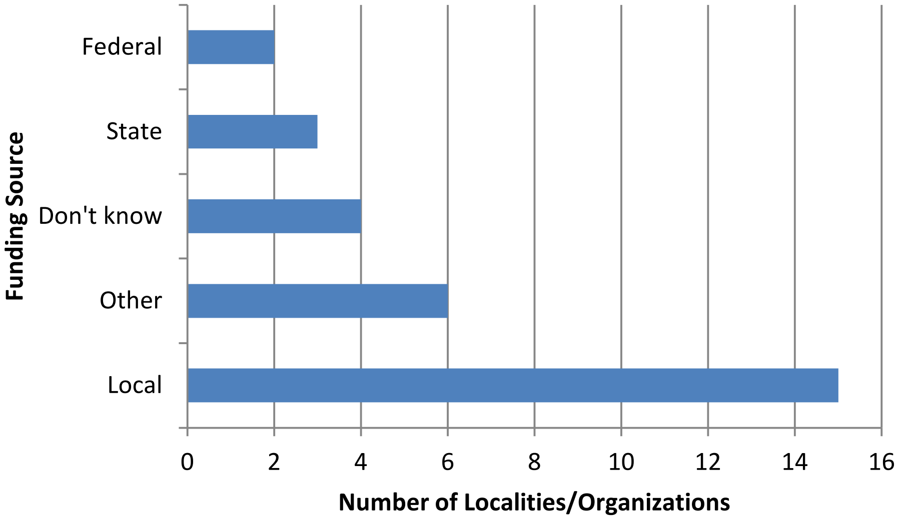

Figure 15. Count Program Funding Sources

Program Oversight

Figure 16 shows that there was a relatively even distribution of entities that oversaw these count programs, with "Parks and Recreation" having a slight plurality at 26%. MPOs and PDCs typically did not have specific departments; other organizations such as TJF and ATC provided responses that were categorized as "Other" ("Gardens and Grounds" at TJF and a cooperative with the National Park Service at ATC).

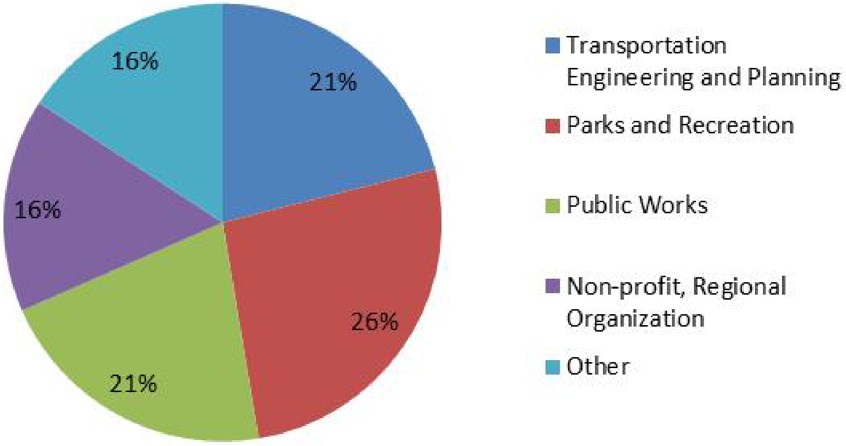

Figure 16. Count Program Oversight

Interest in Counting

Previous Discussions Regarding Counts

Respondents without continuous or periodic counting programs were asked whether there had been any discussion within their locality or organization about conducting nonmotorized counts (if they had not done so) or establishing a nonmotorized count program (if they had conducted only sporadic counts) and, if so, whether such discussions were formal discussions with elected/appointed officials or informal discussions at the staff level. As shown in Figure 17, more than one-third of respondents had discussed the idea informally.

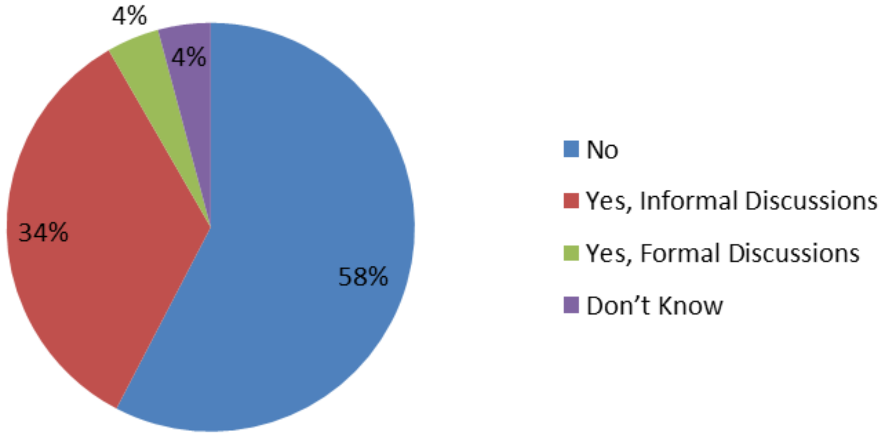

Figure 17. Discussions Regarding Counts for Respondents Without Continuous or Periodic Counting Programs

Beneficial Locations

To gain insight on potential interest in counting from localities and organizations that did not conduct counts, a survey question asked if there were locations (roadways or trails within the respondent's jurisdiction) where having counts would be beneficial. A total of 143 responses were received for this question, with 81% indicating "yes" and 19% indicating "no." Twelve of the 13 MPOs, PDCs, and other organizations that responded (92%) indicated that there were locations that would benefit from counts. Filtering the locality responses by VDOT district yielded the following ratios of "yes" responses compared to total responses:

- Bristol District: 0.67
- Culpeper District: 0.82
- Fredericksburg District: 0.85
- Hampton Roads District: 0.93
- Lynchburg District: 0.71
- Northern Virginia District: 1.0
- Richmond District: 0.58
- Salem District: 0.93
- Staunton District: 0.86.

Respondents from all VDOT districts provided a positive response in terms of interest in conducting counts, with the districts of Northern Virginia, Hampton Roads, and Salem all having more than 90% of respondents with interest. The Richmond District had the lowest percentage, at 58%.

A similar question was posed to localities and organizations that conducted counts but not continuously or periodically. The question asked if there were distinct locations on roadways or trails where continuous or periodic counts would be beneficial. Of the 18 localities/organizations that responded to this question, 17 of 18 (94%) indicated "yes."

Respondents with continuous or periodic counts were asked if there were distinct locations on roadways or trails that were not currently equipped with counters where continuous or periodic counts would be beneficial. "Yes" responses were received from 17 of 18 respondents (94%).

For each group that was asked about beneficial counting locations (non-counters, sporadic counters, and continuous/periodic counters), additional probing questions were asked about specific locations, to include begin and end nodes on roadways and/or trails. Most respondents provided exact locations; those that did not were contacted via telephone or email to obtain exact locations. Figure 18 shows a macro view of locations where respondents thought counting would be beneficial. Tables E1 through E3 in Appendix E provide specific details from each of the responding localities/organizations.

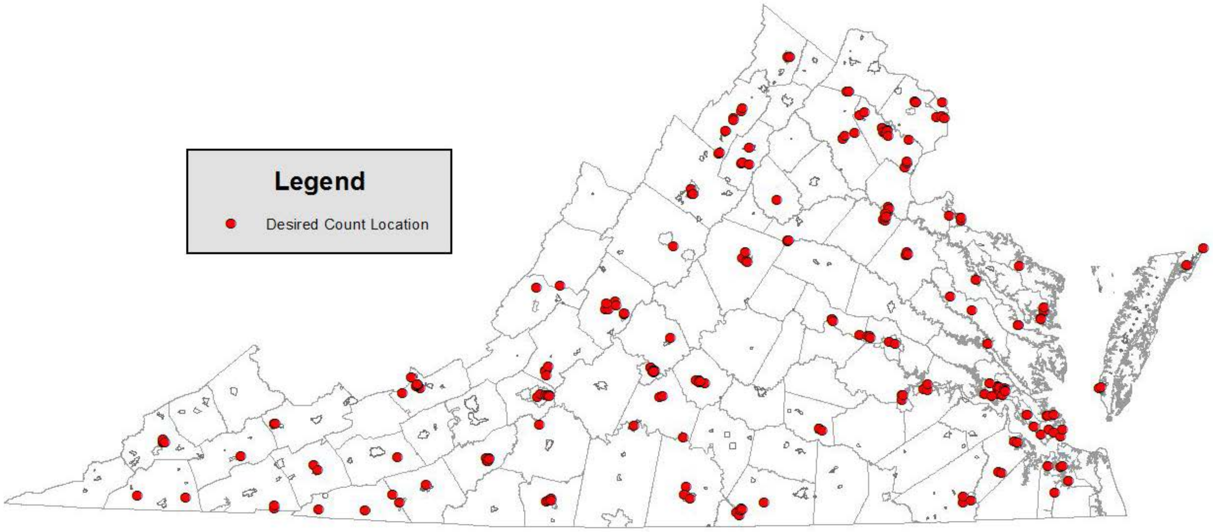

Figure 18. Macro View of Counting Locations of Interest

Interest in Partnering With VDOT Using NCDOT Program Model

Two survey questions gauged interest in partnering with VDOT to assist with the development of a state-managed count program. One question was related to efforts currently underway in North Carolina, where NCDOT installs permanent bicycle/pedestrian counting equipment at their expense and local governments agree to maintain the equipment at their expense (maintenance includes changing batteries and periodically inspecting the equipment). On a scale of 1 to 5, respondents were asked to rate their locality's/organization's interest in such a partnership, with 1 indicating no interest, 3 indicating moderate interest, and 5 indicating high interest. Figure 19 shows the responses filtered by VDOT district. The majority of respondents in each district indicated an interest level of 3 or higher, with the Staunton and Salem districts having the highest number of high interest or moderately high interest responses (interest rating of 5 or 4, respectively).

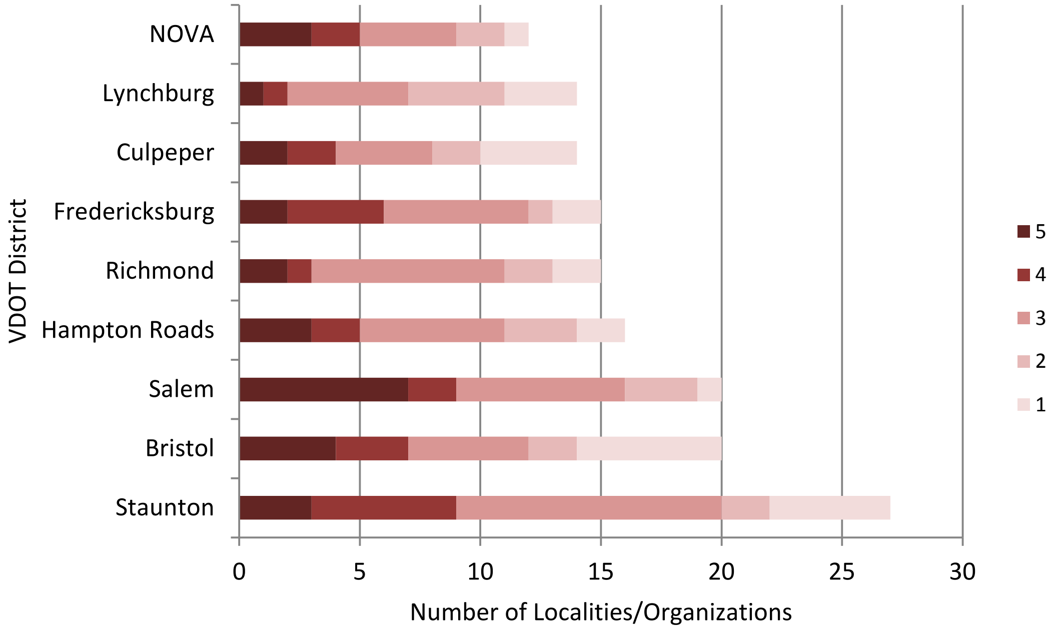

Figure 19. Interest From Respondents, by District, in a Partnership With the State Department of Transportation Installing Counting Equipment and Local Governments Maintaining the Equipment. NOVA = Northern Virginia District. 1 = No Interest; 2 = Low Interest; 3 = Moderate Interest; 4 = Moderately High Interest; 5 = High Interest.

Small-sample Wilcoxon signed-rank tests were conducted by district to determine if the median rating for the NCDOT-type partnership from localities and organizations in that district was significantly greater than 3, an indication that the model would be relatively favorable in that district. The test was performed as follows:

1. Subtract the hypothesized median from each value in the dataset.

2. Sort the resulting values in increasing order by absolute value.

3. Assign rank to each value, starting with 1.

   - If multiple values are the same, assign each the average of their ranks.
   - If the value is negative, the assigned rank is negative.

4. Sum positive ranks to obtain S^+.

For the hypotheses H_0 = median < 3 and H_1 = median ≥ 3, Table 10 shows the descriptive statistics for localities and organizations within each VDOT district and whether to reject or fail to reject the null hypothesis at a 95% confidence level ($p \leq 0.05$). Based on the results of the tests, only the median rating for responses from the Salem District was statistically significantly greater than 3.

Table 10. Descriptive Statistics of NCDOT Hypothesis Tests

VDOT District of Respondents	S^+	n	p	Reject Null?
Bristol	51	15	$p > 0.10$	No
Culpeper	20	10	$p > 0.12$	No
Fredericksburg	27	9	$p > 0.10$	No
Hampton Roads	30	10	$p > 0.12$	No
Lynchburg	10.5	9	$0.10 > p > 0.08$	No
Northern Virginia	26	9	$p > 0.10$	No
Richmond	13	7	$p > 0.11$	No
Salem	72.5	13	$0.05 > p > 0.03$	Yes
Staunton	64.5	16	$p > 0.11$	No

NCDOT = North Carolina Department of Transportation.

Large-sample Wilcoxon signed-rank tests were then conducted to determine if the rating median for the NCDOT-type partnership was significantly greater than 3 for all localities and organizations in Virginia, which would indicate that the program is favorable overall in Virginia. Given the size of the sample, the test statistic is approximately normally distributed and can be used to obtain a *z*-statistic. The equation to calculate the *z*-statistic is given as follows:

$$z = \frac{S^+ - \frac{n(n+1)}{4}}{\sqrt{\frac{n(n+1)(2n+1)}{24}}}$$

where

S^+ = positive rank test statistic = 3,716
n = sample size = 116
z = 0.8898.

Using the hypotheses of H_0 = median < 3 and H_1 = median ≥ 3, the null is not rejected at a 95% confidence level because $p = 0.1867$. Therefore, it cannot be said with confidence that the overall median interest rating in the NCDOT-type program was greater than or equal to 3 (moderately interested).

Interest in Partnering With VDOT Using MnDOT Program Model

Another survey question gauged interest in partnering with VDOT in a way similar to the program currently underway in Minnesota, where MnDOT loans portable bicycle/pedestrian counting equipment to local agencies for short-duration bicycle/pedestrian counts. On a scale of 1 to 5, respondents were to rate their locality's/organization's interest in such a partnership, as with interest in the NCDOT model. Figure 20 shows the responses filtered by VDOT district. The majority of respondents in each district indicated an interest level of 3 or higher, with the Northern Virginia, Staunton, and Salem districts having the highest number of high or moderately high interest responses (interest rating of 5 or 4, respectively).

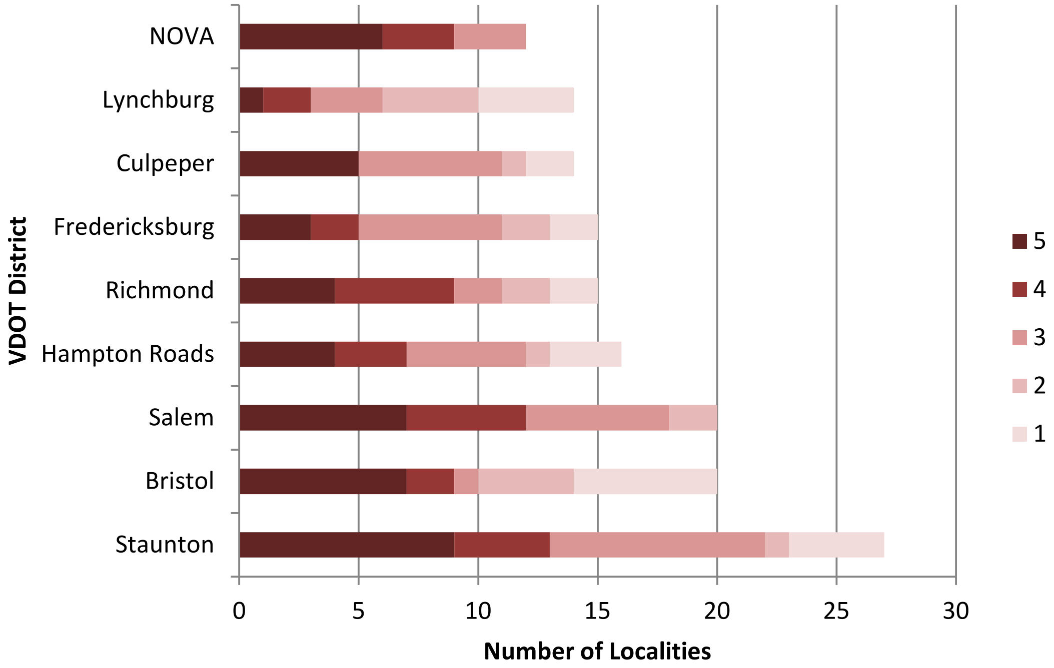

Figure 20. Interest From Respondents, by District, in a Partnership With the State Department of Transportation Loaning Portable Bicycle/Pedestrian Counting Equipment to Local Agencies for Short-Duration Counts. NOVA = Northern Virginia District. 1 = No Interest; 2 = Low Interest; 3 = Moderate Interest; 4 = Moderately High Interest; 5 = High Interest.

The same Wilcoxon signed-rank testing that was performed for interest in the NCDOT-type partnership was performed for interest in the MnDOT-type partnership. For the hypotheses H_0 = median < 3 and H_1 = median ≥ 3, Table 11 shows the descriptive statistics for each district and whether to reject or fail to reject the null hypothesis at a 95% confidence level ($p \leq 0.05$). Based on the results of the tests, the median ratings for responses from the Northern Virginia and Salem districts were statistically significantly greater than 3.

Large-sample Wilcoxon signed-rank tests were then conducted to determine if the rating median for the MnDOT-type partnership was significantly greater than 3 for all localities and organizations in Virginia, which would indicate that the program is favorable overall in Virginia. The descriptive statistics were as follows:

- positive rank test statistic (S^+) = 5771.5
- sample size (n) = 130
- z = 3.52.

Using the hypotheses H_0 = median < 3 and H_1 = median ≥ 3, the null is rejected at a 95% confidence level since $p < 0.05$. Therefore, it can be said with confidence that the overall median interest rating in the MnDOT-type program was greater than or equal to 3 (i.e., at least moderately interested).

Table 11. Descriptive Statistics of MnDOT Hypothesis Tests

VDOT District of Respondents	S^{+}	n	p	Reject Null?
Bristol	98	19	$p > 0.11$	No
Culpeper	25	8	$p > 0.13$	No
Fredericksburg	26	9	$p > 0.10$	No
Hampton Roads	35.5	11	$p > 0.10$	No
Lynchburg	16	11	$0.09 > p > 0.05$	No
Northern Virginia	45	9	$p < 0.01$	Yes
Richmond	62	13	$p > 0.11$	No
Salem	97	14	$p < 0.01$	Yes
Staunton	120	18	$0.09 > p > 0.05$	No

MnDOT = Minnesota Department of Transportation.

Hypothesis Testing for Difference in Means Between NCDOT and MnDOT Interest Ratings

Large-sample Mann-Whitney U tests were used to determine if one type of partnership was favored over the other for respondents from each VDOT district. This was accomplished by assigning rank to the sorted dataset and using the hypotheses $H_0 = \mu_{M \leq} \mu_N$ and $H_1 = \mu_M > \mu_N$. The equation to calculate the z-statistic is given as follows:

$$z = \frac{W - \dfrac{m(m+n+1)}{2}}{\sqrt{\dfrac{mn(m+n+1)}{12}}}$$

where

W = test statistic (sum of ranks corresponding to MnDOT responses)
m = sample size (MnDOT responses)
n = sample size (NCDOT responses).

