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TDOT Bicycle & Pedestrian Counting: Best Methodologies Assessment

Authored by:

Nitesh Shah
Christopher Cherry
Candace Brakewood
Matthew Cate
Airton Kohls
Mareike Ortmann
Frank Proulx

Research Agency:

The University of Tennessee

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16. Abstract

Transportation agencies throughout the United States are systematically counting bicycles and pedestrians to plan, fund, and evaluate nonmotorized infrastructure. This project evaluated nonmotorized count methods and technologies and developed recommendations to integrate them into Tennessee's statewide count program. We first did a nationwide scan of best practices for bicycle and pedestrian count from leading transportation agencies on nonmotorized counts. Then, we developed a semi-structured questionnaire to interview representatives of Tennessee's transportation agencies to assess existing count efforts. We found most of the major count efforts in urban areas of Tennessee (Nashville, Memphis, and Knoxville) and by few transportation agencies at the north-east corner of the state. However, only a few count efforts are programmatic. Chattanooga is planning one while preparing this report. This report comprehensively describes the capabilities of count technologies and strategies, followed by methods to implement and interpret count data.

From this study, we recommend five goals that can guide TDOT's efforts to support improvements in non-motorized counts across the state.

Goal 1: Establish a routine pedestrian and bicyclist count data collection protocol.

Goal 2: Establish and implement a process for data to be consistently uploaded to a centralized database maintained by TDOT.

Goal 3: Develop analytical methods and processes for reporting performance measures.

Goal 4: Share data with stakeholders Goal 5: Institutionalize and build capacity for pedestrian and bicyclist monitoring within TDOT and across Tennessee This report also includes a companion document, the TDOT Bicycle and Pedestrian Count Program Guidance Manual that is an implementation guide to operationalize the findings in this report.			
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Executive Summary

What we did

This project assessed technologies and methods for a statewide bicyclist and pedestrian count program in Tennessee. While bicycling and walking are an essential component of the multimodal transportation system, the Tennessee Department of Transportation (TDOT) currently does not have a systematic count program. The count data is critical to plan, fund, and evaluate nonmotorized infrastructures. This report will guide TDOT and local transportation agencies to plan and implement a nonmotorized traffic count program at the state as well as the local level.

We started by a nationwide scan of best practices for bicycle and pedestrian count programs. Learning from the leading Departments of Transportation (DOT) nonmotorized count programs, we designed a semi-structured questionnaire to interview representatives of 19 transportation agencies in Tennessee to assess their existing count programs. We also evaluated existing, emerging, and prospective technologies and methods to count bicyclists and pedestrians. We developed recommendations for TDOT and local transportation agencies to plan and integrate a nonmotorized count program into their existing traffic count program.

This report is organized in the following chapters:

- **Chapter 1. National and statewide best practices:** a review of national bicycle and pedestrian data sources and best practices of nonmotorized count programs.
- **Chapter 2. Inventory of count programs in Tennessee:** assessing existing count programs of transportation agencies in Tennessee.
- **Chapter 3. Existing and emerging technologies and methods:** an overview of conventional and emerging approaches of counting bicycles and pedestrians.
- **Chapter 4. Prospective technologies and methods:** an overview of potential techniques that could be used to monitor bicycling and walking activities.
- **Chapter 5. Integrating technologies for count program:** approaches to combine different data sources.
- **Chapter 6. Recommendation:** recommendation to establish a statewide bicycle and pedestrian count program.
- **Appendix:** includes a list of the interviewees, interview questionnaire, count inventory and comparison of count technologies

This report also includes a companion document *TDOT Bicycle and Pedestrian Count Program Guidance Manual* targeted for TDOT and agencies within Tennessee for counting bicyclists and pedestrians.

What we found

The need to include bicycle and pedestrian counts in the existing statewide and local traffic count program is increasing in the United States. Although national programs, such as U.S. Census Journey-to-Work and National Household Travel Survey (NHTS), collect bicycling and walking information, these data sources are not detailed enough to evaluate robust statewide and local nonmotorized activities. Counting bicycles and pedestrians is different than counting motorized traffic. FHWA Traffic Monitoring Guide and NCHRP Report 797: Guidebook on Pedestrian and Bicycle Volume Data Collection are documentation that summarizes the best practice technologies and methods to count bicycles and pedestrians.

Bicycle and pedestrian count efforts were mostly found in the major cities of Tennessee (Nashville, Memphis, and Knoxville) as well as a few transportation agencies at the north-east side of the state. However, only few count efforts are active or regular at present. Chattanooga MPO is planning one while preparing this report. Although agency staff have desired to start, as well as, expand their bicycle and pedestrian count program, they mentioned inadequate financial and technical resources as one of the significant constraints.

Bicycles and pedestrians can be counted manually or using an automated counter. The cost of data acquisition for the nonmotorized count is high; therefore, agencies adopt a combination of permanent automated counters and routine short-duration counts. The adjustment factors can be used to expand the temporal and geographical coverage of the count program. Third-party probe data sources, such as Strava, are also emerging for monitoring bicycles and pedestrians. The data collection, management, and analysis processes of probe data are different than traditional methods. Calibration and validation of third-party data sources are essential as these data sources only represent a portion of travel activities.

There are several prospective and emergent technologies and methods to count bicycles and pedestrians. The prospective category includes techniques that can potentially be used to monitor nonmotorized activities, but they have not been implemented on a large scale so far. One such example is the use of current traffic signals with pedestrian actuation phase as a proxy of pedestrian volume. The technologies and methods in these emergent categories can potentially generate data on bicycling and walking activities, but the timeframe of its adoption is highly uncertain.

What we recommend

We recommend five goals that guide TDOT's efforts to define and build the program and will promote coordination between the Department and its partner agencies and organizations across the state.

- **Goal 1: Establish a routine pedestrian and bicyclist count data collection protocol**
  TDOT should identify factor groups, assign permanent count sites to appropriate factor groups, convert short-duration count sites with known travel patterns to permanent count sites, and identify Short Duration Count (SDC) locations where counts will be conducted regularly. In the long term, TDOT should add new permanent count sites as factoring groups are expanded or refined and implement and SDC equipment and locations.

- **Goal 2: Establish and implement a process for data to be consistently uploaded to a centralized database maintained by TDOT**
  TDOT should adopt a standard count data format (such as Travel Monitoring Analysis System (TMAS)), establish minimum data requirements, and implement quality controls for the statewide database. In the long term, TDOT should provide its partners with access that will allow them to upload counts directly to the database.