Table 12 shows the descriptive statistics for respondents from each district and whether to reject or fail to reject the null hypothesis at a 95% confidence level ($p \leq 0.05$). Based on the results of the tests, only the respondents of the Northern Virginia District had statistically significantly different mean interest ratings between the NCDOT-type and MnDOT-type programs. Therefore, it can be said with confidence that respondents from the Northern Virginia District favored the MnDOT-type program over the NCDOT-type program. At a slightly lower confidence level of 90% ($p \leq 0.1$), it can be said that respondents from the Staunton and Richmond districts also favored the MnDOT-type program over the NCDOT-type program.

Table 12. Descriptive Statistics of Hypothesis Test for Difference in Means Between NCDOT-Type and MnDOT-Type Interest Ratings

VDOT District of Respondents	*W*	*m*	*n*	*z*	*p*	Reject Null?
Bristol	421.5	20	20	0.311	0.38	No
Culpeper	277	14	14	0.136	0.14	No
Fredericksburg	227	15	15	-0.228	0.41	No
Hampton Roads	276.5	16	16	0.471	0.32	No
Lynchburg	198	14	14	-0.229	0.41	No
Northern Virginia	211	13	13	1.82	0.03	Yes
Richmond	262.5	15	15	1.24	0.10	No
Salem	435.5	20	20	0.689	0.25	No
Staunton	820	27	27	1.34	0.09	No

NCDOT = North Carolina Department of Transportation; MnDOT = Minnesota Department of Transportation.

A large-sample Mann-Whitney U test was then performed to determine if one of the partnership models was favored over the other when responses from all localities and organizations were considered. Using the same hypotheses, $H_0 = \mu_{M \leq} \mu_N$ and $H_1 = \mu_M > \mu_N$, the descriptive statistics were as follows:

- $W = 34687.5$
- $m = 180$
- $n = 180$
- $z = 2.23$
- $p = 0.0129$.

Based on the results of the test, $p = 0.0129$ and the null is rejected at a 95% confidence level; thus, there is a significant difference in the mean interest rating of the NCDOT and MnDOT programs. Therefore, it can be said with confidence that as a whole, Virginia localities and organizations responding to the survey favored the MnDOT program over the NCDOT program. In addition, for the localities/organizations that already performed counts in some capacity, the MnDOT program was preferred over the NCDOT program, with respondents from the Northern Virginia and Richmond districts having the most interest; respondents from Bristol, Hampton Roads, and Staunton showed the most interest among respondents who did not already count.

Overall Interest

In consideration of responses from localities and organizations that already counted, responses about locations where counting would be beneficial, and interest ratings of 3 or higher for partnering with VDOT using the NCDOT or MnDOT program models (with any of the aforementioned characteristics constituting “interest”), a map was constructed that could be said to represent the overall interest in nonmotorized counting in Virginia (Figure 21).

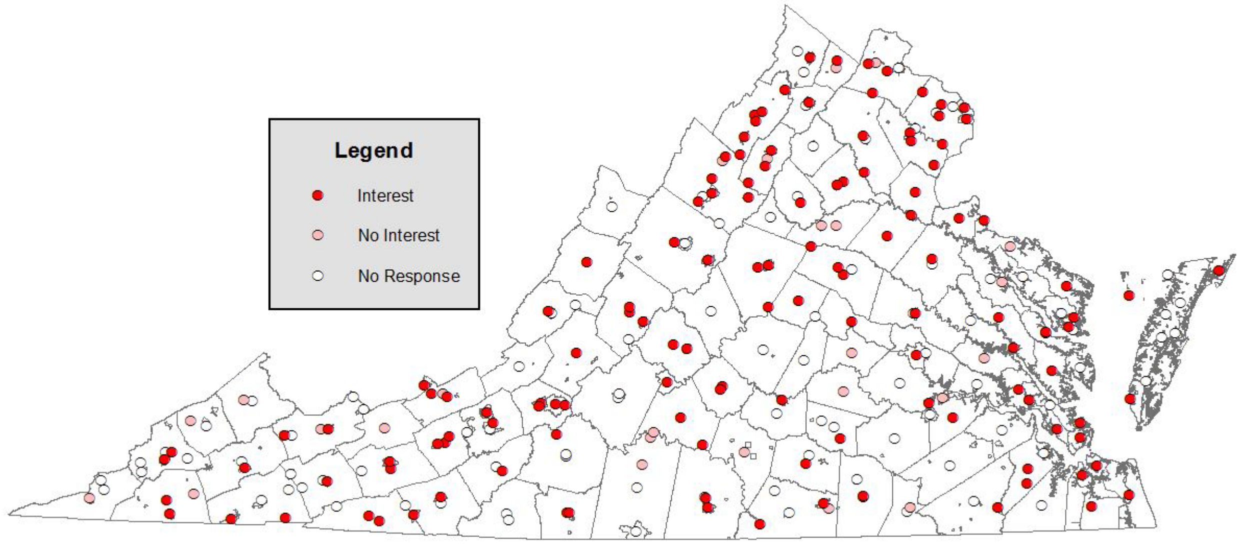

Figure 21. Designation of Virginia Localities and Organizations With Regard to Interest in Nonmotorized Counting. "Interest" includes those that already counted, those that indicated that counts would be beneficial, or those that had an interest level of 3 or higher for at least one partnership model. Dots represent localities and organizations, not specific potential count sites.

Framework for a Pilot Nonmotorized Count Program in Virginia

As other states have recognized with their counting efforts, even if Virginia's eventual goal is to have a truly statewide, state-administered nonmotorized count program (no policy-making body had expressly stated such a goal as of January 2018), such a program would take time to develop. For the purposes of initiating the first steps of an incremental statewide pilot nonmotorized count program, a framework for a pilot program was developed. This section provides the framework in a stepwise process and includes additional considerations for establishing a sustainable long-term count program. The framework and considerations are provided in the areas of program design, outreach to localities, data uses, site selection, data collection technologies, data storage, data quality control, and program administration. Steps in the framework are as follows:

1. Develop program design.
2. Conduct outreach to localities and other organizations.
3. Determine data uses.
4. Select sites.
5. Determine data collection technologies.
6. Identify data storage mechanism.
7. Develop data quality control.
8. Establish program administration.

Develop Program Design

Overview

Because Virginia has several localities with experience conducting manual and automated bicycle and pedestrian counts, including a national leader in Arlington County, any state-administered count program should build on this strength by pursuing local and regional partnerships that can leverage VDOT's investments while assisting localities. Even the developers of a small-scale pilot should have a larger vision in mind, and such a vision should be developed cooperatively with localities, especially those already involved in this area. At the same time, the TRP suggested that as a VDOT initiative, a nonmotorized travel monitoring program should focus on addressing VDOT's needs.

Implementing a pilot nonmotorized travel monitoring program in one or more VDOT districts is one way to proceed with a proof of concept while establishing what a nonmotorized count program would look like. It could help illustrate how much data and what level of effort would be needed in order to achieve results that are useful (what decisions the data will inform and what questions will remain unanswered). Based on the survey results, the Salem and Northern Virginia districts would be good choices, as both had relatively high levels of locality interest in nonmotorized counting and existing count efforts that could be leveraged. For example, RVARC's automated count program in the Salem District provides good coverage of off-street trails but generally does not distinguish between bicycle and pedestrian traffic, so next steps could include adding equipment or conducting short-term counts to estimate mode splits.

The survey found that localities in the Salem District had high interest in both the NCDOT program (local maintenance of state DOT permanent counters) and the MnDOT program (portable counter loan) whereas localities in the Northern Virginia District had more interest in the MnDOT program (see Figures 22 and 23). Because a full nonmotorized travel monitoring program would require both permanent and short-duration count stations, a hybrid program could be initiated in one or both districts to provide, as appropriate, (1) loaner portable count equipment and (2) a small number of permanent CCSs.

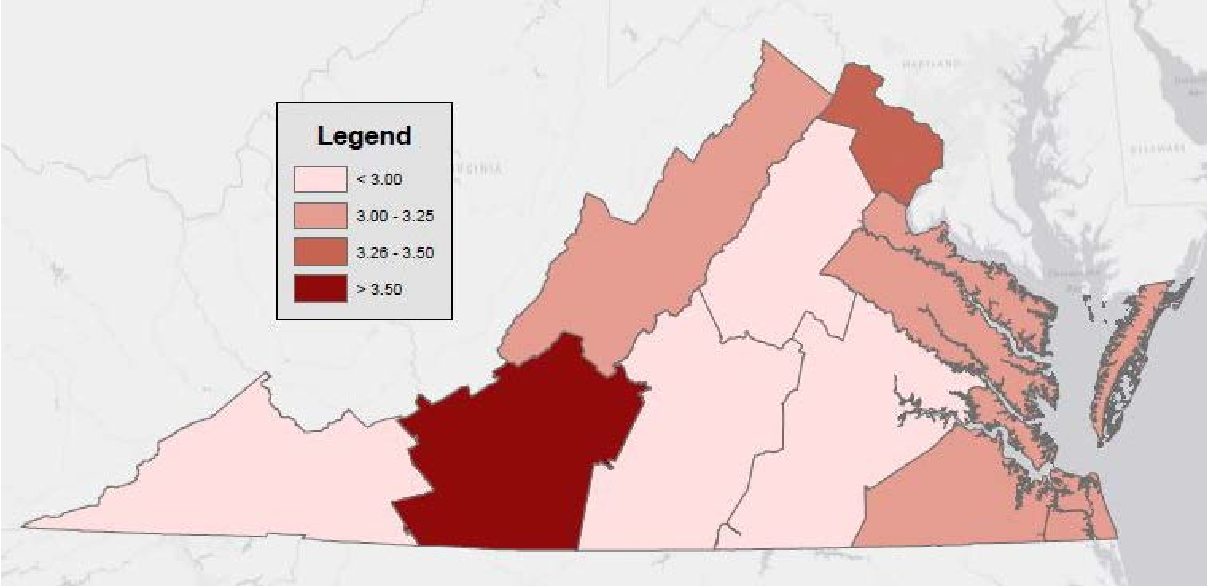

Figure 22. Average Interest in NCDOT Program by VDOT District (Salem District average > 3.50)

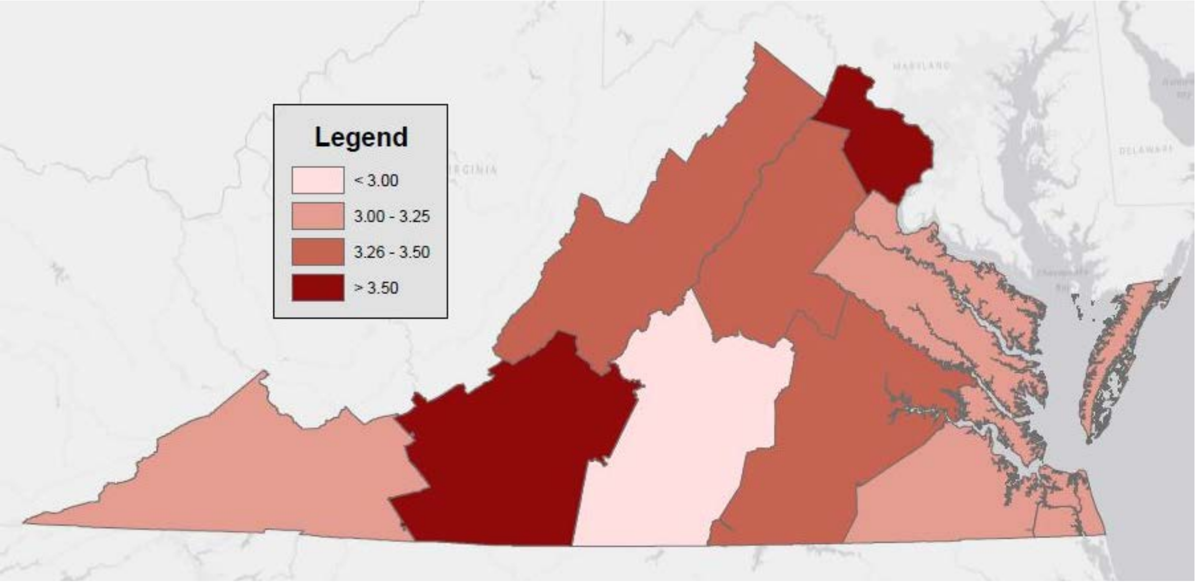

Figure 23. Average Interest in MnDOT Program by VDOT District (Salem and Northern Virginia District average > 3.50)

Additional Considerations

A state-administered program involving permanent count equipment would require that funds and staff time be identified for ongoing maintenance. In some areas of the state, VDOT has had difficulty maintaining automotive travel time sensors. Bicycle and pedestrian sensors would typically be under lighter traffic loads but might also have unique challenges, such as battery replacements or malfunctions caused by pest infestations. Without ongoing funds for maintenance, a program using only mobile or contracted count equipment (such as Miovision or SDC tubes) may be a better choice. The cost of hiring count contractors (e.g., for short-duration video data collection and tabulation) vs. purchasing portable count equipment could be evaluated. Without a clear understanding of future budgets, though, a one-time investment could include purchase of portable count equipment that would have relatively low (but not zero) ongoing costs.

Another option would be to create a nonmotorized count program targeted only at VDOT's needs rather than localities' interests. Such a program could be statewide in availability but not in geography; that is, it could make equipment available to any VDOT planner or engineer for studies as needed but would not attempt to build a statewide network of sensors along local and VDOT facilities. This would not necessarily preclude the possibility of developing an integrated statewide program at a later date but would also not take full advantage of the potential for local partnerships.

With a pilot program rather than a truly statewide approach, constructing a reference network of estimated multimodal traffic volumes for evaluating project proposals may be difficult, but it may be possible to create models at the district level. A similar process could be undertaken to predict latent demand for bicycle and pedestrian travel to help district planners determine what types of facilities might be appropriate in developing areas. This would likely require the use of direct-demand models to predict usage in areas without counting equipment based on characteristics such as land uses and facilities for nonmotorized transportation.

In addition, there is a possibility that video-based counts (e.g., Miovision) that are already being done for VDOT studies could routinely include bicycle/pedestrian counts and archive video footage for optional review later if data are requested on items such as helmet use.

Conduct Outreach to Localities and Other Organizations

Overview

Unless the nonmotorized count program would exclude localities and MPOs, outreach to them would be a critical element in a partnership. Survey results suggested that the majority of localities have no experience with this topic, and those who do may have questions about equipment installation and validation, factoring, and applications of count data. VDOT's existing capabilities in technology transfer and training could be expanded to include training for localities on topics related to nonmotorized travel monitoring. Within the realm of the pilot program, outreach to specific localities within the Salem and Northern Virginia districts that had a high interest in partnering with VDOT are candidates for initial outreach opportunities.

Additional Considerations

Providing training for staff involved in nonmotorized data collection efforts would not need to "reinvent the wheel." For example, the Pedestrian and Bicycle Information Center delivered a two-part webinar on bicycle and pedestrian count data in February 2017; the sessions are archived online along with related resources (Pedestrian and Bicycle Information Center, 2017) and addressed how and why to count, summarized some count programs, introduced the TMG format, and gave an overview of different types of counting equipment and considerations for using each type of counter.

Another training option is to sponsor a course created by an outside entity such as the National Highway Institute; its course on the TMG could be modified or expanded to include nonmotorized data collection techniques.

Safety would be a key topic to include in outreach efforts. In localities where counting efforts are emerging from planning departments (as opposed to streets or public works departments), responsible staff may have a thorough knowledge of best practices for work zone safety. If using VDOT funds, localities would need to comply with VDOT safety policies and have the appropriate training.

Other incremental steps could include (1) producing guidelines for localities and VDOT regarding nonmotorized volume counts with the intent of capitalizing on partnerships while managing liability, and (2) convening bicycle/pedestrian staff members from localities to discuss standardizing their volume data collection processes.

Determine Data Uses

Overview

The pilot program's structure could depend on how the data are to be used. Although no formal effort was conducted to obtain information from VDOT staff, the following uses of bicycle/pedestrian data have emerged during the course of the study as VDOT business needs that could benefit from such data:

- estimating exposure for safety analysis including evaluations of effectiveness of projects funded by the Highway Safety Improvement Program
- evaluating the effectiveness of road diet and bike boulevard projects using before and after data
- evaluating what to do with aging pedestrian bridges over limited access highways and deteriorating shared-use paths along some roadways
- comparing bicycle and pedestrian activity levels on proposed Smart Scale projects (there is currently a method for generating rough estimates of such activity, but counts are used if available; in the most recent cycle of project evaluations, counts were available for only 3 of 346 submitted projects)
- scoring Safe Routes to School project proposals.

Additional Considerations

With a robust program to loan portable counting equipment, VDOT could encourage (or require) localities applying for Smart Scale funds to use that program to collect bicycle and pedestrian data to support project submittals. VDOT could also require localities using its counting equipment to specify how the data have been used (some of which include developing grant applications, assisting with permitting special events that close greenway facilities, and developing performance measures).

The data could also be useful to partner agencies including the Virginia Department of Rail and Public Transportation, which could use bicycle and pedestrian counts when assisting local transit agencies with planning efforts (e.g., route accessibility studies and assessments of local infrastructure needs).

Select Sites

Overview

Based in part on data needs, site selection should balance VDOT's needs with the desires of pilot localities and be driven by VDOT's policy goals (e.g., developing a statewide snapshot of activity vs. supporting local project-related decisions). Especially for CCSs, VDOT should conduct a thorough review of each pilot site's technical feasibility and value to the network of count stations. For example, VDOT could seek to stratify CCSs by facility type as with auto count sites (using the measure of centrality from the literature or another approach). VDOT could also assist pilot localities in selecting sites for SDCs or take a more hands-off approach. Candidates for SDC sites of interest to VDOT would include the following:

- wherever a road re-design is imminent, allowing data to be collected for a before-after study (for roads where bicycle and pedestrian travel is not prohibited; e.g., for road diets that re-purpose one or more auto lanes as bicycle lanes)
- at bridges and other points in the network where bicycle and pedestrian traffic is funneled into a single location or small set of locations
- on older shared-use paths with maintenance issues and no adjacent sidewalk, to decide whether to maintain the path or replace it.

Additional Considerations

There is a dependency between sites and equipment/technology. Sites can dictate what equipment to purchase; on the other hand, if equipment has been purchased before site selection, sites can be determined based on their suitability for the equipment.

Caution should be exercised if counts are requested on recreational facilities such as loop trails. Although such data could be incorporated in a VDOT-coordinated data collection program despite serving little or no transportation function (as long as such counts are clearly flagged), some funding streams are restricted to facilities serving transportation purposes. Activity patterns on recreational facilities can provide a basis for comparison with activity patterns at other count locations and a determination of whether those locations exhibit a recreational, commute, or mixed pattern. One option for designating facilities as mostly recreational is to examine whether they would qualify for federal transportation funds. If they would not, such funds should not be used to obtain counts on those facilities.

Determine Data Collection Technologies

Overview

Identifying a particular vendor for a pilot program is outside the scope of this study, but the survey found that TRAFx and Eco-Counter products were the most commonly used by respondents, and VDOT has recent experience with Eco-Counter products. As previously discussed, there is a dependency between sites and technologies. On-road counts, particularly in mixed traffic, require different equipment than off-road counts. Another dependency is data format. Because it will be critical for all data to be compatible, a first step could be choosing a data format with which any subsequently chosen technology would need to comply (e.g., the GEOCOUNTS open standard format). VDOT should select a data format that is compatible with the TMG format used for the federal TMAS database.

Additional Considerations

Bicycle and pedestrian counting technology continues to evolve in terms of both traditional site-based counting equipment and crowdsourced or big data solutions. Although there may be preferred vendors and technologies at any given time, VDOT should remain flexible and able to adapt to new options rather than selecting a single vendor or set of technologies for the long term.