- **Goal 3: Develop analytical methods and processes for reporting performance measures**
  TDOT should develop volume performance measures and explore options to develop statewide performance functions (e.g., safety) for bicyclists and pedestrians.

- **Goal 4: Share data with stakeholders**
  TDOT should develop templates and standard count report formats, provide annual statewide summary reports, and provide a process to share raw data with partner agencies and stakeholders via an online data management system. In the long term, TDOT should develop an online interactive map to share data with stakeholders and the public.

- **Goal 5: Institutionalize and build capacity for pedestrian and bicyclist monitoring within TDOT and across Tennessee**
  TDOT should develop clear roles and responsibilities for the statewide count program, develop educational materials and training for partnering agencies, and provide funding for partner agencies to purchase a bicycle and pedestrian counter program. In the long term, TDOT should secure funding to maintain or expand the nonmotorized count program to meet the state's needs and integrate count data into planning and project development processes.

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Chapter 1: National and statewide best practices

The need for non-motorized count programs has been gaining momentum throughout the United States. Although some cities have established count programs to understand pedestrian and bicyclist movement, only a few states have an elaborate system of permanent and short duration counters to estimate non-motorized volumes. This, however, is changing with new studies and reports that provide insights into the pedestrian and bicycle count programs.

This section provides a literature review on existing count datasets; resources for the development of non-motorized count methods; equipment and technology in count programs; and lessons learned from the implementation of count programs.

1.1 Review of the existing national count data

As early as the 1970s, researchers and practitioners attempted to estimate pedestrian traffic by correlating the count of the pedestrian with street classification and land use. An early study by Pushkarev and Zupan (1971) related pedestrian density to walkway space and building flow over temporal space in midtown Manhattan.

However, the need to consider bicycle and pedestrian modes as an essential component of the multimodal transportation system has been growing since the introduction of the Intermodal Surface Transportation Efficiency Act (ISTEA) in 1991 (Jones et al., 2010; G. Lindsey, Nordback, & Figliozzi, 2014). Efforts have been taken to understand walking and bicycling behavior, collision rates, and risk exposure with the interest of building livable communities and streets, reducing congestions, creating an active lifestyle, and enhancing pedestrian and bicycle safety. These factors are considered in planning, funding, and evaluation of infrastructures related to non-motorized travel modes.

The bicycle and pedestrian count and survey information can be found in U.S Census Journey-to-Work, National Household Travel Survey (NHTS), and National Survey of Bicycle and Pedestrian Attitude and Behavior (NTHSA) on a national level (Jones et al., 2010). These nationwide data sets are described in more detail in the following paragraphs.

1.1.1 U.S. Census Journey-to-Work

The U.S. Census Journey-to-Work database records the geographic location of work (including work from home), when they start their trip, trip mode choice, trip duration, vehicle availability, and trip expense. The database has been used to estimate pedestrian volumes, although this survey only records the “usual” mode of the trip and does not include the walk component of the work trip, such as walk to and from the bus stop (Greene-Roesel, Diogenes, & Ragland, 2007).

1.1.2 National Household Travel Survey (NHTS)

NHTS is the primary national source of data on household-based travel behavior that includes demographic, economic, and cultural factors. This dataset is widely used by researchers and practitioners to understand how people travel. For example, Barnes and Krizek (2005) combined census and NTHS data to estimate bicycling in a different geographic stratum.

Despite many aspects of the trip being captured in the NHTS, this dataset can only be used at the national level (Greene-Roesel et al., 2007; Jones et al., 2010). Jones et al. (2010) argued that NHTS might under-represent or omit subgroups of the population due to underreporting and that it may have serious implications for small mode share population like bicycling.

Nevertheless, NHTS offers add-on features to the state and MPO to purchase additional samples in their region. This allows trip estimation at the lower level of geography, more precision, or opportunities to explore additional features by the addition of questions that are not part of the national sample (2017 NHTS Data User Guide 2018).

1.1.3 National Survey of Bicycle and Pedestrian Attitude and Behavior (NHTSA)

The scope and magnitude of bicycle and pedestrian activity, as well as the public's behavior and attitude regarding bicycling and walking, is documented in the NHTSA. This survey records the trips in aggregate level and compliments NHTS, however, this data cannot be used to predict future activities. Also, it only provides an overview of activities in the summer months (Jones et al., 2010).

Although there are consistent, nationwide data on walking and bicycling, regional data does not have the same consistency; the data collection at state, regional, and local level are generally tailored to the specific requirement of the community or project (Bicycle and pedestrian data: Sources, needs, & gaps, 2000; Greene-Roesel et al., 2007). To avoid the high cost of collecting data by the conventional survey, agencies apply innovative solutions, such as automated count technologies or integrating non-motorized counts with existing traffic data collection (Jones et al., 2010).

1.2 Guidelines and documentation on non-motorized counts

Counting methods and practices are evolving processes that are documented by several guidelines. They provide insights on the use of best practice methods and technologies, as well as its environmental and legal constraints.

1.2.1 National Bicycle and Pedestrian Documentation Project (NBPD)

In 2004, an effort to standardize the bicycle and pedestrian counts were started by Alta Planning and Design in collaboration with the Institute of Transportation Engineers (ITE) Pedestrian and Bicycle Council. Results from this work are documented at http://bikepeddocumentation.org. The website provides forms, instructions, and additional resources to conduct short-duration bicycle and pedestrian counts. The initial objective of NBPD was to develop a national database which could be used to generalize the estimation of daily, monthly, and annual non-motorized traffic volumes at different temporal and geographic space.

This initiative helped to raise awareness about the need for count programs, and its results kindled several count programs. However, the recommended methods have some drawbacks (G. Lindsey et al., 2014). For example, the non-motorized Annual Average Daily Traffic volume estimation from 2-h short-duration counts is prone to unacceptable high inaccuracy due to the high variability of pedestrians and bicyclists.

1.2.2 FHWA Traffic Monitoring Guide (TMG)

From the 2013 edition of the FHWA Traffic Monitoring Guide (TMG), Chapter 4 offers guidance to agencies on policies, standards, procedures, and technologies for non-motorized traffic volume monitoring. The best and most cost-efficient count methods are discussed with a recommendation to adopt a modest number of permanent counts and many short-duration counts. The objective of permanent counts is to capture the temporal variation, whereas short-duration counts cover the spatial variation of the monitored system.

Sarah Worth O'Brien, Warchol, and Stull (2016) summarized the guidance to establish a non-motorized traffic program from FHWA Traffic Monitoring Guide in Table 1.