Big data may be useful for bicycle/pedestrian traffic monitoring but should be used with caution. Before the data are used, the quality of the data should be evaluated, which is not permitted under some contracts. Knowing what the data represent affects how they can be used; for example, bicyclist route traces from the Strava app may have some value, but the app is geared toward athletes, and this should be considered. As alternatives to traditional monitoring data become available, their costs should be compared. The estimated cost of obtaining Strava data for Virginia was $300,000 for 1 year; budgets are not likely to support this level of expenditure in the short term, but as costs go down and/or benefits become more apparent, there may be opportunities to incorporate big data into a nonmotorized travel monitoring program.

VDOT could also choose to become involved in testing and evaluating new technologies, such as by establishing a test bed for system acceptance and verification. Improved sensors offer the potential to have error rates low enough to eliminate the task of developing correction factors at each site. Testing new equipment would also give VDOT opportunities to collect data and to give vendors feedback on products.

In addition to the technologies covered in the literature review, new technologies continue to emerge. Some that came to the researchers’ attention (but that have not been thoroughly investigated or evaluated) include the following:

- Numina, a pole-mounted, video-based sensor using machine learning for bicycle and pedestrian counts (Nash, 2017; O’Toole and Piper, 2016)

- Placemeter, a relatively low-cost video-based sensor using machine learning for multimodal counts (Nash, 2017; O'Toole and Piper, 2016)

- Waycount, a company offering low-cost bicycle and auto counting devices using pneumatic tubes (Nash, 2017; O'Toole and Piper, 2016)

- sensors and tools developed by universities including the University of Chicago's Array of Things Project (O'Toole and Piper, 2016) and Carnegie Mellon University's Intelligent Mobility Meter (Carnegie Mellon University, n.d.)

- Iteris PedTrax and SmartCycle, technologies to obtain intersection counts from traffic signal detection cameras (O'Toole and Piper, 2016)

- GRIDSMART, a single-camera system for intersection actuation and traffic data collection (GRIDSMART Technologies, Inc., 2018)

- new products from established vendors including MetroCount, JAMAR, and Q-Free (identified through discussions with the TRP).

Identify Data Storage Mechanism

Overview

A count program includes much more than count equipment, and one critical element is a database for data storage. Although the federal TMAS database may be accepting bicycle and pedestrian count data, it is not a substitute for a robust state-level database. VDOT uses iPeMS performance management software and a related module called Counts that allows uploading of traffic count data but has not been heavily used. Using this existing module associated with iPeMS would be a logical place to start in establishing a data repository for the pilot program.

Additional Considerations

A simple first step could be to combine and standardize data that have already been collected by VDOT and localities. This could help identify data gaps and inform the site selection process for additional count locations. The major challenge with aggregating data from localities would be ensuring consistent and reasonable levels of data quality, making it likely that there will be a need to establish a threshold for accepting data. For example, some older data, such as 2-hour counts conducted for the National Bicycle and Pedestrian Documentation Project, cannot be put into the TMG format unless the data were collected in bins of 60 minutes or smaller (FHWA, 2016).

A challenge associated with any statewide database could be the difficulty of allowing staff from multiple localities to upload data, but any platform would need to be accessible by various VDOT divisions. For some sites, it may be possible to automate the process of importing data into Counts from other interfaces (e.g., Eco-Counter's Eco-Visio tool).

One dependency associated with data storage (including for big data such as Strava data) is the creation and maintenance of a statewide asset inventory of bicycle and pedestrian facilities to which count data can be linked. As of December 2017, VDOT had begun tracking additions to the bicycle/pedestrian network that came about as part of roadway projects and had developed a full inventory for the Northern Virginia District and VDOT's TMPD had reasonably good data for on-street bicycle facilities and shared-use paths (but not sidewalks) in other districts. One option for incrementally expanding sidewalk asset inventory data would be for VDOT's TED to collect information about adjacent sidewalks when in the field conducting ongoing assessments of curb ramp accessibility.

Develop Data Quality Control

Overview

As Turner and Lasley (2013) noted, acceptable data quality is determined by data use. A pilot should help determine what levels of accuracy and quality are needed. A combination of automated processes and manual review for ground truth can maximize quality in an efficient manner. Data quality standards should be established for locally collected data submitted to VDOT, which should be flagged as originating with an outside agency.

Additional Considerations

Based on what other states have done, quality checks will likely include flagging of data gaps, consecutive zeros, skewed directional splits, and unusual ranges. Clearly delineated roles and responsibilities, especially for equipment maintenance, would help maximize data quality. For sites or localities where general relative trends are desired rather than an estimation of average daily travel or calculation of exposure, quality control may not be as much of a concern, but such datasets should be flagged and their uses restricted. Data collection techniques such as 2-hour manual counts by volunteers may not be adequate for purposes such as estimating AADBT and AADPT.

Establish Program Administration

Overview

Although multiple entities have business needs for the data that could be produced by a state-coordinated pedestrian and bicycle count program, one VDOT division should be designated the administrator of the program. For example, although VDOT's TMPD could use the data for Smart Scale, VDOT's TED could determine relative bicycle and pedestrian exposure levels for safety analyses, and local governments could develop grant proposals, the TED might also be a logical choice for eventual integration with the motorized count program as its staff are familiar with the technologies and processes involved in travel monitoring. However, if the TED's business need for the data did not outweigh the cost of implementing the program in terms of both monetary cost and opportunity cost (i.e., assuming continued budgetary constraints), implementation of the program by the TED would mean that other TED initiatives could be delayed. Therefore, the TMPD may be the VDOT division with the bigger need and ability to manage the initial development of the pilot program.

Additional Considerations

Program management and staffing could be by VDOT or contract forces. Over time, VDOT's automotive count program has operated using both centralized and district-based VDOT staffing models and as of 2017 was fully operated under contract (although district offices retained some portable automobile counting equipment for special studies). VDOT's business model for the count program as of 2017 was to establish standards with which vendors would comply, freeing VDOT from owning and maintaining a large fleet of counting equipment. Within either VDOT's TED or TMPD, an option would be to use contractors to manage the program. These contractors would oversee the time-consuming aspects of counting, such as equipment setup, validation, and development of site-specific correction factors, freeing VDOT staff to focus on data integration, analysis, and use.

Safety was another reason for contracting out the existing count program; there was a desire to minimize the time VDOT personnel spent setting up equipment in busy roadways. Safety of personnel installing and removing count equipment is less of a concern on trails and other off-street facilities than on highways, but under current VDOT policies, installation of nonmotorized count equipment on busy roads would require substantial traffic control measures similar to those of work zone operations. Contractors are also required to undergo appropriate training.

When the TED's existing contract for automotive SDCs is revisited in 2019, provisions could be incorporated regarding bicycle and pedestrian SDCs. For example, one or more sets of nonmotorized count equipment could collect 7-day counts at rotating sites. One issue that would need to be addressed is that the TED's existing contract cannot be used to assist localities; if such a provision remained, nonmotorized counts would presumably need to be of interest to (and requested by) VDOT rather than localities.

CONCLUSIONS

- *The state of the practice in nonmotorized travel monitoring has evolved and expanded in recent years.* Comprehensive guidance reflecting the differences between counting motor vehicles and counting nonmotorized users has been developed at the national level and is available in the *Traffic Monitoring Guide* (FHWA, 2016) and NCHRP Report 797, *Guidebook on Pedestrian and Bicycle Volume Data Collection* (Ryus et al., 2014a). Many other recent studies address the specifics.

- *Many commercially available technologies exist for conducting nonmotorized counts, and many studies have evaluated them.* There is not an immediate need to "reinvent the wheel" by developing new technologies, although evaluating any (including big data solutions) that address documented limitations of existing options could be worthwhile.

- *The practice of nonmotorized travel monitoring, as with motorized travel monitoring, has several aspects beyond purchase and installation of automatic count equipment.* Maintenance costs; data formatting, quality, and storage; and analysis and/or modeling are key components of a program enabling data to be useful.

- *Several other states are developing nonmotorized count programs and have begun putting their data to use.* In Colorado, top data applications at the state level were using exposure data for safety and establishing a metric using bicycle miles traveled, whereas local agencies planned to use the data to justify physical improvements such as bicycle facilities and pedestrian crossing treatments and to conduct before-after comparisons evaluating whether improvements were associated with an increased level of use. Minnesota has used nonmotorized count data for project prioritization and traffic engineering decisions, and North Carolina was moving toward measuring return on investment and changes in crash rates. Applications of nonmotorized count data from the literature included using counts and models to develop facility-specific safety exposure analyses; estimating mode share changes and associated benefits of infrastructure changes; predicting mode shifts based on climate change; developing land use models for planning, prioritization, and system-level safety analysis; evaluating the necessity of a pedestrian crossing treatment; enhancing travel models; conducting public health assessments; and calculating emissions.

- *Many Virginia localities are interested in some level of pedestrian and bicycle volume data collection, although relatively few already engage in the practice.* This was the case for localities in all VDOT districts.

- *There is interest in partnering with VDOT to collect pedestrian and bicycle volume data.* The level of interest varied by locality and by the type of partnership, but both partnership models introduced in the survey had supporters from parts of Virginia.

RECOMMENDATIONS

1. *VDOT's TMPD, with assistance from VTRC, should establish a pilot nonmotorized count program in one or more VDOT districts.* Recommended program elements include purchasing and installing count equipment, identifying opportunities for training and outreach, and working with VDOT's TED to identify an acceptable data storage mechanism. Survey results indicated that localities in VDOT's Salem and Northern Virginia districts had the most interest in partnering with VDOT, so one or both would be logical targets for a pilot effort; specifically, the Salem District could pilot the NCDOT model (state-installed permanent counting equipment maintained by local governments) and the Northern Virginia District could pilot the MnDOT model (state-owned short-duration counting equipment loaned to localities). The pilot program should retain the flexibility to be responsive to requests from other districts. An equipment test bed is beyond the scope of this program, but evaluation of new technologies could be considered on a case-by-case basis.

2. *VTRC should perform an evaluation of the pilot counting program and document lessons learned.* This evaluation would document items such as technology effectiveness,

interagency coordination, adjustment factors, quality control, data uses, program funding, and other lessons learned in consideration of possible expansion of the pilot program to other VDOT districts.

IMPLEMENTATION AND BENEFITS

Implementation

With regard to Recommendation 1, the VDOT TMPD's Multimodal Programs Section Manager will oversee implementation of the following elements of a flexible, incremental pilot effort of approximately 1 year beginning in summer 2018:

- Purchase portable counting equipment to expand VDOT's capacity to address internal requests from VDOT district offices (by fall 2018). Once the TMPD and district offices are familiar with the equipment, the TMPD, upon request, will provide counting equipment to district offices to assist localities in counting efforts.

- With assistance from VTRC, identify opportunities to purchase and install a small number of permanent counters in the Salem District as appropriate (identify opportunities by winter 2018-2019; procurement and installation timelines for permanent counters are unknown).

- With assistance from VTRC, purchase portable counting equipment to loan to localities in the Northern Virginia District as appropriate (by spring 2019).

- With assistance from VTRC, identify opportunities for training and outreach to VDOT districts, localities, and other interested organizations, especially within target districts (beginning fall 2018 and ongoing as needed). Training could range from technology-specific instruction provided by an equipment vendor to online training sessions or peer exchanges focused on data formats, best practices, maintenance, count equipment, site selection methodologies, factoring, and data management. National efforts such as an ongoing webinar series on bicycle and pedestrian counting could be leveraged, as could the Transportation Training Academy at the University of Virginia, which could sponsor courses led by consultants from other states with more experience in this area. Other outreach could include working with target districts and localities to identify appropriate short- and long-term count sites. VDOT's TED could provide technical assistance with equipment performance evaluations and troubleshooting, as it has done in the past.

- Work with VDOT's TED to identify an acceptable data storage mechanism for nonmotorized counts and methods to accept data from local governments and MPOs (by winter 2018-2019). One likely candidate is the Counts module related to iPeMS. Data quality would need to be considered in selecting a storage mechanism and developing a data acceptance process. Related implementation activities could include establishing data formats, coordinating with outreach efforts to localities, ensuring the storage mechanism is prepared to receive data, testing the interface, and investigating how the storage mechanism could facilitate future data submittals to TMAS.

With regard to Recommendation 2, VTRC's Environment, Planning, and Economics Team will initiate an implementation study or a Phase 2 research study that would include the elements noted in the recommendation and could also include system acceptance/verification testing of technologies that require further evaluation. The evaluation would result in a framework of data elements and data collection protocols to carry forward if counting efforts are replicated in other districts. The exact timing would be dependent on the implementation of Recommendation 1, but VTRC initiated an implementation study in summer 2018 with an evaluation to be completed by October 2020.

Key stakeholders including the VDOT districts and VDOT's TED should be engaged during the implementation of both recommendations.

Benefits

This report documented many examples of how data collection programs have been used. Additional examples include the following:

- *San Jose, California,* where nonmotorized data collection has helped in pursuing grant funding, advocating for sustained development for pedestrian and bicycle infrastructure, and budgeting for operations and maintenance (City of San Jose, 2015)

- *New York City,* where the city's DOT used a range of nonmotorized performance measures to conduct a detailed before-after evaluation of specific projects to determine if overall citywide goals were being met (e.g., designing for safety, designing for all street users, and designing great public spaces) (Semler et al., 2016)

- *The District of Columbia DOT,* which conducted a detailed bicycle facility evaluation to gain a better understanding of potential design flaws, the types of users attracted to protected bicycle facilities, operational and safety trade-offs with autos, and adherence to traffic laws. Such before-after evaluations can be valuable tools for improving future designs and can be seen as "success" stories by the public, stakeholders, and political appointees, assuming appropriate performance measures are used to inform trade-offs and impacts to users (Semler et al., 2016).

Although some of the benefits of nonmotorized volume data collection may accrue directly to localities, likely uses of such data for VDOT include safety analysis (determining exposure), engineering studies, allocation of maintenance funding such as for paved shoulders for bicycle use, management of existing facilities, and prioritization of improvements (including as part of Smart Scale). Some small cost savings could also be possible if the count program eliminated the need for some project-specific bicycle and pedestrian counts. Establishing a source of reliable nonmotorized volume data would help VDOT efficiently use its resources in these applications; thus, efforts as described in Recommendation 1 would further this cause in the pilot districts.

The primary benefits of implementing Recommendation 1 are providing count data that could be of use to localities and VDOT as described in this report and incrementally expanding VDOT's capabilities in this area to inform future development of state-administered counting efforts; getting Virginia localities and organizations "on the same page" through outreach and training in the area of bicycle and pedestrian counts and maximizing the value of their efforts (by using compatible data formats and methodologies); and simplifying data analysis and use for VDOT's TED, VDOT's TMPD, and others by collecting Virginia's nonmotorized count data in a single repository. Another benefit would be facilitating future reporting of such data to the federal data repository; although VDOT is required to report motorized traffic levels to FHWA, and these volumes affect funding levels, there is no similar requirement for nonmotorized modes at present.

The benefits of implementing Recommendation 2 are documenting lessons learned and providing guidance regarding potential future program expansion or termination. Based on the results of the evaluation, future pilots may be administered in other districts and localities, thus supporting an incremental approach to developing a statewide, state-administered nonmotorized count program.

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APPENDIX A

SEMI-STRUCTURED INTERVIEW QUESTIONS

The following interview questions were used to guide discussion with interview participants representing nonmotorized count programs from other states.

1. High-level policy and prioritization
    a. What are your state's strategic goals regarding providing for nonmotorized transportation?
    b. Does your agency's business plan (or strategic plan, etc.) endorse nonmotorized travel with respect to legislation, planning, and infrastructure?
    c. Is there a mechanism to prioritize funding for nonmotorized investments?
    d. Why was the count program initiated?

2. Overview of your count program
    a. How is the program structured? (state-driven vs. locality-driven vs. something else)
    b. How is ownership of count program handled?
    c. How are localities involved? (Coordination? Data standardization? Training local agency employees in counter installation and/or data quality analysis/quality control?)
    d. How is the count program funded?
        i. Is there support both from localities (skin in the game) and for localities (technical assistance, funding)?
        ii. Are there any unfunded mandates? (Does the state require localities to provide counts, or do localities require developers to provide them?)

3. Site selection
    a. Method (judgment vs. quantitative; Do you utilize short-term counts to make decisions on permanent counting stations?)
    b. Who decides which sites to select?
    c. Are counts limited to urban locations? (How do you document bike/ped travel in rural areas, or is doing so not needed?)
    d. How many permanent counting stations do you have?

4. Counting methods and equipment
    a. All users or separated bike/ped counts
    b. Short-term count methods (manual, video, tubes, infrared)
    c. What types of equipment are used for long-term automated counts (video, tubes, loops, infrared)?
    d. How did you select the equipment (based on performance or vendor or something else)?
    e. How is procurement of counting equipment handled? (Does the state or MPO supply/loan equipment to localities?)
    f. Are factoring methods applied for short-term counts?

    g. Do you have experience with or plans to incorporate emerging data sources such as StreetLight, Strava Metro, Placemeter, Bluetooth and wifi detection, Array of Things, etc.?

5. Data warehousing and usage
    a. How is data stored? (state DOT, local agency, or in a national repository such as TMAS; with motorized counts or separate; quality-checked or raw; any future plans to do things differently)
    b. How is the data used? (public, private sector perspectives, operational and planning examples?)

6. What is the best published source describing your state's count program (if there is one)?

7. What specific challenges have you encountered?

8. What advice would you give VDOT in starting the process of establishing a count program?

9. What did we miss? (Who else should we talk to within your state and elsewhere?)

APPENDIX B

SURVEY QUESTIONS FOR VIRGINIA LOCALITIES

Because of the skip logic feature used in the online survey, some questions appear as duplicates in this list but would not have appeared so to an individual respondent.

1. Has your locality/organization conducted counts of pedestrian and/or bicycle volumes on street segments, intersections, or paths at any time from 2010 to present? (Yes/No)

2. Does your locality/organization count pedestrian and/or bicycle volumes continuously or periodically (for example, monthly or yearly) at the same location(s)? (Yes/No)

3. Other than your continuous/periodic count program, has your locality/organization included pedestrian and/or bicycle counts in any of the following project-specific studies? *Select all that apply.* [Intersection turning movement count study / Traffic impact study for land development / Neither / Other project-specific studies (please specify)]

4. What method(s) are being used to conduct counts? [Manual counts only (e.g., humans with clipboards or reviewing video) / Automated counts only (e.g., tube counters, infrared, radar, automated video counts) / Both manual and automated counts]

5. Who performs the manual counts? *Select all that apply.* [Staff / Paid consultants / Volunteers / Other (please specify)]

6. How often are the manual counts conducted? [Yearly / Every two years / Other interval (please specify)]

7. Since 2010, at how many locations have you performed manual counting? (One location / 2-10 locations / 11-20 locations / More than 20 locations)

8. What is the typical manual count duration at leach location (e.g., two hours during morning and afternoon peaks for seven days)?

9. How frequently are automated counts conducted? *Select all that apply.* [Continuously (24/7, 365) / Periodically (i.e. regularly occurring intervals) / As needed (no regular schedule)]

10. How many permanent automated count locations do you have?

11. If you perform short-duration counts, what is the typical time-frame of those counts? (e.g., three days, seven days)?

12. What type of automated count equipment has been used? *Select all that apply.* [Pneumatic tubes / Inductive loops / Passive infrared (sensor placed on one side of the facility) / Active infrared (transmitter on one side and receiver on other side of facility) / Automated video / Thermal imaging / Pressure pads / Radar / Other (please specify)]

13. Please provide brand names and models of counting devices that have been used, if known.

14. Who performs the manual counts? *Select all that apply.* [Staff / Paid consultants / Volunteers / Other (please specify)]

15. How often are the manual counts conducted? [Yearly / Every two years / Other interval (please specify)]

16. Since 2010, at how many locations have you performed manual counting? (One location / 2-10 locations / 11-20 locations / More than 20 locations)

17. What is the typical manual count duration at each location (e.g., two hours during morning and afternoon peaks for seven days?)