Table 1: Summary to establish non-motorized traffic counts recommended by FHWA TMG

Continuous Data Management Program	**Short-Duration Data Program**
1. Review the existing continuous count program 2. Develop an inventory of available continuous count locations and equipment 3. Determine the traffic patterns to be monitored 4. Establish seasonal pattern groups 5. Determine the appropriate number of continuous count sites 6. Select specific count locations 7. Compute temporal factors	1. Select count locations 2. Select the type of count (segment and/or intersection) 3. Determine the duration of counts 4. Determine the method of counting (automated and/or manual) 5. Determine the frequency of short-term counts per location 6. Evaluate counts (accuracy characteristics, variability) 7. Apply factors (occlusion, time of day, the day of week, monthly, seasonal)

Source: Sarah Worth O'Brien et al. (2016)

The TMG acknowledges the differences and challenges of non-motorized traffic counts as compared to well-institutionalized motorized traffic counts (more in Section 1.4.1). The methodology and findings will be updated in the future version of TMG, incorporating state-of-art research in this field.

1.2.3 NCHRP Report 797: Guidebook on Pedestrian and Bicycle Volume Data Collection

This guidebook was published in 2014 to:

- offer guidance for establishing non-motorized count programs,
- provide suggestions on the selection of appropriate methods and technologies,
- summarize best practices for the institutionalization of data management and sharing standards, and
- help users analyze count data.

NCHRP Report 797 focuses on automated count technologies (Figure 1), providing a thorough evaluation of the performance of those technologies and their suitability for the data collection need of a count program. It also includes ten real-world case studies that provide insights into the application of non-motorized counts.

NCHRP Report 797 serves as the comprehensive resource for the pedestrian and bicycle count that “complements the FHWA guide” (Ryus et al., 2014b). However, this guide does not cover trip sampling techniques to estimate the non-motorized volumes using technologies such as Bluetooth and Wi-Fi detection, Global Positioning System (GPS) data collection, Radio Frequency ID Tags, bike sharing data, pedestrian signal actuation buttons, estimation by conventional surveys, presence detection, trip generations method, and other methods.

Figure 1: Automated non-motorized traffic count framework (Adopted from NCHPR Report 979

1.2.4 NCHRP Web-Only Document 205: Methods and Technologies for Pedestrian and Bicycle Volume Data Collection

This report describes the research approach for the preparation of NCHRP Report 797 (Ryus et al., 2014a). It tested and evaluated six automated count technologies (passive infrared, active infrared, bicycle-specific pneumatic tubes, induction loops, piezoelectric strips, a radio beam, and combinations of these) under different environmental and traffic conditions and on various facilities types. Each technology was tested for count accuracy and reliability. In addition to the accuracy and reliability of these technologies, the study included other metrics, such as ease of implementation, labor requirement, security, maintenance, software, cost, and ease of data transmission.

This research found that these technologies are sensitive to the given site conditions. As a result, the same degree of accuracy should not be assumed for a specific technology at other locations or with other products. Thus, it recommends calibration of the automated count technologies on a smaller scale at the installed location.

1.3 Demand models for non-motorized travel

Demand models can be used as an analytical approach to estimate the bicycling and pedestrian volumes at the local level of community, project, and facilities, as well as evaluate and prioritize projects. For instance, direct demand estimation is based on the variation of regression models that explains “demand levels as recorded in counts as a function of measured characteristics of the adjacent environment” (Kuzmyak, Walters, Bradley, & Kockelman, 2014).

Although factors influencing walk or bicycle mode choice are not usually included in the four-step process, methodologies for incorporating it into regional four-step demand models are available (Jones et al., 2010). Demand model methods are summarized in Table 2.

Table 2: Methods for Modelling Non-Motorized Travel Demand

Purpose/Method	**Description**
Demand Estimation	Methods that can be used to derive quantitative estimates of demand
Comparison Studies	Methods that predict non-motorized travel on a facility by comparing it to usage and to the surrounding population and land-use characteristics
Aggregate Behavior Studies	Methods that relate non-motorized travel to the area’s local population, land use, and other characteristics, usually through regression analysis.
Sketch Plan Methods	Methods that predict non-motorized travel on a facility or in an area based on simple calculations and rules of thumb about trip lengths, mode shares, and other aspects of travel behavior.
Discrete Choice Models	Models that predict an individual’s travel decisions based on characteristics of the alternatives available to them
Regional Travel Models	Models that predict total trips by trip purpose, mode, and origin/destination, and distribute these trips using a gravity (time/distance) formula across a network of transportation facilities, based on land-use characteristics such as population and employment and characteristics of the transportation network

Sources: (Federal Highway Administration, 1999; Schwartz et al., 1999)

Demand models have been used to predict non-motorized volumes from spatially varying explanatory variables such as census population, employment characteristics, land use and topography, and transportation network characteristics (Turner et al., 2018). However, their predictions are limited, and existing models typically do not include all of these major variables (Nordback & Sellinger, 2014). Furthermore, these models tend to be location specific and often cannot be applied to other geographic locations.

FHWA has sponsored a Non-Motorized Travel Analysis Toolkit to estimate pedestrian and bicycle volumes (http://nmtk.pedbikeinfo.org/ui/#/). This toolkit has been used as a primary tool to measure bicycle and pedestrian exposure for safety analysis (Turner et al., 2018). The advantages and disadvantages of such a direct demand model are summarized in Table 3.

Table 3: Advantages and Disadvantages of Direct Demand Models

Advantages	Disadvantages
• Software requirements are usually limited to spreadsheets or standard statistical software packages. • It can be mainly created using existing data. • Most necessary data is typically publicly available and can be found at a variety of geographic levels. • Network connectivity can be estimated but requires additional time/ resources to quantify.	• They do not take into account individual trip choices and factors. • Activity level (count) data is costly to collect, depending on the geographic scale. • They may inaccurately correlate activity levels with adjacent land uses. • The validity between datasets may not be satisfactory. • Datasets typically used (i.e., U.S Census Data) are not frequently updated.

Source: (Turner et al., 2018)

There are several guidelines on-demand models that have been developed to estimate the non-motorized traffic. Some of them are summarized below.

1.3.1 NCHRP Report 770: Estimating Bicycling and Walking for Planning and Project Development

Estimating Bicycling and Walking for Planning and Project Development aims to understand better non-motorized activities and its relationship to demographic, social, and physical factors. The audience of this guidebook is not only focused on the bicycle and pedestrian planning community but also on land use and transportation planning, transit, policy evaluation, and project prioritization groups (Kuzmyak et al., 2014).

It provides methods and tools to estimate bicycling and pedestrian demand as part of the regional, corridor, or project level analysis considering key planning factors such as bicycle and pedestrian infrastructure, land use and urban design, topography, and sociodemographic characteristics. New and existing methods are applied to understand complex decisions with multiple factors and tradeoffs for robust estimation of bicycling and walking activities. Also, base data are provided in the spreadsheet for testing of assumptions made by the user.

1.3.2 NCHRP 07-14: Guidelines for Analysis of Investments in Bicycle Facilities

This guideline is developed to assist planners and decision-makers in utilizing limited funds best to provide more transportation choices to travelers. Among the various aspect associated with bicycle facilities, the authors have explored new perspectives as well as original research for measuring and forecasting bicycling demand (Krizek, 2006).

The report explores a practical approach for demand analysis, considering the limited availability of resources and data. A simple sketch planning model is developed to estimate demand in local areas. Also, a report includes detailed information on modeling techniques, evaluate results, and explore the limitations of traditional demand models.

1.4 Establishing a non-motorized count program

Most transportation agencies have well-developed vehicular count methodologies for a wide range of road classifications, traffic patterns, and other variations in traffic flow. Factors have been developed for assessing daily, seasonal, and annual trends using historical data. These factors are applied to expand short-term counts based on count location, traffic flow characteristics, time and duration of the count, and so on.

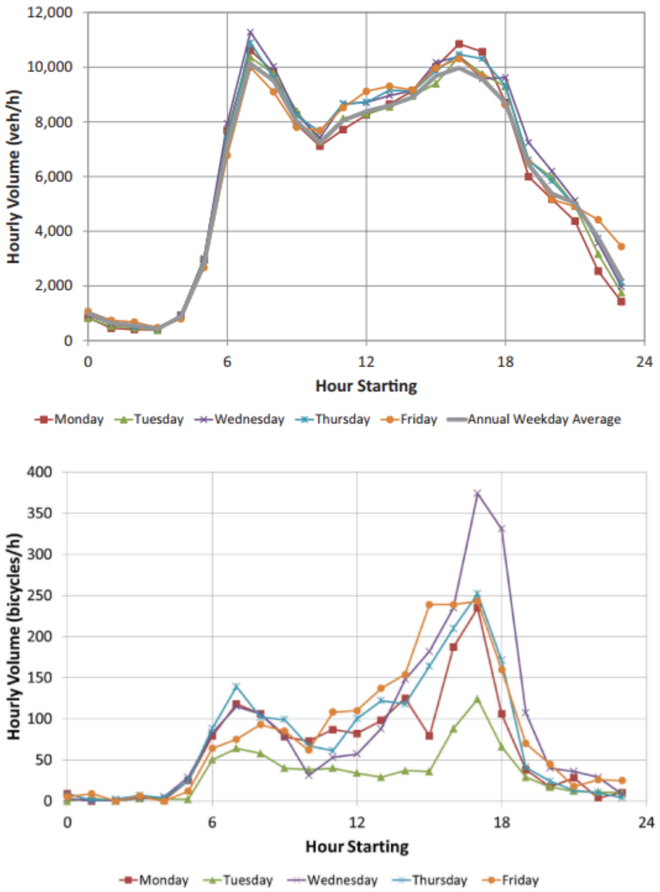
1.4.1 The difference in motorized and non-motorized traffic count

Ideally, a similar methodology could be applied to count bicycle and pedestrian volume. However, some unique challenges make this technique complicated for non-motorized counts. Ryus et al. (2014b) summarized the difference between motorized and non-motorized traffic counts, as described below.

1.4.1.1 The difference in demand variability

Bicycle and pedestrian volumes are highly sensitive to environmental conditions, such as precipitation, temperature, time of day, and so on, as compared to vehicular volume. These key characteristics make the traffic flow pattern of bicycle and pedestrian highly variable based on time of day, day of the week, and season.

For example, a study compared the observed hourly bicycle volumes on a multi-use path in Minneapolis with the observed hourly motorized volume on a parallel freeway nearby for one week in October 2013 (Figure 2) (Ryus et al., 2014b). The authors found that automobile traffic patterns were similar throughout the weekday, with only 5% variability from the lowest to highest volume day. The bicycle, on the other hand, had 200% variability in the PM peak hours. It should be noted that the rainfall in the study area was about 1 inch on Tuesday, 0.5 inches on Monday and Thursday, 0.1 inches on Friday, and 0.01 inch on Wednesday.



Sources: Auto: Minnesota DOT automatic traffic recorder #326 (I-394);
Bicycle: NCHRP Project 07-19 testing, Midtown Greenway.

Figure 2: Comparative variability of the automobile and bicycle volumes (Adapted from Ryus et al. (2014b))

Also, a relatively low hourly pedestrian and bicyclist volume at the count site makes the day-to-day traffic variability much higher for non-motorized traffic than motorized traffic. Consequently, it is hard to identify *when* to do a short-duration count during the “peak,” and it can lead to high amounts of error in annualized volumes.

1.4.1.2 Ease of detection

Detecting pedestrian and bicyclist movement is more challenging than detecting motor vehicle movement. Since pedestrians and bicyclists can travel on paths other than walkways and bikeways, stop at unexpected locations, and move in somewhat irregular patterns, count technologies cannot always detect them accurately (Ryus et al., 2014b). Also, group movement of non-motorized travelers can complicate the detection task of pedestrians and bicyclists.

1.4.1.3 Experience with counting technology

Count technologies used for motorized volume counts are well-established, whereas several technologies for pedestrian and bicyclist counting have emerged in the past few years. However, technologies that are commonly used to count both motorized and non-motorized counts (e.g., pneumatic tubes, inductive loops) have disparate errors during application at different settings (Ryus et al., 2014b).

1.4.2 Application of non-motorized count programs

An elaborate pedestrian and bicyclist count program can be a significant investment with a considerable proportion of the transportation budget. Therefore, the collected data should worth the investment and be appropriate for the context in which it is used. Ryus et al. (2014b) surveyed to rank the common application of non-motorized data in the United States and Canada. The prioritized applications found by authors are listed below:

1. Evaluating usage of pedestrian and bicycle activities over time,
2. Measuring impacts of new infrastructure on walking and bicycling,
3. Evaluating the priority of pedestrian and bicycle project,
4. Modeling the transportation network and estimating annual volumes, and
5. Performing risk or exposure analysis.