18. How frequently are automated counts conducted? *Select all that apply.* [Continuously (24/7, 365) / Periodically (i.e., regularly occurring) / As needed (no regular schedule)]

19. How many permanent automated count locations do you have?

20. If you perform short-duration automated counts, what is the typical time-frame of those counts (e.g., three days, seven days)?

21. What type of automated count equipment has been used? *Select all that apply.* [Pneumatic tubes / Inductive loops / Passive infrared (sensor placed on one side of facility) / Active infrared (transmitter on one side and receiver on other side of facility) / Automated video / Thermal imaging / Pressure pads / Radar / Other (please specify)]

22. Please provide brand names and models of counting devices that have been used, if known.

23. If your locality/organization has departments or divisions (e.g., Parks and Recreation or Public Works), which one (or ones) oversee(s) the count program?

24. What source(s) of funding are used to sustain your locality's count program? *Select all that apply.* (Federal / State / Local / Other / Don't Know)

25. How are your count data stored? *Select all that apply.* [Paper files / Computerized, non-tabular (e.g., scanned PDFs) / Computerized, tabular (e.g., Excel) / Computerized, spatial (e.g., GIS, shapefile, interactive map) / Vendor or 3rd party system (e.g., Eco-Visio) / Other (please specify)]

26. Are your data made available to others outside your organization? *Select all that apply.* [Yes, to the general public / Yes, to governmental planning partners (e.g., MPO, VDOT) / Yes, to stakeholders and/or advocacy groups / No]

27. Please provide specific examples of how your count data are used.

28. Do you use any of the following data services provided by an equipment vendor or another third party? *Select all that apply.* (Automatic data transmission from counter / Tools to help identify irregular data / Tools to reconstruct missing data / None of the above)

29. Do you validate automated counters (e.g., verify the accuracy of the counts)? (Yes/No)

30. Is data quality checked? (Yes/No)

31. In your opinion, are there distinct locations on roadways or trails that are not currently equipped with counters where continuous or periodic counts would be beneficial? (Yes/No)

32. In North Carolina, the state DOT installs permanent bicycle/pedestrian counting equipment at the DOT's expense, and local governments agree to maintain the equipment at their expense. Examples of maintenance are changing batteries and periodically inspecting equipment. For locations not already equipped with permanent counters, how would you rate your locality's/organization's interest in such a partnership? [1 to 5 scale (1: Not interested, 3: moderately interested, 5: very interested)]

33. In Minnesota, the state DOT loans portable bicycle/pedestrian counting equipment to local agencies for short-duration bicycle/pedestrian counts. For locations not already equipped with portable counters, how would you rate your locality's/organization's interest in such a partnership? [1 to 5 scale (1: Not interested, 3: moderately interested, 5: very interested)]

34. Regarding the counts that your locality/organization have performed, in what years were counts conducted? *Select all that apply.* (2010 / 2011 / 2012 / 2013 / 2014 / 2015 / 2016 / Not known)

35. What counting methods were used? [Manual only (e.g., persons with clipboards or persons reviewing video) / Automated only (e.g., tube counters, infrared, radar, video) / Both manual and automated]

36. What were the purposes of counting?

37. Has there been any discussion within your locality/organization about establishing a bicycle/pedestrian count program where counts are conducted continuously or periodically at distinct locations? (Yes, formal discussions with elected/appointed officials / Yes, informal discussions at staff level / No / Don't know)

38. In your opinion, are there distinct locations on roadways or trails where continuous or periodic counts would be beneficial? (Yes/No)

39. In North Carolina, the state DOT installs permanent bicycle/pedestrian counting equipment at the DOT's expense, and local governments agree to maintain the equipment at their expense. Examples of maintenance are changing batteries and periodically inspecting

equipment. For locations not already equipped with permanent counters, how would you rate your locality's/organization's interest in such a partnership? [1 to 5 scale (1: Not interested, 3: moderately interested, 5: very interested)]

40. In Minnesota, the state DOT loans portable bicycle/pedestrian counting equipment to local agencies for short-duration bicycle/pedestrian counts. For locations not already equipped with portable counters, how would you rate your locality's/organization's interest in such a partnership? [1 to 5 scale (1: Not interested, 3: moderately interested, 5: very interested)]

41. Has there been any discussion within your locality/organization about conducting counts of pedestrian and/or bicycle volumes on streets or paths? (Yes, formal discussions with elected/appointed officials / Yes, informal discussions at staff level / No / Don't know)

42. In your opinion, are there locations (roadways or trails) in your jurisdiction where having counts would be beneficial? (Yes/No)

43. In North Carolina, the state DOT installs permanent bicycle/pedestrian counting equipment at the DOT's expense, and local governments agree to maintain the equipment at their expense. Examples of maintenance are changing batteries and periodically inspecting equipment. For locations not already equipped with permanent counters, how would you rate your locality's/organization's interest in such a partnership? [1 to 5 scale (1: Not interested, 3: moderately interested, 5: very interested)]

44. In Minnesota, the state DOT loans portable bicycle/pedestrian counting equipment to local agencies for short-duration bicycle/pedestrian counts. For locations not already equipped with portable counters, how would you rate your locality's/organization's interest in such a partnership? [1 to 5 scale (1: Not interested, 3: moderately interested, 5: very interested)]

45. We're almost done! Sometimes non-governmental organizations collect bicycle and pedestrian volume counts (e.g., counts conducted on a volunteer basis by a cycling club or nonprofit). If you are aware of any non-governmental organizations in your area that conduct counts, please list them and provide contact information if available.

46. Would you like to receive a copy of the final report (expected completion early 2018)?

47. So we can send you a copy of the final report, please provide the following information:
Your name: ___ Locality/Organization name: ___ Phone: ___ Email: ___

48. Please provide the name of the locality or organization you represent.

49. Thank you for your time! If you have other comments, please provide them below. You may also contact us at Peter.Ohlms@VDOT.Virginia.gov and Lance.Dougald@VDOT.Virginia.gov.

APPENDIX C

LITERATURE SUMMARY TABLES

Tables C1 through C7 present relevant literature in the general topic categories listed here; studies that span multiple categories appear in multiple tables. Within each table, studies are organized by study focus. (Researchers also reviewed additional studies that are not listed in these tables because they were not directly related to the scope of this study or did not provide novel information.) An additional table covering older studies that may be of historical interest is available from the authors.

1. Table C1: Studies containing guidance on how to establish and maintain a nonmotorized data collection program.

2. Table C2: Summaries of efforts in other states or in specific regions.

3. Table C3: Evaluations of the accuracy and practicality of specific technologies for site-based nonmotorized data collection. This included computer vision/video evaluations but excluded studies that simply summarized detailed algorithms for video image processing optimization.

4. Table C4: Studies of route-tracking smartphone applications and crowdsourcing data.

5. Table C5: Studies outlining methods for count adjustments (e.g., for weather conditions and seasonality), factoring, or quality assurance.

6. Table C6: Descriptions of data warehouses and archives for nonmotorized count data.

7. Table C7: Studies primarily describing how counts are used. Although these studies are less useful for developing a count program, they may give examples of how other places have used nonmotorized counts.

Table C1. Studies Containing Guidance on How to Establish and Maintain a Nonmotorized Data Collection Program

Citation: Title	Study Focus	Study Region; Data Year; Methods	Selected Findings	Limitations and Recommendations
FHWA (2016): *Traffic Monitoring Guide* (TMG)	Comprehensive: Chapter 4 covers nonmotorized transportation methods including policies, standards, procedures, equipment, and guidance for state highway agencies regarding traffic monitoring	U.S.; 2016; federal guidance	Nonmotorized data do not have the same scale as motorized data and have higher use on roads of lower functional classification and shared-use paths. Short-duration counts (SDCs) are becoming more common with nonmotorized traffic. Screenline counts can identify trends; intersection counts can support safety studies.	Error rates for nonmotorized traffic counts are still much higher than for motorized; people walking or biking can make unpredictable movements; multiple people may be counted as one.
Ryus et al. (2014b): *Guidebook on Pedestrian and Bicycle Volume Data Collection*	Comprehensive: methods and technologies, program guidance, examples of data use, correction factors	U.S.; 2014; research-based guidance	Bicycle/pedestrian counts can track changes over time (before-after counts) and support prioritization of projects. Contains details for how to plan and implement a collection program.	Bicycle/pedestrian traffic is more variable than motorized traffic, involves shorter trips, and can be harder to detect; in general, there is less experience with bicycle/pedestrian counts than with motorized counts.
Nordback (2017): *Guide to Bicycle & Pedestrian Count Programs*	Step-by-step guide for creating or improving a nonmotorized count program	Occasionally has a Midwestern bias; mostly based on 2013 TMG	A combination of some permanent count locations with SDCs is the best way to perform long-term nonmotorized counts. Validation should be performed at initial setup and after equipment maintenance along with ongoing monitoring for bad data.	Fairly comprehensive, but portions have not been updated since February 2014. Contains no specific recommendations for one method over another but rather summarizes how to perform counts.
Nordback et al. (2017): *Estimating Walking and Bicycling at the State Level*	Statewide: three approaches for estimating nonmotorized travel: travel survey data, sample-based count data, and aggregate demand model combined with count data	Washington State and King County; 2014-2017; performed literature review and investigated sample-based, aggregate demand, and travel survey data modeling	The travel survey method is useful for a statewide measure, but it does not provide the detail needed for facility-level estimates. For bicyclists, the sample-based method is appropriate if volumes are desired at the facility level. For pedestrians, the aggregate model might be more appropriate, because of the more dispersed nature of pedestrian travel.	Because of data limitations, none of the methods could be properly implemented on the statewide level. Recommendations include improving statewide travel survey data and pedestrian and cyclist traffic count data, which feed these methods; including a continuous counting program in addition to the SDC program; and using stratified random sampling to select SDC sites after the continuous count program is in place.
Figliozzi et al. (2014): *Design and Implementation of Pedestrian and Bicycle-Specific Data Collection Methods in Oregon*	Statewide: Oregon system methods, technology review, and pilot study of counts using Type 2070 signal controllers	Oregon; 2012; evaluated Type 2070 controllers at chosen intersections	Pneumatic tubes did not accurately count bikes; other brands were to be tested in the future.	Recommendations cover factoring methods and the implementation of a statewide nonmotorized data collection system.
North Central Texas Council of Governments et al. (2013): *North Central Texas Council of*	From the regional (MPO) perspective: phased approaches, funding, equipment management, and	U.S. MPOs (most participants were west/midwest; 2013; peer exchange	Goals and recommendations of the peer exchange (outlined under "Limitations and Recommendations")	Recognize that bicycles and pedestrians are different and monitoring will be different from motorized monitoring. Prioritize community outreach and communication of

Governments Peer Exchange on Bicycle and Pedestrian Count Programs	challenges	summary		results. Communicate limitations of technologies being used. Identify ahead of time where the data will be stored. Manual surveys still provide added benefits (e.g., demographics).
Kittelson & Associates, Inc. et al. (2013): *Conducting Bicycle and Pedestrian Counts—A Manual for Jurisdictions in Los Angeles County and Beyond*	Regional perspective: a manual to standardize the format of and approach to counts, including comparable and reliable counts across jurisdictions	Los Angeles; 2013; regional guidance	Counts of 7-14 days are most cost-effective without sacrificing too much accuracy. Count locations should be chosen to collect the most accurate representation of the area's nonmotorized transportation.	When there is a specific location being counted, consider counting adjacent routes to identify mode and route choice behavior. Each type of counter should be considered before choosing one for a site.
Jackson et al. (2015): Nonmotorized Site Selection Methods for Continuous and Short-Duration Volume Counting	Nonmotorized count site selection process in the context of establishing a nonmotorized traffic volume counting program	North Carolina; 2014-2015; pilot project by NCDOT	Site selection components include gathering potential sites, conducting site visits, gathering additional data needed to inform the decision-making process, and ultimately selecting sites and developing an equipment inventory.	Use a standardized method for site selection that complies with TMG recommendations. Provide regional documentation that makes clear when and where sites will be installed. Involve multiple agencies using formal agreements.
Lindsey et al. (2017b): *Strategies for Monitoring Multiuse Trail Networks: Implications for Practice*	Various approaches to monitoring multiuse trail networks	Indiana, Minnesota, Ohio, and D.C.; collected information from localities that monitor multiuse paths	Jurisdictions are following the FHWA principles of monitoring. Designs are evolving to meet new challenges, such as large trail networks. Results from specific organizations are included.	FHWA guidelines can be adapted to many circumstances and can provide information for decision-making.
Mobarak and Albright (2015): *Need for National Standards in Transportation System Information, Acquisition, Processing, and Sharing*	Recommends new transportation system standards (including bicycle/pedestrian count standards) based on the involvement of and cooperation among governmental agencies, the private sector, and standard-setting organizations.	Bernalillo County, New Mexico; 2007-2013; examined 3 demonstration projects (adaptive traffic control, speed monitoring network, and regional bike monitoring)	There is a need for standards for Bluetooth and crowdsourced data and for counts using video, infrared, or inductive loops. Data standards would help ensure comparable, consistent counts.	Recommends new transportation system standards based on the involvement of government agencies, the private sector, standard-setting organizations, etc.

Table C2. Summaries of Efforts in Other States or in Specific Regions

Citation: Title	Study Focus	Study Region; Data Year; Methods	Selected Findings	Limitations and Recommendations
Griffin et al. (2014): *Monitoring Bicyclist and Pedestrian Travel and Behavior: Current Research and Practice*	Statewide and regional: identifies advancements in nonmotorized data monitoring and introduces ongoing projects expected to contribute to the state of the practice.	U.S.; 2014; review of current research and practice	More localities were starting to collect multimodal transportation data. New policies were driving the need for data collection.	Multiple technologies could be integrated/standardized to make data more plentiful and accurate (e.g., accelerometers or trackers for indoor movement); intermodal transportation will require a new kind of analysis.
Lindsey et al. (2014): *Institutionalizing Bicycle and Pedestrian Monitoring Programs in Three States*	Statewide: Colorado, Minnesota, and Oregon programs	Colorado, Minnesota, Oregon; 2014; information provided by involved states	Colorado has counts from DOT and localities using infrared and pneumatic tubes. Minnesota has automated and manual counts from DOT and localities (localities primarily use manual counts); the Oregon DOT does most counts in Oregon, primarily manual.	No states have the capacity for routine recording of AADT, bicycle miles traveled (BMT), or pedestrian miles traveled (PMT). General protocols are needed for guiding counts in these states and elsewhere.
Nordback et al. (2013a): *Development of Estimation Methodology for Bicycle and Pedestrian Volumes Based on Existing Counts*	Statewide: estimating bike/ped volumes using a limited sample of existing counts; factoring.	Colorado; 2012; tested different methods to find the most accurate for determining average annual daily bicyclists (AADB) and average annual daily bicyclists and pedestrians (AADBP).	Factoring methods are most efficient without sacrificing accuracy. Factors can be applied to existing continuous count data to represent AADB and AADBP accurately.	Having at least 7 continuous counters per factor group is desirable for precise results. Bicycles and pedestrians should be counted separately because they exhibit different traffic patterns in the same locations. At least 7 days of counts should be performed, and August and September are the best months for limiting error.
Lindsey et al. (2013): *The Minnesota Bicycle and Pedestrian Counting Initiative: Methodologies for Nonmotorized Traffic Monitoring*	Statewide: Minnesota program's methodologies for manual and automated counts; inventory of local count programs	Minnesota; 2013; analyzed existing count locations and counts to determine best counting method for nonmotorized traffic	Few automated continuous counters were in use at the time, but there was growing support for nonmotorized traffic counts and analyzing them as with motorized counts.	Statewide coordination of recurring manual counts should be continued. Results-reporting methods should be improved (e.g., to a web-based system). Automated technologies should be explored and their data incorporated into existing databases. The state and localities should collaborate to establish a network of automated continuous count sites supported by short-duration count (SDC) sites.
Minge et al. (2017): *Bicycle and Pedestrian Data Collection Manual*	Statewide: comprehensive Minnesota program manual including case studies, details of installation, calibration, QA/QC	Minnesota; 2014-2016; case studies	MnDOT and localities are implementing monitoring programs and using the results to inform planning, engineering, and policy decisions.	Long-term plans include integrating state and local counts into existing (motorized) count databases.

Lindsey et al. (2017a): *The Minnesota Bicycle and Pedestrian Counting Initiative: Institutionalizing Bicycle and Pedestrian Monitoring*	Statewide: Minnesota's structure is designed to support existing projects and includes a program to loan equipment to localities.	Minnesota; 2014-2016; review of program including 25 permanent and 33 impermanent locations	Basing bicycle and pedestrian counting methods on the FHWA's *Traffic Monitoring Guide* allows such counts to be incorporated along with motorized vehicle counts. For large projects, it is important to partner with other organizations with common interests rather than relying solely on government funding.	Most Minnesota communities still lack nonmotorized monitoring capabilities; it was unclear if localities would use the loan program. Despite the uncertainty, the authors argued that the interest and information provided by the counts warranted a continuation of the study.
Lindsey et al. (2015): *The Minnesota Bicycle and Pedestrian Counting Initiative: Implementation Study*	Statewide: Minnesota program's efforts to install and validate permanent automated sensors, use portable sensors, and extrapolate counts	Minnesota; 2015; review of program in cities, suburbs, and small towns	Sensors produced accurate measures of nonmotorized traffic. Undercounting was common because of occlusion.	Data management is challenging, and institutionalizing nonmotorized travel monitoring activities within the traditional program will take years.
Figliozzi et al. (2014): *Design and Implementation of Pedestrian and Bicycle-Specific Data Collection Methods in Oregon*	Statewide: Oregon system methods, technology review, and pilot study of counts using Type 2070 signal controllers	Oregon; 2012; evaluated Type 2070 controllers at chosen intersections	Pneumatic tubes did not accurately count bikes; other brands were to be tested in the future.	Recommendations cover factoring methods and the implementation of a statewide nonmotorized data collection system.
Nordback and Sellinger (2014): *Methods for Estimating Bicycling and Walking in Washington State*	Statewide: sample-based method to compute statewide BMT and PMT.	Washington; years vary (2008-2012 for state count program; earlier for Seattle); sample-based computation method	Adjustment factors must be appropriate for the location and cannot be used across the state.	Recommendations include expanding the statewide nonmotorized documentation program geographically and installing automated counters to complement SDCs.
Nordback et al. (2017): *Estimating Walking and Bicycling at the State Level*	Statewide: 3 approaches for estimating nonmotorized travel: travel survey data, sample-based count data, and aggregate demand model combined with count data	Washington State and King County; 2014-2017; performed literature review and investigated sample-based, aggregate demand, and travel survey data modeling	The travel survey method is useful for a statewide measure, but it does not provide the detail needed for facility-level estimates. For bicyclists, the sample-based method is appropriate if volumes are desired at the facility level. For pedestrians, the aggregate model might be more appropriate because of the more dispersed nature of pedestrian travel.	Because of data limitations, none of the methods could be properly implemented on the statewide level. Recommendations include improving statewide travel survey data and pedestrian and cyclist traffic count data, which feed these methods; including a continuous counting program in addition to the SDC program; and using stratified random sampling to select SDC sites after the continuous count program is in place.
Baas et al. (2016): *FHWA Bicycle-Pedestrian Count Technology Pilot Project—Summary Report*	Multi-regional: summarizes FHWA's 1-year Bicycle-Pedestrian Count Technology Pilot Project at 10 MPOs	10 MPOs in California, New York, Indiana, Ohio, Tennessee, Florida, Rhode Island, Puerto Rico, Virginia, Wisconsin; counts from 1 week to 6 months starting in 2015; reviewed efforts at 170	There is no one-size-fits-all technology; each location should be addressed separately. Pilot programs are an effective way to teach MPOs and localities about count technology.	Data accuracy varies with each type of counter, requiring cross-checking with manual or video data. Pilot programs can promote the use of counters and can encourage the development of count programs.

		count locations		
Schneider et al. (2005): *Case Study Analysis of Pedestrian and Bicycle Data Collection in U.S. Communities*	Multi-regional: 29 U.S. case studies, some including count sites	U.S.; earliest count programs reportedly began in the 1980s including D.C. and Baltimore manual pedestrian counts; data were acquired through a 2004 survey of states	Integrating manual counts with existing motor vehicle counts can reduce costs; manual counts are labor-intensive; manual counts are accurate and can include other observations such as behaviors. Automated counts can reduce labor costs; settings and siting must be adjusted to maximize accuracy; placement should minimize vandalism and interference with pedestrian/bicycle movement; most technologies work regardless of weather; most devices will not count all types of nonmotorized transportation users and cannot observe behaviors.	Case studies should include locations of bike racks, pedestrian signals, lighting, etc., all of which affect bicycle/pedestrian travel. A national data collection format should be explored to enable standardized analyses between communities and regions.
Ryan (2013): *Establishing an Automated Regional Nonmotorized Transportation Data Collection System to Support Active Transportation Performance Monitoring*	Regional: siting methodologies, validation of automated counts, and using counts for nonmotorized performance monitoring	San Diego; 2012; documentation of how the network of 170 automated counters and 35 additional count sites was created	Eco-Counters were determined to be best suited for San Diego's needs because of their abilities to upload data to a server automatically and to distinguish between cars and bikes.	Only 17 counters had been installed when this paper was written. It described which sites were chosen in the San Diego effort but did not have any findings or recommendations.
Ryan et al. (2014b): *Designing and Implementing a Regional Active Transportation Monitoring Program Through a County-MPO-University Collaboration*	Regional: equipment selection and siting methodologies	San Diego; pre-2012; case study of multidisciplinary planning and implementation effort covering 54 automated Eco-Counter units at 35 sites	76 sites were identified as appropriate for counting; 35 were equipped with counters, which required hiring a construction contractor and obtaining permits from 14 localities. Training for regional agency staff was provided.	It was suggested that a similar approach could be applied in other regions. In places without funding to establish a comprehensive network all at once, it recommended using the siting methodology to develop a planned network of sites that would be equipped as funds become available.
Ryan et al. (2014a): *Estimating Daily Bicycle Volumes Using Manual Short Duration and Automated Continuous Counts*	Regional: San Diego's approach to siting automated counters; average daily cycling across roadway networks based on A.M./P.M. peak	San Diego; 2012; extrapolated data from count equipment installed across San Diego	The percentage of total daily bike travel during P.M. peak periods was fairly consistent across multiple sites, so that rate can be used with P.M. peak period manual counts to extrapolate daily volumes.	Public health agencies can play a major role in transportation planning and policy. Future work should involve securing funds for installation, validation counts, and combining automated counts with other data sources.
Jones et al. (2010): *Seamless Travel: Measuring Bicycle and Pedestrian Activity in San Diego County and Its*	Regional: describes what was claimed to be the “largest and longest combined count and survey effort in the U.S.	San Diego; 2006-2010; case study	Nonmotorized travel was similar to that of motorized vehicles and not just for recreational use. Physically separated bike paths and multi-use paths were key facilities in terms of volumes when	California should implement a nonmotorized count or survey program. Counts should always be measured or extrapolated to 1 year for ease of comparison.

Relationship to Land Use, Transportation, Safety, and Facility Type	focusing only on bicyclists and pedestrians.”		compared to on-street facilities.	
Wilbur Smith Associates and Traffic Research & Analysis, Inc. (2003): *Bicyclist and Pedestrian Data Collection and Analysis Project*	Regional: 9-county bicyclist and pedestrian data collection effort including counts and mail-back user surveys	San Francisco; 2002; counts (performed at 100 locations during A.M. and P.M. peaks) and user surveys	Urban and high-bike-density locations tend to have lowest collision rates; more bike/ped activity in the evening period (55%)	Surveys need to be clear and concise to encourage response; conversion from peak period data to daily and annual counts would improve collision analysis.
Nordback et al. (2013b): *Estimating Annual Average Daily Bicyclists: Error and Accuracy*	Regional: timing and frequency of counts	Boulder, Colorado; 1999-2012; created factors, estimated AADB, compared short-term scenarios, and analyzed error using continuous counts	The most cost-effective length for short-term bicycle counts is 1 full week when automated counting devices specifically calibrated for bicycle counting are used. Seasons with higher bicycle volumes have less variation in bicycle counts and thus more accurate estimates.	There should be at least 5 permanent continuous count locations per factor group; fewer leads to higher error. If manual counting must be done, it should be completed over 3 peak hours on Tuesday, Wednesday, or Thursday.
Hudson et al. (2010): *Forecasting Bicycle and Pedestrian Usage and Research Data Collection Equipment*	Regional: appropriate data collection methods, forecasts, MPO planning	Austin, Texas; 2009-2010; equipment testing using researchers as pedestrians at varying speeds and spacings	All 4 counters tested (Jamar, TRAFx, Diamond Trail, Eco-Counter PYRO) had trouble counting users that were close together; both Jamar and TRAFx were challenged by fast cyclists but had easy interfaces; Diamond Trail worked better for crowds but was hard to use; overall, Eco-Counter was the easiest to use with the best results.	Bottleneck areas should be identified and targeted before non-bottleneck areas. Connected networks should be chosen over isolated segments. Data used for these models may be outdated, updated every 5-10 years. The current model estimates weekday travel, and future work could address weekend/recreational travel.
Sullivan et al. (2015): *Regional Models of Bicycle and Pedestrian Travel in Chittenden County, Vermont*	Regional: application of nonmotorized travel data methods and procedures, including estimating BPMT.	Burlington, Vermont; 2007-2013; direct spatial-buffer method and k-means clustering method based on 62 shared-use path and shoulder locations	Adjustment factors were used to determine BPMT for each classification. No findings regarding which method is better.	Widespread counts would help support claims about infrastructure needs. Surveys underestimate use (respondents may not include all trips) and are typically biased toward dense residential areas.
City of Columbus and Alta Planning + Design (2015): Bicycle and Pedestrian Counts Pilot Project	Regional: determining bicycle/pedestrian travel patterns, infrastructure effectiveness, safety; informing modeling	Columbus, Ohio; 2014; deployed loops, tubes, and infrared at 31 bicycle and 18 pedestrian count locations	Contains specific tips on equipment deployment along with specific challenges (e.g., wind impacts to devices on signs, durability of tube clamps)	Sites with variability should be counted longer. Rotate equipment through locations: tubes/infrared, 2 weeks; inductive loops, 4 weeks
Jackson et al. (2017): Quality Assurance and Quality Control Processes for a Large-Scale Bicycle and Pedestrian Volume Data Program	Regional: processes used in North Carolina's Nonmotorized Volume Data Program—Phase 1	Triad-Piedmont region of North Carolina; 2014; quality assurance and quality control on data collected by continuous automated counters at 12 locations	Data quality has a lot more components than initially considered or proposed.	Weekly data inspections and validation should be used to identify maintenance issues related to batteries, sensitivity, data transmission, damage or vandalism, equipment malfunction, or the site itself. Data cleaning should be documented.

Hankey et al. (2016): *Designing a Bicycle and Pedestrian Traffic Count Program to Estimate Performance Measures on Streets and Sidewalks in Blacksburg, VA*	Regional: seasonal, daily, and hourly patterns of nonmotorized traffic; variation by location, street functional classification, and infrastructure	Blacksburg, Virginia; 2015-2016; automated and manual counts, validated/corrected, at 101 count sites (4 permanent, 97 short-duration)	Contains comprehensive data and models for Blacksburg, illustrating how a network-wide count program could be deployed in a small city.	Sites chosen should match study purposes; use a measure such as their “centrality” as base information when no data exist; SDCs should be scaled to yearly volumes; create factor groups for count sites.

Table C3. Evaluations of the Accuracy and Practicality of Specific Technologies for Site-Based Nonmotorized Data Collection

Citation: Title	Study Focus	Study Region; Data Year; Methods	Selected Findings	Limitations and Recommendations
Ryus et al. (2014b): *Methods and Technologies for Pedestrian and Bicycle Volume Data Collection*	Multiple: evaluated technologies in different count settings and weather and traffic conditions to determine accuracy and reliability.	California, Minnesota, Oregon, Virginia, D.C., Canada; 2012-2014; procure counting devices, install/test devices, reduce video data	[Partially outdated; see Ryus et al. (2016) for updated findings.] Technology (Weighted Average Percent Deviation/Correction Factor): passive infrared (18.68%/1.137), active infrared (11.9%/1.139), pneumatic tubes (14.15%/ 1.135), radio beam (27.41%/1.13), inductive loops (5.7%/1.05), piezoelectric strips (25.24%/1.059). Factors that influenced accuracy: calibration, occlusion, facility width. No influence on accuracy: age of equipment, temperature, weather events.	Product-specific factors should be used for data adjustment. The research provided should be used as guidance, not applied blindly to new sites. Consider implementation time, including necessary approvals. There should be additional testing for automated technologies not accounted for in this report, as well as improved methods for extrapolating short-duration counts and determining adjustment factors. It is critical for practitioners to calibrate and evaluate the effectiveness of the counters they install at specific sites.
Ryus et al. (2016): *Methods and Technologies for Pedestrian and Bicycle Volume Data Collection: Phase 2*	Multiple: evaluated technologies that came on the market too late for previous study; same study variables as Ryus et al. (2014b)—added radar, thermal imaging camera, and standard pneumatic tubes.	Virginia, D.C., California; 2015-2016; procure counting devices, install/test devices, reduce video data	Technology (Weighted Average Percent Deviation/Correction Factor): passive infrared (-9.5%/1.016-1.369), active infrared (-7.6%/1.082), radar (14.2%/0.851), thermal imaging (2.7%/0.974), pneumatic tubes (-17.1%/1.124-1.081), piezoelectric strips (-4.1%/1.035-1.061).	Same as Ryus et al. (2014b).
Nordback et al. (2016a): *Investigation of Bicycle and Pedestrian Continuous and Short Duration Count Technologies in Oregon*	Multiple: pneumatic tubes, inductive loops and thermal cameras for bikes; passive infrared and ped phase actuation for pedestrians	Oregon; 2015; site selection used several criteria, and performance metrics were overall error, mean percent error, and mean absolute percent error.	All bicycle counting technologies were adequate to count bicycles under controlled, favorable conditions, but in mixed traffic conditions, only pneumatic tubes attained less than 20% error and were found to be the most accurate bicycle counting technology while also being low cost. The pedestrian counting technologies attained satisfactory results; passive infrared worked well in pedestrian-only environments when volumes were low and the counter was properly located.	Bicycle counts in mixed traffic conditions with pneumatic tubes are more accurate when bicycle-specific vehicle classification schemes are used and bicycle traffic passes within 10 ft of counting device. Tubes had high errors when cyclists riding side by side were counted. Inductive loops or thermal cameras at intersection approaches in mixed traffic were not recommended. Other specific recommendations were provided for each technology and for various types of sites.
Proulx et al. (2016): *Performance Evaluation and Correction Functions for Automated Pedestrian and Bicycle Counting Technologies*	Multiple: passive and active infrared, radio beam, pneumatic tubes, inductive loops, and piezo strips; correction functions.	Virginia, California, Minnesota, Oregon, D.C., Canada; 2013; 13 sites in 7 cities; compare counts to ground-truth counts from video data	Net undercount was observed that appeared to worsen at higher volumes. Average error rates ranged from 0.55% for inductive loops to 17.38% for pneumatic tubes. Correction functions improved accuracy for nearly all technologies.	Counter accuracy can be adversely affected by improper installation. Portability, cost, ease of installation, ease of data capture, and level of aggregation should all be considered when choosing equipment.

Aultman-Hall et al. (2012): *Innovative Data Collection for Pedestrians, Bicycles, and Other Non-Motor Vehicle Modes*	Multiple commercially available bike/ped counting technologies	United States (general applications); 2012; assessment of current technologies and literature	No findings reported for specific devices; new data collection technologies and the associated challenges create the urgent need for uniform guidelines for the collection of nonmotorized travel data.	Commercial devices have trade-offs regarding accuracy and duration and may not be suitable for mixed-traffic or poor weather conditions.
Munro (2013): *Evaluation of Automatic Cyclist Counters*	Multiple commercially available bicycle counting devices: computer vision, piezo strips, radar, active infrared, and inductive loops; best sites for each type of device	Australia; 2013; calculating accuracy compared to demand	Inductive loop device and the 2 piezoelectric strip devices were suitable for off-road paths and separated bike routes. Active infrared and 1 of the piezo devices were acceptable for on-road use but were limited. Computer vision systems were evolving quickly but were not yet reliable enough for practical deployment.	Each device has its own limitations, from requiring installation on both sides of the road to being severely affected by weather. Each device would need to be evaluated for a specific site before being installed.
Ozbay et al. (2010): *Automatic Pedestrian Counter*	Multiple: passive infrared and thermal sensor deployed simultaneously and compared, and post-processing (calibration) techniques were applied to the infrared sensor data	New Jersey, 5 sites: 1 bridge, 2 trails, and 2 crosswalks; 2008-2009; collected video and deployed the 2 sensors at 4 of 5 locations (infrared only at the 5th)	Passive infrared was easier to deploy, but thermal sensor produced less error (up to 14.6% where its detection area was obstructed by waiting pedestrians) than the passive infrared sensor, which undercounted substantially (up to 27.9%) at high-volume sites. Rain, snow, and clear weather conditions did not affect the sensors.	It was known before the experiment that the manufacturer of the passive infrared counter did not recommend its use at intersection locations. Video baseline data collection was time-consuming (4 hr of data reduction effort for each hour of video). Results can be influenced by many factors that should be considered when choosing a counter. Calibration requires site-specific baseline data.
Nordback et al. (2016b): *Accuracy of Bicycle Counting With Pneumatic Tubes in Oregon*	Pneumatic tubes: minimizing error	Oregon; 2015; 3 types of pneumatic tube counters (6 total counters)	Equipment studied generally undercounted cyclists, especially those in groups; 0% to 12% undercounting error in controlled test and 10% to 73% in mixed traffic.	Counting accuracy decreased with increases in bicycle and motor vehicle traffic and longer tube lengths. Higher accuracy can be achieved by careful selection of equipment type, classification scheme, and tube configuration.
Brosnan et al. (2015): *Validation of Bicycle Counts From Pneumatic Tube Counters in Mixed Traffic Flows*	Tube counter validation for bicycle counting in mixed traffic	Minnesota; 2013 and 2014; comparison of MetroCount (lighter weight) and Timemark (heavy-duty) tubes with manually counted video	Most estimates were undercounts; percent error ranged from 57% undercount to 6% overcount. Error was lower where bike and auto traffic volumes were lower. Timemark devices had a higher error percentage than MetroCount devices.	Occlusion caused most of the undercounting. Pneumatic tubes should not be used across multiple lanes to count bicycles. Substantial validation and calibration were required for valid results. Additional studies should be conducted in specific applications to determine the overall performance of devices.
Hyde-Wright et al. (2014): *Counting Bicyclists With Pneumatic Tube Counters on Shared Roadways*	Bicycle-specific tube counters (BSCs, with proprietary thicker tubes and a special lining that amplifies the air pulse generated by bicycle wheels) vs. general	12 locations in or around Minneapolis; 2012; compared 3 GSCs and 1 BSC and developed new Boulder County (BOCO) classification scheme, and then calculated	BSCs had high accuracy (95%) for bikes crossing the tube 4 and 27 ft from the counter; its lower accuracy (57%) at 33 ft was comparable to the GPC accuracy at that distance. GPC accuracy and reliability varied depending on attachment method and classification scheme, but the accuracy of	BSCs can accurately count bicyclists on both sides of a 2-lane road with no aftermarket modifications, but use caution if the road is wider than 27 ft. GPCs require an attachment method that secures the tubes without pinching them, and 1 GPC should be used on each side of the

	purpose tube counters (GPCs, with thin-walled "bicycle" tubes)	weighted average accuracy	the BOCO scheme was higher than that of a widely available classification scheme.	road. Any counter should have correction factors developed. At some unknown traffic volume, autos passing bicyclists at the counter location could reduce accuracy substantially.
Veenstra et al. (2013): Monitoring Urban Bicycle Volumes Using Inductive Loops at Signalized Intersections	Bicycle volume estimation based on inductive loop detectors	Enschede, The Netherlands; 2012; compared inductive loop data with visual counts	Inductive loops at an intersection on a physically separated cycle path can be used to estimate bicycle volumes accurately. At volumes above 200 cyclists/hr, the probability increases that 2 bikes will be counted as 1.	Can be applied in medium-sized cities in The Netherlands where bike volumes are typically below 50 cyclists/15 min. The random arrival process should be used to correct for underestimation at high volumes.
Nordback et al. (2011): *Using Inductive Loops to Count Bicycles in Mixed Traffic*	Accuracy of off-the-shelf inductive-loop technology used in mixed-traffic conditions; compared accuracy in mixed traffic to accuracy on physically separated facilities.	2 locations on 13th Street in Boulder, Colorado; 2010; volunteer cyclists rode over sensors continually for 30 min while counts were conducted. Special cases were tested in 3-min intervals.	Eco-Counter could differentiate bikes from motor vehicles. There was a 4% overcount on shared roadways using the Eco-Twin and a 3% undercount on separated paths using Eco-Pilot. Special cases revealed weaknesses in single-loop and multi-loop products that resulted in undercounts (bikes riding side by side and bikes riding one behind another, respectively).	Inductive loop technology provides an automated method of counting bicycles on shared roadways; however, placement away from electrical interference is vital, and installation and maintenance must be performed carefully to ensure accurate counts.
Nordback and Janson (2010): *Automated Bicycle Counts: Lessons From Boulder, Colorado*	Path counts using loop detectors vs. manual counts	Boulder, Colorado; 2009; compared automated counts to manual counts for at least 90 min	On average, the loop detectors (in service for 10 years with little or no maintenance) counted 4% fewer bicycles than the manual counters at the same locations. Of the 22 detector channels with sufficient counts to judge their accuracy, roughly 68% were considered accurate.	The most dramatic inaccuracies were caused by detector settings and software-related problems. Inductive loop detectors can provide accurate measures of bicycle use on a pathway when properly installed, calibrated, maintained, and free of external interference.
Yang et al. (2011): *Enhancing the Quality of Infrared-Based Automatic Pedestrian Sensor Data by Nonparametric Statistical Method*	Passive infrared sensor optimization	New Jersey; 2009; 1-2 days of data collected at 3 sites	Case studies showed that a nonparametric statistical method for calibrating raw data could reduce discrepancies between sensor counts and ground truth.	Differences between infrared sensor counts and ground truth varied but were more than 20% in some cases. The statistical method should be tested at pedestrian facilities other than trails and sidewalks.
Brewer et al. (2007): *Evaluating the Accuracy of Pedestrian/Bicycle Counters*	Passive infrared and break-beam counter evaluation (unclear if the break-beam counter was active infrared or radio beam)	College Station and Austin, Texas; 2006; 4-hr counts at 3 trail/walkway sites	Break-beam counters had best overall count accuracy but were not user-friendly. One infrared counter had moderate ease of use and counting accuracy but missed many bikes. A second infrared counter was user-friendly but the least accurate overall.	Slight modifications of a sensor's detection algorithms can improve the accuracy of data and enhance the ease of use. Site-specific (and possibly time-of-day-specific) adjustment factors could be developed to account for the consistent undercounting by all counters.
Zangenehpour et al. (2015): *Video-Based Automatic Counting for Short-Term Bicycle Data*	Automated video detection and accuracy	Montreal, Canada; year not stated; mobile video-camera-mast hardware, moving road-user	For 5-min interval counts, the accuracy of the automated counts ranged from 73% for intersections without a cycle track to 90% for road segments with a cycle track; for 15-	Automated video-based counts can be feasible and accurate and can count flows in multiple directions, although camera angles precluded bidirectional bicycle