1.4.3 Factors affecting walking and bicycling

Studies have found that time of year, weather, and land use factors are influential for walking and bicycling activities. Understanding these influences enables the creation of sampling frameworks to estimate these activity volumes (Nordback, Sellinger, & Phillips, 2017), the development of expansion factors for short counts, and comparative analysis across facilities (Miranda-Moreno, Nosal, Schneider, & Proulx, 2013).

1.4.3.1 Trip purpose and time variability

In general, bicycle trips can be classified into utilitarian (for means of transportation) and recreational (leisure, fitness, etc.) trip purposes. Miranda-Moreno et al. (2013) analyzed the bicycle trip patterns of 38 locations in five North American cities to study the bicycle volume profile by facility location (Figure 3). The authors, however, argued that the bifurcated classification of utilitarian and recreational trips is overly simplistic, as they observed users with mixed trip purpose independent of facility design.

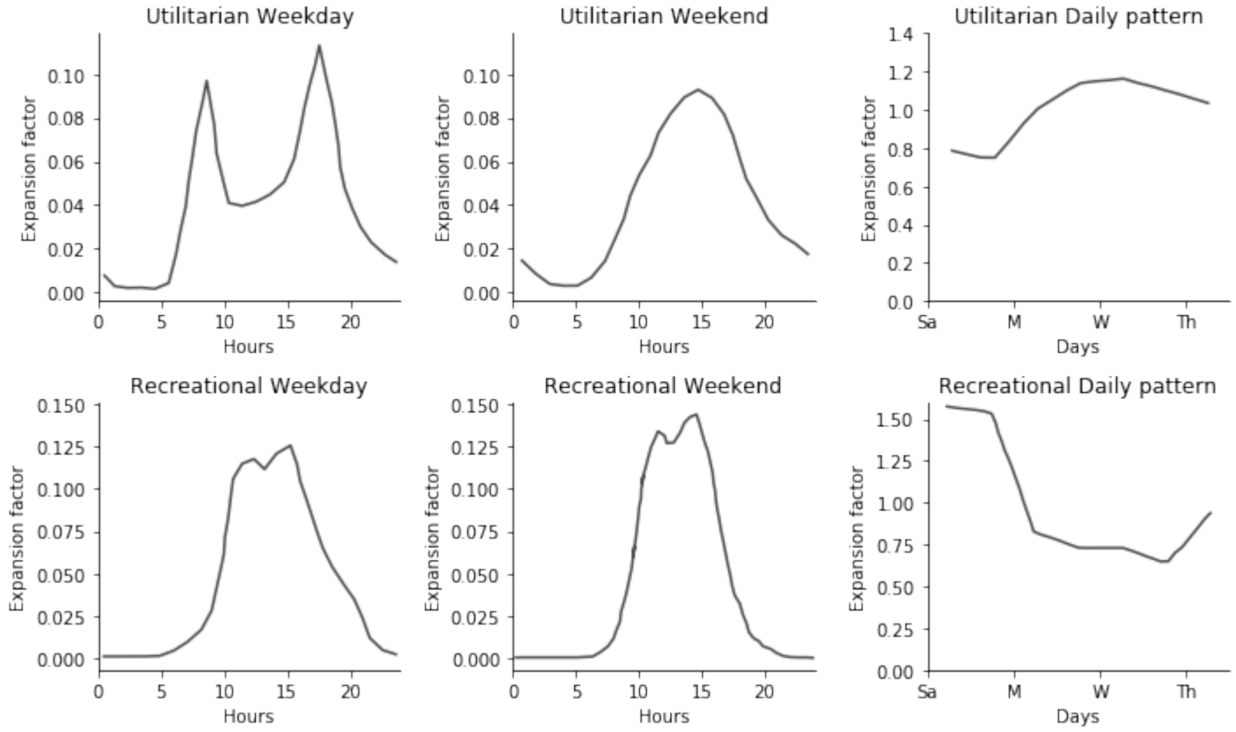


Figure 3: Bicycle volume profile at utilitarian and recreational locations (Source: Miranda-Moreno et al. (2013))

As can be seen in Figure 3: Bicycle volume profile at utilitarian and recreational locations (Source: Miranda-Moreno et al. (2013)), the utilitarian location has two distinct weekday peaks like automobile commuter peaks and has higher volume during weekdays than on weekends. The weekend profile, on the other hand, has a single smooth evening peak. The recreational location, however, has a higher volume during the weekend than weekdays; this peak has steep peaks with a plateau at midday.

1.4.3.2 Spatial variability

Several studies have found a significant correlation between walking and bicycling and spatial factors. In a detailed literature review, Pratt (2012) explores the travel response of non-motorized infrastructure for both isolated and complete urban settings. Nordback, Sellinger, et al. (2017) found that there are some common variables for both pedestrian and bicyclist volumes, such as employment density, population, and proximity to an economic attraction point (such as downtown). Variables associated with facility type and connectivity of roads influence pedestrians, whereas geometric features of roads influence bicyclists.

In addition to these variables, other factors such as climate and topography also influence walking and bicycling activities on the state level. An extensive literature review of the impact of weather on non-motorized travel is done by Böcker, Dijst, and Prillwitz (2013). Rodríguez and Joo (2004) found that the likelihood of bicycling is more sensitive to an increase in sloping terrain than walking. Nordback, Sellinger, et al. (2017) claimed that both geography and climate tend to impact walking less than bicycling.

1.5 Planning a count program

Colorado Department of Transportation (CDOT) classifies non-motorized count programs into four distinct program phases (Colorado DOT, 2016); these are shown in Table 4 below and is supplemented by a map in Figure 4 below. The authors noted that the fully institutionalized program of stage is an "aspirational stage" for now, without any clear example in the U.S. Furthermore, CDOT emphasized that it is not possible to leapfrog from basic program stage to the fully institutionalized program stage, as the lessons learned from systematic program stage are key to formulate the goals for fully institutionalized program stage.