Collection in a Variety of Environments		detection and tracking techniques, and classification-counting algorithms compared to manual counts from the videos	min interval counts, the accuracy ranged from 81% for intersections without a cycle track to 93% for road segments with a cycle track.	counts at 5 sites and complex movements at intersections may have led to reduced accuracy.
Eriksson (2014): *Leveraging Traffic and Surveillance Video Cameras for Urban Traffic*	Video: Traffic cameras, police cameras, red-light cameras, and security cameras for traffic monitoring	Illinois; year not stated; evaluate existing video data to determine bike/ped counts	Current optical flow–estimating algorithms were not well-suited for current video quality. Using optical flow with a learning detector for each object provides some ability to track.	The system could track autos, bicycles, and pedestrians but could not distinguish among them automatically. Future research should focus on correcting for occlusion and classifying objects.
Ling et al. (2010): *A Multi-Pedestrian Detection and Counting System Using Fusion of Stereo Camera and Laser Scanner*	Computer vision system using a stereo camera and a laser scanner	Walpole, Massachusetts; 2010; compared 2 hr of data collected at an intersection with manual counts	The pedestrian counting system could accurately detect, track, and count multiple pedestrians walking in a large group with more than 90% accuracy.	Limited resolution in the 3D detection data requires a high-resolution laser scanner to be used in conjunction with the stereo camera in order to count pedestrians walking in groups.
Sayed et al. (2013): *Enabling Automated Pedestrian Data Collection Using Computer Vision*	Computer vision: identification of gender, pedestrian violations, and classification of road users	Vancouver, Canada; Kuwait City; Oakland, California; 2011; comparison with manually identified pedestrians	First case study showed a 78% correct classification rate for gender. Second study showed 90% accuracy when measuring pedestrian crossing compliance. Classification of pedestrians in mixed traffic had a correct classification rate of about 90%.	Not an applied study; more about computer vision techniques. Classification technique could be extended to other road users including cyclists.
Kristoffersen et al. (2016): *Pedestrian Counting With Occlusion Handling Using Stereo Thermal Cameras*	Thermal cameras	Aalborg, Denmark; 2015; evaluated technology based on two 5-min video sequences	Proposed methods accurately and efficiently counted pedestrians (95% accuracy)	Children are at risk of not being counted because of their height. Each setup requires careful calibration and fine-tuning, especially with a stereo setup. There were no factory-calibrated stereo thermal cameras on the market.
Lesani et al. (2015): *Development and Testing of an Ultrasonic-Based Pedestrian Counting System*	Ultrasonic sensors	Montreal, Canada (McGill University campus); year not stated; system was conceptualized and then tested based on 1-2 days of data from 3 sites	The ultrasonic sensor system is appropriate for wide sidewalks without walls, a condition that challenges infrared-based systems.	Ultrasonic sensors had much higher energy consumption than infrared sensors (battery life of a few days vs. a few years). Multiple potential sensor improvements remained unexplored.
Lovas and Barsi (2015): *Pedestrian Detection by Profile Laser Scanning*	Profile laser scanning technology in oblique position	Indoor stairway; 2014; 10-min scanning period compared to phone-camera videos	Laser scanning can determine the height and width of humans and their position, direction, and velocity. When 2 or more people pass by at once, they are detectable.	Laser scanning could be used for pedestrian counts, flow analysis, and velocity determination. No sensitive information is collected. Oblique mounting may be a limitation.
Charreyron et al. (2013): *Toward a Flexible System*	Kinect depth camera for pedestrian detection	Region and data year not stated; primarily indoor	98% accuracy for speed data; acceptable counting performance in low to moderate	Occlusion is the main limitation; using the built-in developer tools, the Kinect had to

for Pedestrian Data Collection With a Microsoft Kinect Motion-Sensing Device		lab verification with some outdoor testing	volumes (undercounting error around 8%), including in low-light conditions that thwart computer vision.	be placed at person height facing the detection zone, so people in groups blocked each other. A possible multisensor system could include video for daytime use and Kinect for low-light use.
Lesani and Miranda-Moreno (2016): *Development and Testing of a Real-Time Wi-Fi-Bluetooth System for Pedestrian Network Monitoring and Data Extrapolation*	Mapping pedestrian flows using Bluetooth and Wi-Fi detectors	Montreal, Canada (McGill University campus); 2015; detection rate based on 50+ hr of manually tallied video over 6 days	Compared to Bluetooth, Wi-Fi had relatively high detection rates (26.4%) and high correlation between sensors and ground truth. Using Bluetooth alone is not feasible.	Computation of travel times can be complicated by people loitering or working near a sensor. Off-the-shelf products may not perform as well as the researchers' system. More investigation is required for Wi-Fi and Bluetooth double-counting on non-Apple devices and for classifying pedestrians vs. bicycles.
Kurkcu and Ozbay (2017): *Estimating Pedestrian Densities, Wait Times, and Flows With Wi-Fi and Bluetooth Sensors*	Monitoring nonmotorized traffic using Wi-Fi and Bluetooth sensors	Transit terminal (location and year not stated); apply filtering and moving block algorithm methods to 2-month-long data collection to determine pedestrian flows and wait times	Capturing recurring patterns of passengers in the terminal is probable. Peak periods and busiest hours can be determined at sensor locations, allowing for passenger demand estimates. Moving block algorithm is able to eliminate double counts and non-mobile devices and reaches 90% accuracy when device discoverability is 100%. Filters must be used to clean collected data.	Factors limiting the accuracy of algorithms include short-lived network addresses, non-mobile devices that transmit intermittent probe requests, and devices that are detectable at low frequencies. Future work should include the addition of more sensors and long-term data collection that would provide data on seasonal variations.
Blanc et al. (2015): *Leveraging Signal Infrastructure for Nonmotorized Counts in a Statewide Program: Pilot Study*	Model 2070 signal controllers with advanced software to log pedestrian phase actuations and detections from bicycle lane inductive loops	Oregon; 2013; 24-hr video data as ground truth compared to controller log for that time period	Pedestrian-pushbutton phase logging using signal controllers may be a cost-effective method to estimate pedestrian activity, with some caveats. A correction factor was calculated (based on 1 day only) of 1.24 pedestrian crossings/phase logged, on average. Bike loops were less promising, overcounting by more than 1,000%, likely because of the loops detecting nearby auto traffic.	Phase logging will not work if signal is on pedestrian recall. Pedestrian counts should involve developing adjustment factors after accuracy testing (i.e., by comparing to videos). For bike counts, video validation, using appropriate inductive loop sensitivity, and placement of loops relative to motor vehicle movements are critical items that affect the usefulness of the data.
Figliozzi et al. (2014): *Design and Implementation of Pedestrian and Bicycle-Specific Data Collection Methods in Oregon*	Statewide: Oregon system methods, technology review, and pilot study of counts using Type 2070 signal controllers	Oregon; 2012; evaluated Type 2070 controllers at chosen intersections	Pneumatic tubes did not accurately count bikes; other brands were to be tested in the future.	Recommendations cover factoring methods and the implementation of a statewide nonmotorized data collection system.
Kothuri et al. (2017): *Bicycle and Pedestrian Counts at Signalized Intersections Using Existing Infrastructure: Opportunities and*	Using existing hardware (loop detectors, signal controllers) and software to gather bicycle counts and pedestrian delay	Oregon; 2015; 2 tests for bicycle technologies, 1 for pedestrian technologies, some in controlled environments, some in both controlled	Inductive loops and thermal camera counted bikes accurately in the controlled environment but failed at an intersection in mixed traffic. Passive infrared accurately counted at an intersection and in the controlled environment.	Loops and thermal cameras are not recommended for use in mixed traffic at intersections for combined counting and detection, but loops in a bicycle-only environment could be viable. Further testing is warranted as products are

Challenges		and real-world environments.		refined. Pedestrian signal actuation data (pushbutton presses) can be a low-cost way to measure pedestrian activity at signalized intersections.
Chagas et al. (2007): *Pedestrian Counting Methods at Intersections: A Comparative Study*	Manual counts on paper, using clickers, and by reviewing video	San Francisco; 2006; 4-hr studies conducted at 10 intersections (sheets at 8, clickers at 2)	Manual counts with either paper or clickers systematically undercounted pedestrians (error rates of 8% to 25%). Error rates were greater at the beginning and end of the observation period, possibly because of the observer's lack of familiarity with the tasks or fatigue, but were not strongly related to pedestrian volumes.	Counts from videos were assumed to be accurate. Attention of the observer is impossible to control; they could become distracted and not record properly. Video recordings should be used for studies when count accuracy is the main concern.
Lowry et al. (2016): *Practitioner Survey and Measurement Error in Manual Bicycle and Pedestrian Count Programs*	Manual intersection count error analysis and stated reasons for counting	U.S. (survey), Idaho and Seattle (counts); year not stated; 92 responses from 25 states about manual counts and observed 5 manual counts by volunteers for errors	The overall median absolute percent error for the 12-movement technique (i.e., all intersection movements) was 27% and 7% for bicyclists and pedestrians, respectively. Lower measurement error rates were observed when using a 4-movement technique (i.e., counting users exiting each leg of the intersection); however, the differences were not statistically significant.	Did not assess the measurement error associated with screenline counts. Volunteer count error could be due to first-time counters, fatigue, or other reasons, but may be overshadowed by unreliability because of the infrequent, short-duration nature of most volunteer count programs. The authors concluded that some of the reasons for conducting manual counts cited by survey respondents seemed unrealistic and possibly flawed.

Table C4. Studies of Route-Tracking Smartphone Applications and Crowdsourcing Data

Citation: Title	Study Focus	Study Region; Data Year; Methods	Findings	Limitations and Recommendations
Barbeau and Cetin (2017): *Rapidly Expanding Mobile Apps for Crowd-sourcing Bike Data to New Cities*	Crowdsourcing bike route data	San Francisco; Atlanta; Portland, Oregon; 2016; analyzed existing crowdsourcing apps in 3 cities	A proof-of-concept, multi-region architecture for the Cycle Atlanta Android and iOS apps was designed and implemented, allowing each city to develop its own server within an existing app, rather than necessitating an entirely new app.	Future work should focus on partnering with existing organizations that have apps to test and release multi-region improvements. Additional platforms and collection methods should be explored.
Watkins et al. (2016): *Using Crowdsourcing to Prioritize Bicycle Network Improvements*	Cycle Atlanta smartphone app	Atlanta; 2014-2016; GPS-enabled smartphone app to collect sociodemographic and route data from Atlanta cyclists	The main goal of developing the app for collecting cycling infrastructure preferences was successfully achieved. App-based data can play a role in bridging the gap between survey data and data required for bicycle planning efforts.	Dataset was dominated by white male cyclists aged 25 to 44, not representative of Atlanta's population but possibly representative of the cycling population. By design, those without a smartphone are excluded.
Griffin and Jiao (2015): *Crowdsourcing Bicycle Volumes: Exploring the Role of Volunteered Geographic Information and Established Monitoring Methods*	Use of GPS and crowdsourced data to extend counting programs	Austin, Texas; 2015; 5 trails in Austin, previous CycleTracks app survey and Strava data	App users represented between 2.8% and 8.8% of all trail users, typically skewed toward male fitness cyclists. Relatively small number of trips recorded at most sites would likely not reach statistically representative thresholds.	Crowdsourced data are promising as a tool for evaluating bike volumes, but it is important to recognize that they represent only their users, which may or may not represent the total population.
Jackson et al. (2014): *Adaptation and Implementation of a System for Collecting and Analyzing Cyclist Route Data Using Smartphones*	Smartphones to log route data, travel time, distance, and route choice	Montreal; 2013; use GPS data to log routes, travel time, distance, route choice; obtain demographic questionnaire for each user	More than 2,300 logged trips by 500 cyclists within 3 weeks; new system adapted well from previous foundations (Cycle Atlanta, CycleTracks) and was well accepted.	Possible applications include prioritizing infrastructure, identifying origins and destinations, and determining demand characteristics. GPS can lose connection, which needs to be accounted for so data remain accurate.
Jestico et al. (2016): *Mapping Ridership Using Crowdsourced Cycling Data*	Strava vs. manual bike counts	Victoria, Canada; 2013; linear regression and other modeling of crowdsourced data from Strava vs. manual bike counts at 18 locations in 4 seasons	Crowdsourced data and manual counts had a linear relationship (r-squared of 0.4 to 0.58). Crowdsourced data improved prediction capabilities of a model based on factors such as slopes, traffic speeds, on-street parking, etc.	Crowdsourced fitness data comprise a biased sample but may be a good proxy for daily, categorical volumes such as weekday commuting periods in urban areas. Comparisons across urban and rural settings and in places with more manual count data are needed.

Table C5. Studies Outlining Methods for Count Adjustments (e.g., for Weather Conditions and Seasonality), Factoring, or Quality Assurance

Citation: Title	Study Focus	Study Region; Data Year; Methods	Findings	Limitations and Recommendations
Beitel et al. (2017): *Quality Measure of Short-Duration Bicycle Counts*	Average annual daily bicyclists (AADB) quality when extrapolated from short-term bicycle counts	Montreal; Arlington, Virginia; 2014 (Montreal), 2015 (Arlington); evaluated data from cities separately (14 Eco-Counters in Montreal, 15 Eco-Counters in Arlington) acknowledging weather factors and performed 5-step analysis.	AADB estimation can result in inaccurate measures. This method estimates the quality and allows for validation through a database of counters. Lowest quality class had average absolute relative error (ARE) of 13.5%; highest quality class had average ARE of 3%.	Future work: test the quality measures with larger datasets and develop error estimates for short-term counts with only duration, estimated demand, and time-of-year factors.
El Esawey (2016): *Toward a Better Estimation of Annual Average Daily Bicycle Traffic: Comparison of Methods for Calculating Daily Adjustment Factors*	Factoring and annual average daily bicycle traffic (AADBT): the AASHTO method, the monthly and weather-specific method, and the day-of-year method for calculating daily adjustment factors	Vancouver, Canada; 2005-2011; 810,000+ hours of permanent inductive loop count data	Day-of-year method was superior in terms of estimation accuracy, then the monthly and weather-specific method, then the AASHTO method.	A full year of daily bike volume data is required to calculate any of these adjustment factors. The day-of-year method is not temporally transferable: it cannot be applied to the same day of year for a previous or subsequent year for forecasting or backcasting, and it is useful only for estimating the AADB volumes for short-term count stations in the same year the full year of count data exists.
El Esawey et al. (2013): *Development of Daily Adjustment Factors for Bicycle Traffic*	Daily adjustment factors	Vancouver, Canada; 2010-2011; assessment of estimation accuracy on 74 links for monthly average daily cycling volumes and of temporal transferability	The best estimation results of the monthly average cycling volumes were achieved with the use of daily factors that were disaggregated by weather conditions. Reliability degraded over time for daily adjustment factors.	Do not use transferred factors from one year to another unless factors for the same year are unavailable. Transfer the daily factors spatially from other stations even if they belong to a different road class, rather than using factors of similar stations of a different year. Transferability to other cities with similar weather conditions requires further study.
Hankey et al. (2012): *Estimating Use of Nonmotorized Infrastructure: Models of Bicycle and Pedestrian Traffic in Minneapolis, MN*	Scaling factors to get 12-hr "daily" counts from hourly counts, models using ordinary least squares and negative binomials	Minneapolis; 2007-2010; models based on 259 locations	1-hr counts were highly correlated with 12-hr "daily" counts, suggesting that planners may focus on short time scales without compromising data quality. Weather, sociodemographics, built environment characteristics, and street type were significant factors.	Models were based on locations of interest, not a representative sampling, so their valid applicability to all areas of the city was limited. Policy-makers should use models to estimate nonmotorized traffic where counts are unavailable or to estimate changes in nonmotorized traffic associated with anticipated changes in the built environment.
Beitel and Miranda-Moreno (2016): Methods for Improving and Automating the	AADBT estimation methods: data validation, matching, and extrapolating	North America (primarily U.S. and Canada major cities); 2013; validate, match, and extrapolate data	Disaggregated factor methods (DFM) with filtering improved estimation of AADB over previous method, with error reduced from 5.6% to 4.2%. DFM with separate treatment	Validation, matching, and extrapolation methods developed in this study should be applied to additional long-term counting sites from various regions over multiple

Estimation of Average Annual Daily Bicyclists		for 22 long-term bike counters and 3 reference sites	of weekdays/weekends reduced error from 6% to 4.9%. Five clusters of count sites emerged: utilitarian, mixed-utilitarian, mixed-recreational, recreational, and non-urban-recreational.	years. Methods should be improved to be able to match short-duration counts (SDCs) with similar traffic patterns for AADB extrapolation.
Hankey et al. (2014): *Day-of-Year Scaling Factors and Design Considerations for Nonmotorized Traffic Monitoring Programs*	Scaling factors and guidance on SDCs	Minnesota; 2011; day-of-year factors were applied for 6 off-street trail locations	(a) Day-of-year scaling factors have smaller error than day-of-week and month-of-year, especially from SDCs (<1 week); (b) extrapolation error decreases with SDC length, with only marginal gains in accuracy for counts > 1 week; (c) errors in estimating AADT are lowest when SDCs are taken April-October; (d) impact of sampling on consecutive (successive) vs. nonconsecutive (separate) days on AADT estimation is minimal but may reduce labor requirements; and (e) design of a monitoring program depends on acceptable error, equipment availability, and monitoring period duration.	Resource constraints will determine the trade-off between count duration and estimate accuracy. Day-of-year factors improve accuracy of AADT estimation.
Schmiedeskamp and Zhao (2016): Estimating *Daily Bicycle Counts in Seattle, Washington, From Seasonal and Weather Factors*	Applied a negative binomial model to 2 years of automated bike counts at 1 Seattle location	Seattle; 2012-2014; negative binomial model, counterfactual simulation and visualization	Statistically significant variables: season (+), temperature (+), precipitation (-), holidays (-), day of week (+ for Monday-Saturday, relative to Sunday), and overall trend (+)	Alternative model specifications could be proposed, such as the incorporation of cloud cover data. Building the model based on a single site is a limitation. The highest temperature observed was 85 F.
Wang et al. (2012): Estimating Nonmotorized Trail Traffic Using Negative Binomial Regression Models	Estimating variation in traffic in response to weather and day of week	6 trail locations in Minneapolis, Minnesota; 2010-2011; aggregate-level analysis methods and negative binomial modeling based on surveys and active infrared counts of nonmotorized traffic	Negative binomial models outperform models estimated using ordinary least squares regression. These models, on average, estimate within 30%, which is considered reasonable.	Limited data availability and unequal time periods limited the accuracy of analysis. A larger dataset was recommended, including data from the entire year, more high- and low- volume counts, and more monitoring sites. Only total volume models could be used because active infrared counters cannot differentiate between modes. Future work could include other counter technologies that distinguish travel by mode.
Gallop et al. (2012): A Seasonal Autoregressive Model of Vancouver Bicycle Traffic Using Weather Variables	Weather effects on hourly bicycle counts	Vancouver, Canada; previously collected data from Vancouver (2009-2011); used Box-Jenkins analysis on first 75% of data and held back remaining data for verification	An increase in temperature by 1 degree C was correlated with a 1.65% increase in bicycle traffic. Humidity and clearness had small impacts on bicycle traffic. Temperature, rain, rain in past 3 hr, and humidity had significant impact on counts.	Expanded analysis into other modes could show how different modes fluctuate relative to one another based on weather conditions.

Wang et al. (2016): *Monitoring and Modeling of Urban Trail Traffic: Validation of Direct Demand Models in Minneapolis, Minnesota, and Columbus, Ohio*	Estimates and validates direct demand models for average annual daily traffic (AADT) using national and local variables	Minneapolis, Minnesota, and Columbus, Ohio; newer analysis of data from 2013-2014; follows *Traffic Monitoring Guide* procedures to estimate AADT for urban trail segments (counts are mixed-mode rather than separate bike and ped counts)	Reasonably good model fits, but not accurate for many lower-volume segments (more than 33% of segments had predicted volumes that were more than 60% higher than actual volumes). Columbus metro area model had a much lower fit than Columbus city model, indicating that models attempting to capture more variation in population density, land use, and other spatial factors will do worse.	Applying the models to other cities was not successful. Such models can be used for planning studies (e.g., identifying potential trail corridors) but not for engineering studies (e.g., determining *Manual of Uniform Traffic Control Devices* warrant volumes for signals or pedestrian hybrid beacons).
Gobster et al. (2017): *Up on the 606: Understanding the Use of a New Elevated Pedestrian and Bicycle Trail in Chicago, Illinois*	Use of urban trails, regression model	The 606 in Chicago; 2016; screenline calibration tests of active infrared counters	Active infrared counters had high rates of occlusion. Most users were pedestrians. Regression models, using weekdays and weekends, explained 80% of daily use variation.	Management implications and additional research should be explored.
Turner and Lasley (2013): *Quality Counts for Pedestrians and Bicyclists: Quality Assurance Procedures for Nonmotorized Traffic Count Data*	Data quality procedures	Variety of international source locations; year not stated; data accuracy measures applied to agency-collected data	Key principles: (a) quality assurance starts before data are collected, (b) acceptable quality is determined by the data's use, and (c) measures can quantify varying quality dimensions.	Targeted visual review should be used to identify suspect data that may not be picked up by automated processes. It is recommended that uniform procedures be developed to evaluate accuracy of counters so data can be pooled and used to develop a comprehensive picture of equipment performance.
El Esawey and Mosa (2015): *Determination And Application of Standard K Factors for Bicycle Traffic*	Design hour factors, also known as K factors, for bikes	Vancouver, Canada; 2009-2011; data from 22 count stations were filtered for outliers, and K factors were developed	A K factor calculated as the ratio of the peak hour volume to the total daily volume resulted in the least error (16.6%); use of the best factors and daily/monthly adjustment resulted in 28.3% error. A K factor calculated as the ratio of the daily peak hour volume to the annual average daily bicycle volume had 28.9% error.	It was recommended that local data be used to calculate K factors while realizing that such data could vary greatly from one location to another. It was recommended that different K values be calculated for weekdays vs. weekends and that K factors be used with hourly bicycle volume data collected during a summer weekday.

Table C6. Descriptions of Data Warehouses and Archives for Nonmotorized Count Data

Citation: Title	Study Focus	Study Region; Data Year; Methods	Findings	Limitations and Recommendations
Nordback et al. (2015): *Creating a National Nonmotorized Traffic Count Archive: Process and Progress*	First steps in creating a national bicycle and pedestrian count data archive	U.S.; 2013-2014; analyze data pulled from regional, publicly available nonmotorized count archives to develop a national archive	The archive was to include input, quality evaluation, data visualization functions, and the ability to download user-specified data. Its structure was to allow for both mobile counters and validation counts of the same traffic flow, and it was to provide a platform for data sharing.	The next steps were to include improving the user interface, quality checking, and expanding the tools to compute nonmotorized average annual daily traffic (AADT). The success of the national archive was limited by the willingness of localities and agencies to use and fund it.
Zhang et al. (2014): *Develop a Plan to Collect Pedestrian Infrastructure and Volume Data for Future Incorporation Into Caltrans Accident Surveillance and Analysis System Database*	Pedestrian data archive (could be expanded to include bicycle data)	California; 2012-2014; inventories of pedestrian infrastructure and pedestrian volume models	The database (Excel format) allows automatic importing of Miovision files containing volume data and offers flexibility and ease of updating/maintaining; pedestrian facilities are adequately incorporated, allowing use for safety analysis.	Recommended that Caltrans initiate construction of the proposed database, input a full infrastructure inventory, and connect the database with the state's existing motor vehicle infrastructure and volume database, among several other more specific recommendations. Volume data should be updated more frequently than infrastructure data.
Huff and Brozen (2014): Creating the Bicycle Count Data Clearinghouse for Los Angeles County, California	Data archive that was intended to be regional	Los Angeles; 2012-2013; develop a clearinghouse for regional bike count data, develop standards for methods, input existing data	Online clearinghouse was not yet tested but was to standardize historical data, count protocols, etc.	Recommended having a standard regional count methodology and making volume data easy to access without letting the inability to create a perfect data standard prevent the use of a working standard. Without this, "As more and more agencies conduct counts, the set that results from compiling these data together is frustratingly incomplete for the purposes of identifying general use trends and factors as well as regional patterns."
Tischler et al. (2014): Creating Countdracula: An Open Source Counts Management Tool	Open-source tool that replaced Excel and an unwieldy file structure	San Francisco; 2007-2010; overview of tool development	Open-source tools improve efficiency (e.g., by allowing projects to be completed once to benefit all participants, rather than having separate entities complete the same project multiple times).	Collaborators need to be involved to improve the future of CountDracula; pedestrian data were not included in CountDracula at the time but should be added to reflect accurately the transportation landscape of San Francisco; the program needs to be expanded to handle more inputs.

Table C7. Studies Primarily Describing How Counts Are Used

Citation: Title	Study Focus	Study Region; Data Year; Methods	Findings	Limitations and Recommendations
Turner et al. (2017): *Synthesis of Methods for Estimating Pedestrian and Bicyclist Exposure to Risk at Areawide Levels and on Specific Transportation Facilities*	Exposure to risk; includes summary of direct measurement (i.e., counts)	U.S.; 2016-2017; sketch planning based on the National Household Travel Survey, American Community Survey, and regional household travel surveys	Geographic scale is a key parameter for exposure analysis; area-wide exposure methods are inconsistent (e.g., focusing on journey-to-work trips vs. total trips); and facility-specific exposure analyses often use counts in combination with models.	It will be difficult to single out a single best practice for future methodological development in terms of estimation models; one possibility is to focus on the direct demand model (most common). Next phase of work was to include development of a conceptual framework and design for risk exposure estimation at several geographic scales.
Rasmussen et al. (2013): Estimating the Impacts of the Nonmotorized Transportation Pilot Program: Developing a New Community-Wide Assessment Method	Estimates mode share changes and avoided vehicle miles traveled using count data from the Nonmotorized Transportation Pilot Program	Columbia, Missouri; Marin County, California; Minneapolis, Minnesota; and Sheboygan County, Wisconsin; 2007-2011; before-after counts in pilot communities	Between 2007-2011, biking and walking increased 67% and 31%, respectively, equivalent to 3 million gallons of gas saved.	Results support the assertion that improving nonmotorized transportation networks will make more people choose to walk and bike.
Fields et al. (2014): Assessing the Impact of Bicycle Facilities on Use: Evaluation of Minneapolis Nonmotorized Transportation Pilot Program	Uses count data to examine impact of a major investment in new bicycle facilities	Minneapolis; 2007-2011; collected pre- and post-count data around Minneapolis to determine impact of program	Bike facilities proved to be the prime correlate of counts and of growth in counts over time. The length of the network of bike facilities near a count location was also associated with increases in the rate of change in its counts over time.	Manual counts represent a snapshot and do not capture trip purposes. Models do not account for spatial auto-correlation. New bicycle facilities are a key factor in driving increased levels of bicycling, along with network effects of bicycle facilities. Future research should examine behavior over longer time horizons.
Wadud (2014): Impact of Climate Change on Bicycle Count	Projected impact of climate change on bicycle patterns	London; 2008-2011; applied negative binomial count-data model incorporating projected weather data to automated bicycle counter data maintained by Transport for London	Predicts a 0.5% increase in average annual hourly bicycle flows by 2041, affected by increased temperatures and increased rain; leisure cycling will be more affected, with a 7% increase during weekends and holidays.	Variables other than weather could have greater effects than what is modeled. Results represent a lower bound of potential bicycle volume increases but do not consider impacts of extreme weather-induced events. The modeling framework can be applied universally, although the specific results are not generalizable to other regions.
Griswold et al. (2011): Pilot Models for Estimating Bicycle Intersection Volumes	Models of bicycle volumes at intersections	Alameda County, California; 2008-2009; models developed based on 2-hr counts at 81 intersections	Bike volumes were higher at intersections surrounded by commercial retail, close to a major university, and with a marked bike lane on at least 1 leg. Bike facilities had a strong positive association with volumes, and hills had a weak negative association.	Models are preliminary; further testing and refinement are needed before accurate predictions can be made. Counts were taken different times of the day on weekdays and Saturdays, not consistent hours. Weather effects were not included but might be significant in less temperate climates.

Schneider et al. (2009): *Pilot Model for Estimating Pedestrian Intersection Crossing Volumes*	Models of pedestrian volumes at intersections	Alameda County, California; 2008; estimated ordinary least squares regression models for manual 2-hr pedestrian count data, 1 weekday and 1 Saturday, from 50 intersections	Number of jobs, commercial properties within 0.25-mi radius, total population within 0.5-mi radius, and presence of a regional transit station within 0.1-mi radius of intersection were significant factors in the recommended model (R-squared = 0.897).	More consistent counts were needed for validation, and additional research was needed to apply the data to a larger sample size, incorporate additional variables, and incorporate network distances. Model results could be used for planning, prioritization, and safety analysis, but actual counts should be used for site-level analyses.
McDaniel et al. (2014): Using Origin-Destination Centrality to Estimate Directional Bicycle Volumes	Estimating bike volumes with centrality	Moscow, ID (case study); 2012; 4 methods applied to 2-hr A.M. and P.M. manual intersection counts by volunteers: Origin-destination (O-D) centrality, preferred bicycle paths, O-D pairs, and O-D multipliers	O-D centrality is an advantageous method of modeling that provides strong explanatory and predictive power (P.M. model explained 61% of variability in calibration dataset and 73% of variation in the validation dataset) and requires only the street network, a digital elevation map, and residential/nonresidential parcels.	O-D centrality is better than traditional multistep demand models and direct demand models (less data- and software-intensive, accounts for network characteristics, etc.) but could be improved with more explanatory variables, different O-D multipliers, or a distance decay function. Results could be used for project prioritization, exposure analysis, or scenario planning.
Pulugurtha and Maradapudi (2013): Pedestrian Count Models Using Spatial Data Based on Distance Decay Affect	Non-linear count models for estimating pedestrian activity in 3 different scenarios	Charlotte, NC; 2005; developed models based on spatial data and transit stops for 12-hr manual counts at 176 signalized intersections by trained technicians	Spatially weighted models provided better results than the non-linear models; separate models for high and low pedestrian activity yielded more meaningful outputs. Critical variables included population, employment, transit stops, presence of a median, number of lanes, and number of legs/approaches.	Better, "more accurate models can be developed by extracting and combining data from different bandwidths"; that is, future models should include demographics and Census-based variables. More research was recommended on the selection of weights and how to account for level of activity in modeling. The methodology should be tested with data from other areas.
Strydom and Mavroulidou (2009): *Automated Surveys for the Provision of Pedestrian Crossings*	Automatic traffic detection systems to help make pedestrian infrastructure decisions for smaller projects	U.K.; 2006; software developed to transform automatic count data into spreadsheets based on 2 counts: 1 automatic, 1 manual	In one instance, the automated count and manual counts (which were based on estimated peak hours) gave differing results on the necessity of a pedestrian crossing, with the automated count being more advantageous because it identified the actual peak hours.	The use of automatic rather than manual counters to perform counts could result in significant time savings, especially after several counts. Manual counts should perhaps be used only for validating automatic counters.
Kingsley et al. (2013): Tools for Estimating Benefits of Bicycle Count Data	Tools for estimating benefits of bicycle travel as related to a regional travel demand model	Los Angeles; overview and comparison of various tools as of 2013	Tools include the Metro Bicycle Investment Scenario Analysis Model, Integrated Transportation and Health Impact Modeling Tool, Health Economic Assessment Tool, NCHRP Report 552 Bike Cost Tool, Quantifying the Cost of Physical Inactivity, California Air Resources Board method for calculating emissions reductions, and a method for quantifying benefits from a bikeshare system.	Bicycle count data can be used in applications including travel model enhancement, scenario planning, public health assessments, and emissions calculations.

APPENDIX D

POPULATION, AREA, AND DENSITY OF LOCALITIES
(U.S. Census Bureau, 2016)

Table D1. Population, Area, and Density of Counties That Had Conducted Counts

County	Population	Area (sq. mile)	Density (pop./sq. mile)
Albemarle	98,970	720.70	137.3
Arlington	207,627	25.97	7,993.6
Fauquier	65,203	647.45	100.7
Lunenburg	12,914	431.68	29.9
Roanoke	92,376	250.52	368.7
Spotsylvania	122,397	401.50	304.9
Fairfax	1,081,726	390.97	2,766.8
Loudoun	312,311	515.56	605.8
Rockingham	76,314	849.09	89.9

Table D2. Population, Area, and Density of Cities That Had Conducted Counts

City	Population	Area (sq. mile)	Density (pop./sq. mile)
Alexandria	139,966	15.03	9,314.3
Bristol	17,835	13.01	1,370.6
Fredericksburg	24,286	10.44	2,326.2
Galax	7,042	8.24	854.6
Harrisonburg	48,914	17.42	2,808.2
Portsmouth	95,535	33.65	2,838.8
Richmond	204,214	59.81	3,414.7
Roanoke	97,032	42.56	2,279.8
Norfolk	242,803	54.12	4,486.4
Salem	24,802	14.44	1,717.9
Charlottesville	43,475	10.24	4,246.4

Table D3. Population, Area, and Density of Towns that Had Conducted Counts

Town	Population	Area (sq. mile)	Density (pop./sq. mile)
Front Royal	14,440	9.24	1,562.4
Ashland	7,225	7.13	1,012.9
Berryville	4,185	2.30	1,819.6
Glen Lyn	115	0.74	155.4
Marion	5,968	4.12	1,447.5
Stanley	1,689	1.10	1,535.5
Vienna	15,687	4.41	3,560.4

Table D4. Population, Area, and Density of Counties That Had Not Conducted Counts

County	Population	Area (sq. mile)	Density (pop./sq. mile)
Accomack	33,164	449.50	73.8
Alleghany	16,250	445.46	36.5
Amelia	12,690	355.27	35.7
Amherst	32,353	473.93	68.3
Appomattox	14,973	333.49	44.9
Augusta	73,750	967.00	76.3
Bath	4,731	529.16	8.9
Bedford	68,676	753.02	91.2
Bland	6,824	357.73	19.1
Botetourt	33,148	541.20	61.2
Brunswick	17,434	566.17	30.8
Buchanan	24,098	502.76	47.9
Buckingham	17,146	579.66	29.6
Campbell	54,842	503.87	108.8
Caroline	28,545	527.51	54.1
Carroll	30,042	474.69	63.3
Charles City	7,256	182.82	39.7
Charlotte	12,586	475.27	26.5
Chesterfield	316,236	423.30	747.1
Clarke	14,034	176.18	79.7
Craig	5,190	329.53	15.7
Culpeper	46,689	379.23	123.1
Cumberland	10,052	297.46	33.8
Dickenson	15,903	330.53	48.1
Dinwiddie	28,001	503.72	55.6
Essex	11,151	257.12	43.4
Floyd	15,279	380.42	40.2
Fluvanna	25,691	286.01	89.8
Franklin	56,159	712.00	78.9
Frederick	78,305	413.50	189.4
Giles	17,286	355.78	48.6
Gloucester	36,858	217.81	169.2
Goochland	21,717	281.42	77.2
Grayson	15,533	442.18	35.1
Greene	18,403	156.25	117.8
Greensville	12,243	295.23	41.5
Halifax	36,241	817.84	44.3
Hanover	99,863	468.54	213.1
Henrico	306,935	233.70	1,313.4
Henry	54,151	382.33	141.6
Highland	2,231	415.16	5.6
Isle of Wight	35,270	315.61	111.8
James City	67,009	142.44	470.4
King and Queen	6,945	315.14	22.0
King George	23,584	179.64	131.3
King William	15,935	273.94	58.2
Lancaster	11,391	133.25	85.5
Lee	25,587	435.52	58.8
Louisa	33,153	496.30	66.8
Madison	13,308	320.68	41.5
Mathews	8,978	85.93	104.5

Mecklenburg	32,727	625.49	52.3
Middlesex	10,959	130.31	84.1
Montgomery	94,392	387.01	243.9
Nelson	15,020	470.86	31.9
New Kent	18,429	209.73	87.9
Northampton	12,389	211.61	58.5
Northumberland	12,330	191.30	64.5
Nottoway	15,853	314.39	50.4
Orange	33,481	340.78	98.2
Page	24,042	310.86	77.3
Patrick	18,490	483.10	38.3
Pittsylvania	63,506	968.94	65.5
Powhatan	28,046	260.22	107.8
Prince Edward	23,368	349.96	66.8
Prince George	35,725	265.16	134.7
Prince William	402,002	336.40	1,195.0
Pulaski	34,872	319.86	109.0
Rappahannock	7,373	266.23	27.7
Richmond	9,254	191.49	48.3
Rockbridge	22,307	597.56	37.3
Russell	28,897	473.82	61.0
Scott	23,177	535.53	43.3
Shenandoah	21,993	508.78	82.5
Smyth	32,208	450.93	71.4
Southampton	18,570	599.15	31.0
Stafford	128,961	268.96	479.5
Surry	7,058	278.95	25.3
Sussex	12,087	490.22	24.7
Tazewell	45,078	518.85	86.9
Warren	37,575	213.47	176.0
Washington	54,876	560.98	97.8
Westmoreland	17,454	229.38	76.1
Wise	41,452	403.19	102.8
Wythe	29,235	461.82	63.3
York	65,464	104.78	624.8

Table D5. Population, Area, and Density of Cities That Had Not Conducted Counts

City	Population	Area (sq. mile)	Density (pop./sq. mile)
Buena Vista	6,650	6.70	991.9
Chesapeake	222,209	340.80	652.0
Colonial Heights	17,411	7.52	2,315.3
Covington	5,961	5.47	1,090.2
Danville	43,055	42.93	1,002.8
Emporia	5,927	6.89	859.7
Fairfax	22,565	6.24	3,616.8
Falls Church	12,332	2.00	6,169.1
Franklin	8,582	8.21	1,045.8
Hampton	137,436	51.41	2,673.2
Hopewell	22,591	10.28	2,198.0
Lexington	7,042	2.50	2,820.2
Lynchburg	75,568	49.13	1,538.2
Manassas	37,821	9.88	3,827.6
Manassas Park	14,273	2.53	5,632.6
Martinsville	13,821	10.96	1,261.5
Newport News	180,719	68.71	2,630.0
Norton	3,958	7.48	529.1
Petersburg	32,420	22.93	1,413.7
Poquoson	12,150	15.32	793.2
Radford	16,408	9.87	1,662.1
Staunton	23,746	19.98	1,188.8
Suffolk	84,585	400.17	211.4
Virginia Beach	437,994	249.02	1,758.9
Waynesboro	21,006	15.04	1,396.8
Williamsburg	14,068	9.02	1,559.3
Winchester	26,203	9.23	2,838.0