Table 4: Non-motorized count program phases classified by CDOT

Stages	Experimentation	Basic program	Systematic program	Fully institutionalized program
Objective	Understand pedestrian and bicycle volume in a location or series of locations	Consistent routine data collection with fundamental analysis	High-quality data collection and analytics	High quality and reliable data for extrapolation of pedestrian and bicycle volume throughout the network
Resources	Short manual counts or portable counters	One person dedicated for counts or sharing responsibilities with several staffs	Strategic resource mobilization	Dedicated resources for the count program
Program sustainability	None	Low	Strong	High
Examples	Texas, Ohio, Michigan, Florida, Louisiana, Virginia, Vermont, New Hampshire, Washington, Oregon, Idaho, and Utah	Colorado, North Carolina, Minnesota DOT	Boulder, CO; Seattle, WA; Delaware DOT; Arlington County, VA	None

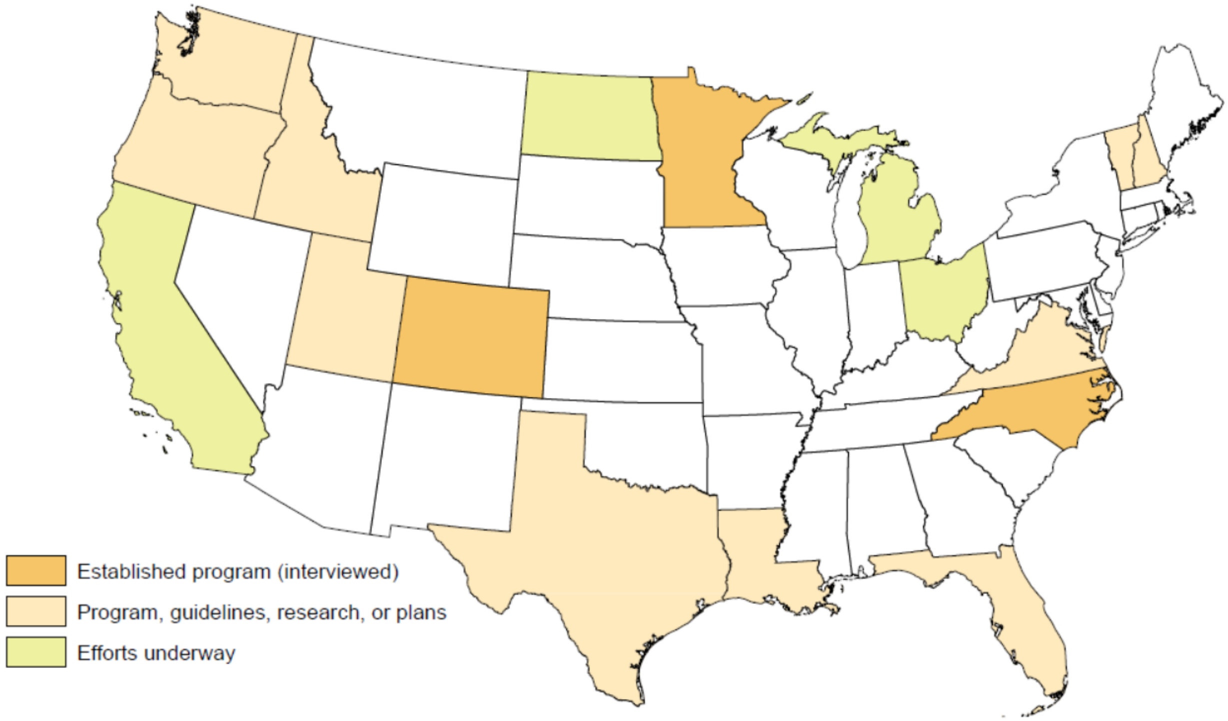


Figure 4: Status of nonnotarized traffic monitoring program by states (Source: Ohlms, Dougald, and MacKnight (2018))

Ohlms et al. (2018) interviewed representatives of count programs at Colorado, Minnesota, and North Carolina Department of Transportation to summarize their count programs, including challenges and lessons learned. The authors found that non-motorized data collection is a quickly evolving field, and none of the states have a complete picture of bicycle and pedestrian travel. At best, agencies use a combination of travel survey data, short- and long-term samples of count data, and travel models to estimate non-motorized volumes. For scaling short counts to annual volumes, the authors found that the adjustment factors derived for a local environment cannot be applied statewide, and data quality control can be demanding.

Ideally, permanent counters throughout the network are desired to monitor pedestrian and bicycle volume. This, however, is constrained by resource limitations. Alternatively, a robust and cost-effective count program can be implemented by a combination of travel survey data, short-term and long-term sample-based count data, and travel models.

In a recent publication on the feasibility of the pedestrian and bicycle count program in Virginia, Ohlms et al. (2018) showed that the following aspects are essential for count programs:

1. *Program design*: implementing a small-scale pilot on initial stage based on a broader vision of non-motorized travel monitoring program with considerations of technical and financial capabilities of a state as well as local agencies
2. *Outreach to localities*: understanding the existing capabilities of local agencies for bicycle and pedestrian counts and implementing technology transfer and training on a topic related to non-motorized counts

3. *Data use:* consideration of how collected data can be used and structuring the pilot program accordingly
4. *Site selection*: count location selection of pilot program by balancing the state agency's policy goal (e.g., developing statewide monitoring vs. supporting local project-related decisions)
5. *Data collection techniques*: identify the most appropriate technologies that are cost-effective and would facilitate a statewide data repository like TMG format for federal TMAS database
6. *Data storage*: establish a database that would allow a robust state-level data of non-motorized counts
7. *Data quality control*: apply a combination of automated and manual review to verify the reliability of counts
8. *Program administration*: create a mechanism to oversee the statewide count program

Ryus et al. (2014b) outlined the planning of a count program into four steps:

1. Specifying the general data collection purpose,
2. Identifying data collection resources,
3. Selecting count locations and determining the count timeframe, and
4. Considering available counting methods and technologies.

Although the steps are presented in a specific order, the authors asserted that they are often iterative. For instance, agencies might have to reconsider the resources required for the count program after realizing the need for an additional count location. Furthermore, an organization planning a count program for the first time should expect their program to be modified in the future.

1.6 Archiving and sharing count data

A robust bicycle and pedestrian count program offers several advantages: for example, it allows for data-driven planning, and it provides support for funding decisions. Additionally, an accessible database can also encourage innovation through research, design, and planning. However, a centralized data archive is often lacking in non-motorized traffic count programs. This may often lead to unutilized data and even misplaced or lost data. Huff and Brozen (2014) summarized the challenges of creating a centralized bicycle database as follows:

1. Standardizing historical data (as older count data may not have been collected in the same way or may not be strictly comparable for other reasons),
2. Recommending a standard data collection protocol that can be implemented by diverse authority, and
3. Creating a user-friendly process for new data collection.

At present, several publicly available archives are managed by local or regional agencies. However, a public online database of state-level pedestrian counts is not available (Nordback et al., 2015). FHWA is initiating a national level database with standardization of all the counts throughout the nation. FHWA's Traffic Monitoring Guide (TMG) has included instructions on coding and entering count data in TMG format to update a Travel Monitoring Analysis System (TMAS) for long-term data storage and processing. This will enable the sharing and collaboration of datasets from statewide sources ranging from federal to local authorities (G. Griffin, Nordback, Götschi, Stolz, & Kothuri, 2014). Although each state could maintain its statewide database using TMAS, integrating data from vendors using multiple technologies would be one of the challenges (Ohlms et al., 2018).

Also, Nordback et al. (2015) at Portland State University developed the first national, open-source online bicycle, and pedestrian count archive (http://bikeped.trec.pdx.edu/bp/). The main features of this archive are online data upload, data quality evaluation, and data visualization. The archive also provides an option to download user-specified data as well as share data with other archives and applications.

Chapter 2: Inventory of count programs in Tennessee

Although Tennessee does not have a state-wide bicycle and pedestrian count program, there have been some efforts to count non-motorized modes on an agency level. Interviews were conducted with MPO, RPO, city, and non-profit organization representatives about their bicycle and pedestrian counting efforts. This chapter summarizes the findings of these interviews.

2.1 Interview design

The main objective of the interviews was to understand the bicycle and pedestrian count program of the agencies/organizations, their experiences, and their needs for such counts. The research team designed a semi-formal interview process to fulfill this objective and gather an inventory of the count programs throughout Tennessee.

The team prepared a list of prospective interviewees that would include all the MPO, RPO, City, and non-profit organizations promoting bicycling and walking in Tennessee. This list was forwarded to TDOT representatives for feedback, and the list of potential interviewees was revised. There were 23 contacts in the final list of interviewees. Then, a questionnaire was developed to guide the discussion of the interview. These questions can be broadly classified into the following three groups:

1. General background about the count program;
2. Bicycle and pedestrian count requirements; and
3. Interest in state-wide bike-ped count program.

All of the prospective interviewees (Attached in Appendix B) were sent an email that included a brief introduction, a summary of the scope of the research project, the interview questionnaire, and a link to schedule a 30-minute virtual meeting. The questionnaire is available in Appendix A. If more than one person were identified in an administrative division, the research team sent an email to all of them and scheduled meetings with the most appropriate person based on their responses.

The first round of interviews was conducted using the online Zoom platform or via telephone in April of 2019, in coordination with the interviewees. A few of the interviewees emailed their responses to the questionnaire in a comprehensive format so that a virtual meeting was no longer required. Representatives from four agencies did not reply to the email. Thus, the research team conducted 16 interviews, and another three representatives replied to the interview questions by email. The second round of follow-up interviews was done in August 2020, focusing on count programs of Nashville, Memphis, Knoxville, and Chattanooga. A count inventory for these four major cities in Tennessee is provided in Appendix C.

2.2 Interview Findings

This section summarizes the findings of the interviews. The following quotation from one interview respondent provides a good summary, as follows:

> *"There has been a culture change as far as bicycle is going… [from my 25 years of experience working with MPO] there was a big push back [for bicycling infrastructure investment] in the 90s… it angered a lot of people and the first response by the city leaders was why are we spending this money and nobody is using these facilities. That has kind of changed over the years to where we understand that there is a need [for bicycle infrastructures] and we are seeing people use them"– interview respondent*

2.2.1 Overview of bicycle and pedestrian count efforts in Tennessee

Figure 5 summarizes the bicycle and pedestrian count efforts for the past five years in Tennessee. We found that most of the count efforts were in major cities (Nashville, Memphis, and Knoxville) and by a few transportation agencies at the north-east side of the state. However, very few of the count efforts are active or regular at present. Based on the interviews in August 2020, Knoxville Regional Planning Organization did not have any active count efforts, and the City of Memphis had few active count locations. Walk Bike Nashville was planning to use Streetlight data to evaluate bicycling activity in a few locations. Chattanooga TPO did not have an active count program when drafting the report but is planning to start one in September 2020. It should be noted that bicycle and pedestrian count efforts could also be affected by the coronavirus disease (COVID-19). Moreover, very few urban areas have taken a programmatic approach to their count efforts.

A detailed inventory of count efforts at Nashville, Memphis, Knoxville, and Chattanooga can be found in Appendix C. The inventory is organized by cities and includes details of count effort in previous years (from 2014 until April 2019), the most recent year (May 2019 to July 2020), and future plans (after August 2020).

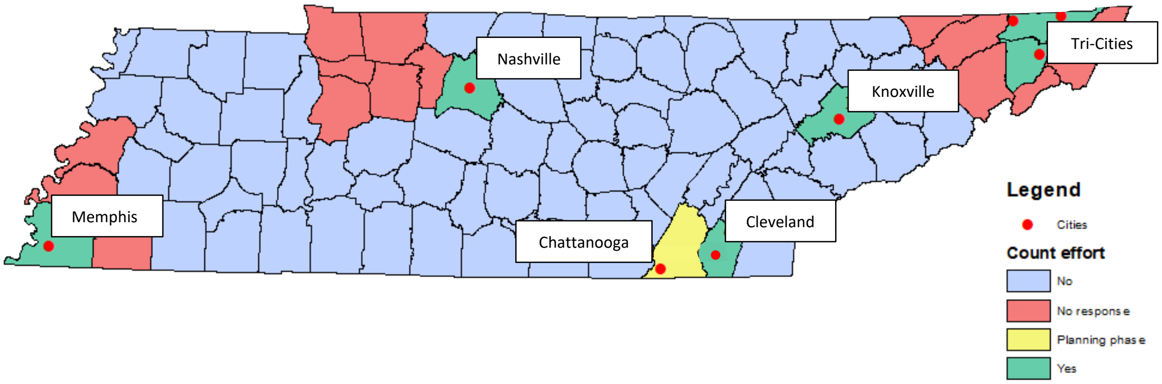


Figure 5: Bicycle and pedestrian count efforts in Tennessee during the last five years (Note: the map shows county boundaries)

2.2.1.1 Purpose of data collection in existing count programs

The primary reason for counting bicycles and pedestrians in the major cities were as follows:

- Gather trends of bicycling and pedestrian activities over time,
- Data collection based on project needs,
- Evaluate the use of non-motorized facilities, and
- Count bicycles and pedestrians for advocacy purposes.

Whereas in the remaining (small city and rural) locations, count programs were mostly done for funding purposes and to estimate bicycling and walking activities in hiking trails. Some agencies wanted to use the data for multimodal transportation planning as well as tourism infrastructure planning.