Table D6. Population, Area, and Density of Towns That Had Not Conducted Counts

Town	Population	Area (sq. mile)	Density (pop./sq. mile)
Alberta	298	1.85	161.1
Altavista	3,450	71.68	48.1
Appalachia	1,754	2.22	790.1
Bedford	6,222	6.88	904.6
Big Stone Gap	5,614	4.89	1,148.1
Blacksburg	42,620	19.89	2,142.5
Blackstone	3,621	4.49	806.5
Bluefield	5,444	9.32	584.1
Bridgewater	5,644	2.53	2,227.3
Broadway	3,691	2.35	1,570.6
Cedar Bluff	1,137	2.22	512.2
Chase City	2,351	2.19	1,073.5
Chilhowie	1,781	2.57	692.9
Chincoteague	2,941	9.11	322.8
Christiansburg	21,041	14.38	1,463.2
Clifton Forge	3,884	3.02	127.2
Coeburn	2,139	2.07	1,033.3
Colonial Beach	3,542	2.55	1,389.0
Crewe	2,326	2.01	1,157.2
Culpeper	16,379	6.72	2,437.7
Dayton	1,530	1.02	1,500.0
Dumfries	4,961	1.54	3,213.1
Elkton	2,726	3.04	896.7
Floyd	425	0.46	923.9
Farmville	8,216	7.21	1,140.3
Fries	484	0.8	947.8
Gate City	2,034	3.91	520.2
Glade Spring	1,456	1.22	1,193.4
Glasgow	1,133	1.48	765.5
Gordonsville	1,496	0.92	1,626.1
Gretna	1,267	1.73	732.4
Grottoes	2,668	1.88	1,419.1
Grundy	1,021	4.98	205.0
Halifax	1,309	3.78	346.3
Herndon	23,292	4.27	5,454.8
Hillsville	2,681	8.88	301.9
Hurt	1,304	3.48	374.7
Independence	947	2.34	404.7
Irvington	432	1.50	288.0
Kilmarnock	1,487	3.42	434.8
La Crosse	604	1.17	516.2
Lawrenceville	1,438	1.15	1,250.4
Lebanon	3,424	4.46	767.7
Leesburg	42,616	12.39	3,439.5
Louisa	1,555	1.83	849.7
Luray	4,895	4.75	1,030.5
Middleburg	673	1.04	647.1
Mineral	467	0.89	524.7
Mount Jackson	1,994	2.72	733.1
Narrows	2,029	1.26	1,610.3
New Market	2,146	2.03	1,057.1

Nickelsville	383	0.48	797.9
Occoquan	934	0.17	5,494.1
Onancock	1,263	1.05	1,202.9
Orange	4,721	3.31	1,426.3
Painter	229	0.64	357.8
Pearisburg	2,786	3.16	881.6
Pennington Gap	1,781	1.62	1,099.4
Pocahontas	389	0.52	748.1
Pulaski	9,086	7.90	1,150.1
Purcellville	7,727	3.15	2,453.0
Remington	598	0.22	2,718.2
Richlands	5,823	5.72	1,018.0
Rocky Mount	4,799	6.84	701.6
Round Hill	539	0.37	1,456.8
Rural Retreat	1,483	2.29	647.6
Saltville	2,077	7.91	262.6
Saxis	241	0.42	573.8
Scottsville	566	1.53	369.9
Shenandoah	2,373	2.18	1,088.5
Smithfield	8,089	9.48	853.3
South Boston	8,142	13.06	623.4
South Hill	4,650	9.83	473.0
St. Charles	128	0.18	711.1
Stephens City	1,829	2.39	765.3
Strasburg	6,398	3.75	1,706.1
Stuart	1,408	3.24	434.6
Tangier	727	1.25	224.4
Tappahannock	2,375	2.59	916.9
Tazewell	4,627	6.91	669.6
Timberville	2,522	1.27	1,985.8
Troutdale	178	3.12	57.1
Urbanna	476	0.42	1,133.3
Victoria	1,725	2.82	611.7
Vinton	8,098	3.16	2,562.7
Wachapreague	232	0.23	1,008.7
Warrenton	9,611	4.50	2,135.8
West Point	3,306	5.05	654.7
White Stone	352	0.98	359.2
Windsor	2,626	4.01	654.9
Wise	3,286	3.05	1,077.4
Woodstock	5,097	3.91	1,303.6
Wytheville	8,211	14.49	566.7

APPENDIX E

COUNTING LOCATIONS OF INTEREST

Tables E1 through E3 use the following terms for Facility Type:

- Shared Road: road that does not currently have a bike lane but may have sharrows
- Shared Road With Sidewalk: road without a bike lane but with sidewalks or shared-use paths along the road
- Intersection: an intersection with or without pedestrian signals and crosswalks
- Paved Trail: hard-surfaced (typically asphalt) shared-use path
- Unpaved Trail: natural-surfaced shared-use path
- Park: park or recreation area (may or may not have trails)
- Bike Lane: road that has a designated bike lane
- Proposed Trail: indicated as potential future trail location.

Table E1. Specific Locations Suggested by Counties for Nonmotorized Counts

County	Location	Facility Type
Albemarle	Ivy Road (to city limits)	Shared Road
	Hydraulic Rd and Lambs Rd	Intersection
	5th St (to city limits)	Shared Road
	Avon St (to city limits)	Shared Road
Alleghany	Jackson River Scenic Trail	Unpaved Trail
	Douthat State Park	Park
	Route 220	Shared Road
	Route 18	Shared Road
	Route 311/159	Shared Road
Appomattox	Ferguson St	Shared Road With Sidewalk
	Heritage Trail	Paved Trail
	Confederate Blvd	Shared Road With Sidewalk
	Court St	Shared Road With Sidewalk
Arlington	Lee Hwy and N Lynn St	Intersection
Augusta	Route 636	Shared Road
Botetourt	Town Blvd and Marketplace Dr	Intersection
	Catawba Rd	Shared Road
	Roanoke Rd (Tinker Mountain Rd–Commons Pkwy)	Shared Road
	Ashley Way/International Parkway	Shared Road
Campbell	Broad St (Main St–3rd St)	Shared Road
	Route 24 (Route 460–Route 646)	Shared Road With Sidewalk
	Route 24 (Route 501N–Route 501S)	Shared Road With Sidewalk
	Route 24 (Route 615–Route 501N)	Shared Road With Sidewalk
Fauquier	Warrenton Branch Greenway	Paved Trail
	White’s Mill Greenway	Paved Trail
	Brookside Greenway	Paved Trail
Giles	Route 61 (Town of Narrows to Bland County Line)	Shared Road
	Lurich Rd	Shared Road
	Mill Creek Falls Recreation Area	Park/Unpaved Trail
Goochland	Route 6 (Route 522–Bulldog Way)	Shared Road
	Route 522 (Route 6–Fairground Rd)	Shared Road
	River Rd W (Courthouse Circle–Sandy Hook Rd)	Shared Road With Sidewalk
	Hockett Rd (Route 6–Route 250)	Shared Road
	W Creek Parkway (Route 6–Route 6)	Shared Road
	Route 6 (Henrico County–Hermitage Rd)	Shared Road
	River Rd (Henrico County–Route 6)	Shared Road
Grayson	Grayson Highlands State Park	Park
	New River Trail	Unpaved Trail
	USBR 76	Shared Road
	Independence Recreation Park	Park/Paved/Unpaved Trail
Henry	Jack Dalton Park	Paved Trail
	Collinsville Jaycee Park	Unpaved Trail
	Fieldale Heritage Trails	Unpaved Trail
	Dick and Willie Trail	Paved Trail
Isle of Wight	Main St (downtown to Westside Elementary School)	Shared Road With Sidewalk
	S. Church St (downtown to bypass)	Shared Road With Sidewalk
James City	Capital Trail	Paved Trail
	Freedom Park	Park/Unpaved Trail
	Greensprings Trail	Unpaved Trail
King and Queen	Route 721	Shared Road
	Route 14	Shared Road
	Route 33	Shared Road

Lancaster	Route 200 (Kilmarnock–Irvington)	Shared Road
Montgomery	Peppers Ferry Rd	Bike Lane With Sidewalk
	Union Valley and Route 8	Intersection
	Route 11	Shared Road
	Route 460 and Alleghany Spring Rd	Intersection
Northumberland	Route 360 (Callao–Lottsburg)	Shared Road
Prince George	Route 10 (Hopewell Line–Jordan Point Road)	Shared Road
Prince William	Silver Lake Park	Park/Unpaved Trail
	James Long Park	Park/Unpaved Trail
	234/Prince William Parkway Trails	Paved Trail
	Locust Shade Park	Park
	Lake Ridge Park	Park/Unpaved Trail
Richmond	Route 360 (Tappahannock to Warsaw)	Shared Road
Rockbridge	Brushy Hills Trail	Unpaved Trail
	Chessie Trail	Unpaved Trail
	Route 251	Shared Road
	Route 39	Shared Road
Rockingham	Port Hills Dr	Shared Road
	Will Springs Rd	Shared Road
	Spring Port Dr	Shared Road
	Rock Port Dr	Shared Road
	Stone Spring Rd	Shared Road
	Port Republic Rd (Route 11–Boyers Rd)	Shared Road With Sidewalk
Scott	Clinch River Highway (Highway 23–Manville Rd)	Shared Road
	3449 AP Carter Highway	Intersection
Spotsylvania	Southpoint Parkway	Shared Road With Sidewalk
	Jefferson Davis Highway (I-95–Route 17)	Shared Road
	Lafayette Blvd (Olde Greenwich Dr–Harrison Rd)	Shared Road
	VCR Trail	Paved Trail
	Route 1	Shared Road
	Route 17	Shared Road
	Route 3	Shared Road With Sidewalk
	Route 208	Shared Road
Westmoreland	Route 205	Shared Road
Wythe	Route 52 and Route 94	Intersection

Table E2. Specific Locations Suggested by Cities for Nonmotorized Counts

City	Location	Facility Type
Alexandria	Holmes Run Trail	Paved Trail
	King St (Tuckahoe St–Scroggins Rd)	Bike Lane
	Cameron St	Bike Lane
	Prince St	Bike Lane
Buena Vista	Riverwalk	Unpaved Trail
	Chessie Trail	Unpaved Trail
Charlottesville	Emmet St	Shared Road With Sidewalk
	W Main St	Bike Lane With Sidewalk
Chesapeake	Western Branch Trail	Unpaved Trail
	Dismal Swamp Canal Trail	Paved Trail
	Deep Creek Connector	Unpaved Trail
	Oak Grove Lake Park	Park/Unpaved Trail
Colonial Heights	Boulevard	Shared Road With Sidewalk
	CHARTS	Paved Trail
	Interstate 95/Temple Ave	Intersection
Franklin	General Thomas Highway	Shared Road
	Camp Parkway	Shared Road
	US 58 Southampton Parkway	Shared Road
	General Mahone Blvd	Shared Road
	Meherrin Rd	Shared Road
Fredericksburg	VCR Trail	Paved Trail
	Heritage Trail	Paved Trail
Galax	East Stuart Dr	Shared Road
	New River Trail	Paved Trail
Hampton	Coliseum Dr	Shared Road With Sidewalk
	Settlers Landing Rd	Shared Road With Sidewalk
	Fort Monroe Boardwalk	Park
	Buckroe Beach Boardwalk	Park
Harrisonburg	Bluestone Trail	Paved Trail
Lexington	Route 251 (Union Run–Mateer Rd)	Shared Road
Lynchburg	Rivermont Ave	Bike Lane With Sidewalk
	5th St	Shared Road With Sidewalk
	12th St	Bike Lane With Sidewalk
	Blackwater Trail	Paved Trail
Manassas	Godwin Dr (Wellington Rd–Sudley Rd)	Shared Road
	Winter Branch Trail (Hastings Dr–Wellington Rd)	Paved Trail
	Clover Hill Rd (Hastings Dr–Wellington Rd)	Shared Road With Sidewalk
	Hendley Dr (Hastings Dr–Wellington Rd)	Bike Lane With Sidewalk
	Main St (Prince William St–Wellington Rd)	Shared Road
Martinsville	Fayette St	Shared Road With Sidewalk
	220 Business and Fayette St	Intersection
	Market St and Commonwealth Blvd	Intersection
	Dick and Willie Trail	Paved Trail
	Mulberry Rd to Uptown	Shared Road With Sidewalk
	Uptown Connection Trail	Paved Trail
Newport News	Warwick Blvd (J. Clyde Morris Blvd–Nettles Dr)	Shared Road With Sidewalk
	Warwick Blvd (Main St–Center Ave)	Shared Road With Sidewalk
	Denbigh Blvd (Warwick Blvd–Oriana Rd)	Shared Road With Sidewalk
	Warwick Blvd (Bland Blvd–Denbigh Blvd)	Shared Road With Sidewalk
	Jefferson Ave (36th St to Cul-de-sac)	Shared Road With Sidewalk
	Jefferson Ave (Mercury Blvd–36th St)	Shared Road With Sidewalk
Norton	Flag Rock Recreation Area Trails	Paved/Unpaved Trail

Poquoson	Victory Blvd	Shared Road
	Wythe Creek Rd	Shared Road With Sidewalk
	South Lawson Park	Park
Portsmouth	Elm Ave (High St–County St)	Shared Road With Sidewalk
	Portsmouth Seaboard Coastline Trail	Paved Trail
	High St (Elm Ave–Effingham St)	Shared Road With Sidewalk
Richmond	Floyd Ave (Thompson–Laurel)	Shared Road With Sidewalk
	Franklin St (Belvidere St–9th St)	Shared Road With Sidewalk
Roanoke	Route 11	Shared Road With Sidewalk
	Lick Run Greenway	Paved Trail
	Memorial Ave and Roanoke Blvd	Intersection
	10th St and Shenandoah Ave	Intersection
	Colonial Ave and Overland Dr	Intersection
	Peters Creek Ext. and Shenandoah Ave	Intersection
	Gus Nicks Blvd and King St	Intersection
	Brandon Ave and Grandin Rd	Intersection
	13th St and Tayloe Ave	Intersection
	5th St and Luck Ave	Intersection
	13th St and Patterson Ave	Intersection
	10th St and Ferdinand Ave	Intersection
	Brandon Ave and Edgewood St	Intersection
	Campbell Ave and Williamson Rd	Intersection
	Columbia Ave and Plantation Rd	Intersection
	Brambleton Ave and Spring St	Intersection
	10th St and Lick Run Greenway	Intersection
	Brandon Ave and Franklin Rd	Intersection
	Jefferson St and Walnut Ave	Intersection
	Elm Ave and Franklin Rd	Intersection
	Garst Mill and Grandin Rd	Intersection
	Westside Rd and Melrose Ave	Intersection
	Ferdinand Ave and Elm Ave	Intersection
	Tinker Creek Greenway Trail	Unpaved Trail
Waynesboro	South River Greenway	Paved Trail
Williamsburg	Monticello Ave (Ironbound Rd to Richmond Rd)	Shared Road
	Longhill Rd (city limits to Ironbound Rd)	Bike Lane With Sidewalk
	Ironbound Rd (Depue Rd to Richmond Rd)	Shared Road With Sidewalk
	Jamestown Rd (Route 199 to Merchant’s Square)	Shared Road With Sidewalk
	Henry St (Route 199 to Lafayette St)	Shared Road With Sidewalk
	Francis St	Shared Road With Sidewalk
	Capital Landing Rd (DMV to Lafayette St)	Shared Road With Sidewalk
	Parkway Dr (2nd St to Bypass Rd)	Shared Road With Sidewalk
	Richmond Rd (Ironbound Rd to Merchant’s Square)	Shared Road With Sidewalk
	York/Lafayette St (city limits at York to Virginia Ave)	Shared Road With Sidewalk
Winchester	W. Jubal Early Dr at Valley Ave	Intersection
	Millwood Ave at University Dr	Intersection
	Lowry Dr at S. Pleasant Valley Rd	Intersection

Table E3. Specific Locations Suggested by Towns for Nonmotorized Counts

Town	Location	Facility Type
Amherst	Main St	Shared Road With Sidewalk
Appomattox	Route 24	Shared Road
	Court St	Shared Road With Sidewalk
	Church St	Shared Road With Sidewalk
	Confederate Blvd	Shared Road With Sidewalk
	Main St	Shared Road With Sidewalk
Blacksburg	Harding Ave	Shared Road
	Main St	Shared Road With Sidewalk
	Patrick Henry Dr	Shared Road With Sidewalk
	Clay St	Shared Road With Sidewalk
	Prices Fork Rd	Bike Lane With Sidewalk
	University City Blvd	Bike Lane With Sidewalk
	Glade Rd	Shared Road
	Huckleberry Trail	Paved Trail
Blackstone	Route 40 (Downtown–Fort Pickett)	Shared Road
Boones Mill	Main St	Shared Road
Bowling Green	Milford St	Shared Road With Sidewalk
	Maury Ave	Shared Road
	Main St	Shared Road With Sidewalk
	Chase St	Shared Road
Brookneal	Main St	Shared Road With Sidewalk
Cape Charles	Bay Ave Boardwalk	Shared Road With Sidewalk
	Washington Ave	Shared Road With Sidewalk
Chincoteague	Maddox Blvd (Route 175–Assateague)	Bike Lane/Paved Trail
Clarksville	Virginia Ave	Shared Road With Sidewalk
	College St	Shared Road With Sidewalk
	58 Business Bridge	Shared Road
	US 15	Shared Road
Colonial Beach	Monroe Bay Ave	Shared Road
	Irving Ave	Shared Road
Damascus	Shady Ave	Shared Road With Sidewalk
	Laurel Ave	Shared Road With Sidewalk
Dumfries	Tebbs Ln to Summer Duck Dr (along power lines)	Proposed Trail
	Quantico Creek (town limits to Possum Point Rd)	Proposed Trail
Edinburg	Stony Creek Blvd	Shared Road With Sidewalk
	Main St	Shared Road With Sidewalk
Floyd	Webbs Mill Rd (Parkview Rd–Locust St)	Shared Road With Sidewalk
	S Locust St (Parkway Ln S–Downtown)	Shared Road With Sidewalk
	E Main St (Commerce Center Dr–Downtown)	Shared Road With Sidewalk
	Baker St (High School–Locust St)	Shared Road
	E Main St and Barberry Rd to Blue Ridge Parkway	Shared Road
	Franklin Pike and Floyd Hwy N to Blue Ridge Parkway	Shared Road
Gordonsville	West Gordon Ave	Shared Road
	High St	Shared Road With Sidewalk
	Main St	Shared Road With Sidewalk
Halifax	Mountain Rd and US 501	Intersection
Hillsville	Main St (downtown)	Shared Road With Sidewalk
Independence	Bike/ped trail alongside US 58	Paved Trail
Irvington	Irvington Rd	Shared Road With Sidewalk
Kilmarnock	Route 3 and Route 200	Intersection
Lebanon	Main St	Shared Road With Sidewalk
Luray	Hawksbill Greenway	Paved Trail

Marion	Park Blvd (Hungry Mother State Park to downtown)	Bike Lane
Middleburg	Washington St	Shared Road With Sidewalk
	Marshall St	Shared Road
	Federal St	Shared Road With Sidewalk
Mount Jackson	Main St	Shared Road With Sidewalk
	Conicville Blvd	Shared Road
Narrows	Route 61 (town limits to Monroe St)	Shared Road With Sidewalk
	Lurich Rd to Princeton Ln	Shared Road
	Monroe St (Park Dr–Princeton Ln)	Shared Road With Sidewalk
	Main St	Shared Road With Sidewalk
New Market	Congress St	Shared Road With Sidewalk
	Click’s Ln	Shared Road
Richlands	Front St (Crosswalks)	Shared Road With Sidewalk
	Second St (Crosswalks)	Shared Road With Sidewalk
South Boston	Berry Hill Rd	Shared Road
	N Main St	Shared Road With Sidewalk
South Hill	Tobacco Heritage Trail	Paved/Unpaved Trail
Stanley	Park Rd	Shared Road
	Painter Dr	Shared Road
	Marksville Rd	Shared Road
Strasburg	River Walk (Strasburg Town Park–High School)	Unpaved Trail
Urbanna	Virginia St	Shared Road With Sidewalk
	Rappahannock Ave	Shared Road
	Cross St	Shared Road With Sidewalk
Vienna	W&OD Trail	Paved Trail
Vinton	Walnut Ave and 8th St	Intersection
	Lee Ave and S Pollard St	Intersection
	Gus Nicks Blvd/Washington Ave and Pollard St	Intersection
	Hardy Rd (Spruce St–Bypass Rd)	Shared Road With Sidewalk
	Washington Ave and Mountain View Rd	Intersection
	Wolf Creek Greenway	Unpaved Trail
Windsor	N Prince Blvd	Shared Road
	Shiloh Dr	Shared Road
Wise	Norton Rd	Shared Road With Sidewalk
	Main St	Shared Road With Sidewalk
	Park Ave	Shared Road With Sidewalk
	Lake St	Shared Road
Woodstock	Route 42 to Walmart	Shared Road With Sidewalk
	WO Riley Park	Park
	Court St and Main St	Intersection