2.2.1.2 Count duration, location, and methods

Most of the count efforts in Tennessee were for a short duration, although few agencies installed permanent counters for a longer duration. The count duration depended on the local resources and the purposes of counts. The periodic counts were typically done when there is a high volume of bicycling and walking activities in warmer weather. Memphis MPO, for instance, used permanent counters for seven days to collect bicycling volume in 2017, while agencies in Knox and Blount counties conducted 2-hour counts at intersections in the fall and spring seasons.

The major cities of Tennessee (Nashville, Memphis, and Knoxville) had higher numbers of count locations than the smaller MPOs. For example, Memphis and Nashville had more than 20 count locations. Bicycle and pedestrian counts in cities were primarily performed in the urban core and where there are non-motorized activities like shared-use paths and greenways. Counts were also done on trails that are popular for hiking and mountain biking. These locations were selected based on the judgment of agency staff members.

Agencies’ counting strategies vary based on the type of technology that they have available to them, which, in turn, impacts the count duration and location. Agencies in cities used various counting devices like pneumatic counters, infrared counters, video, and others. For example, Figure 6 presents the use of a combination of a pneumatic tube and an infrared sensor to count bicycles and pedestrians by the Memphis MPO. Most of the agencies used mobile counters or manual counting methods for periodic counts. However, validation of counters was done only in a few cases, and some of the agency staff expressed concerns about the accuracy of their count efforts. Agencies who used volunteers for short duration counts in the past reported challenges for mobilizing new volunteers. While most of the count programs described here are overseen by agency staff, a few agencies like the City of Memphis had used a private consultant to perform counts.

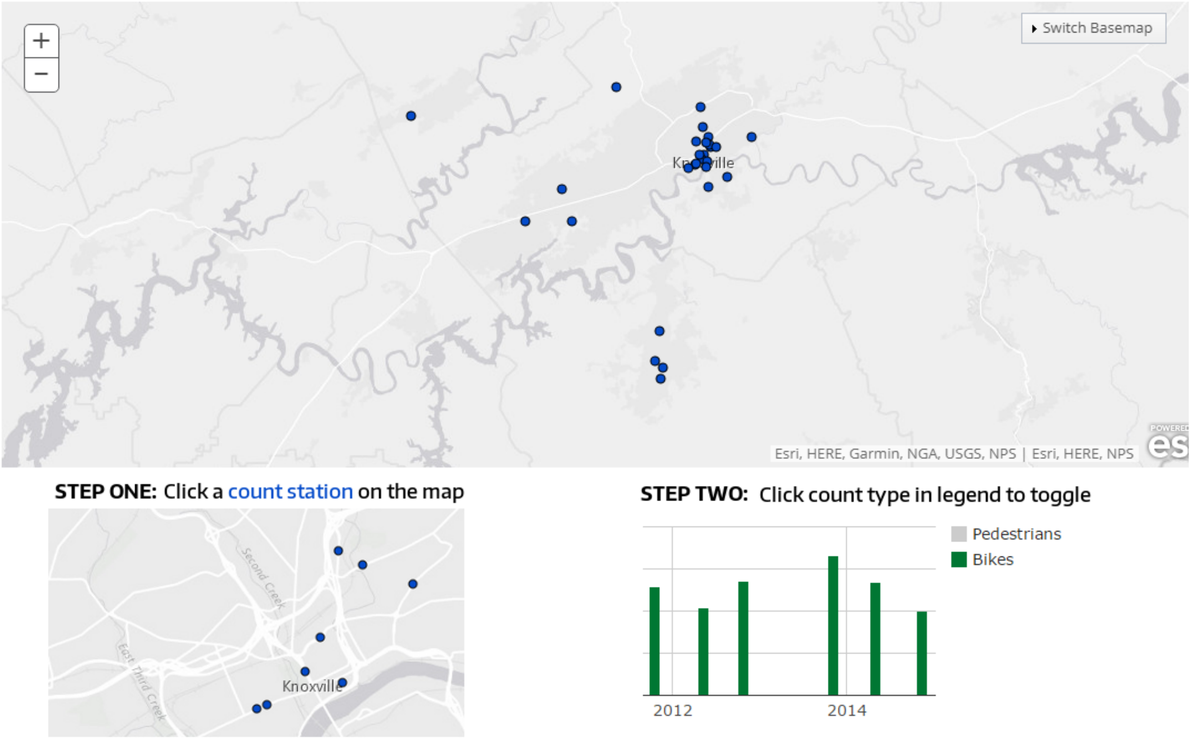
Figure 6: Pneumatic tube and passive infrared counter at Main and Adams, Memphis

Agencies, especially in Tennessee's major cities, were exploring emerging technologies to estimate bicycle and pedestrian volumes. For instance, Chattanooga was considering automated video collection technologies as a primary method and third-party data sources (like Strava, Streetlight, Remix, and such) as secondary methods. Some agencies, like the City of Nashville, were also considering new mobility modes such as e-scooters within the scope of the count program. A few of the agencies used national-level data like the US Census Journey-to-work, NHTS, and National Survey of Bicycle and Pedestrian Attitude and Behavior; however, they had concerns about the accuracy and precision of that data.

2.2.1.3 Data storage and its use

Most agencies used Excel to store and manage their bicycle and pedestrian count data, while Knoxville has a web-based GIS platform. The web-based visualization dashboard of Knoxville is presented in Figure 7. Some agencies also used vendor dashboards, such as Eco-counter's dashboard, to extract and visualize the data.

None of the agencies adjust their SDCs based on permanent counts to estimate the average annual pedestrian and bicyclist volume (a process called "annualization"). Most agencies generate simple descriptive statistics on raw, unadjusted/unannualized data. Results of analyzing count data are used in reports and planning-level reports.



STEP ONE: Click a count station on the map

STEP TWO: Click count type in legend to toggle

Figure 7: Web-based platform of bike-ped count program in Knoxville

2.2.2 Reasons not to have a non-motorized count program

The primary reason for not performing bicycle and pedestrian counts by the agencies who do not have any non-motorized count programs are:

- Lack of funding,
- Insufficient staff resources,
- Inadequate technical and technological knowledge for a count program, and
- Lack of interest from agencies for such count programs where there are low bike-ped activities.

Agencies conducting some non-motorized counts mentioned the following reasons for not having more elaborate count programs:

- Insufficient financial and human resources,
- Inadequate technical knowledge about count technologies and methods, and
- Intra-jurisdiction complexity for a convenient count program.

2.2.3 Prospective count program requirements

When agency representatives were asked about prospective non-motorized count requirements, they mentioned the following locations to focus on:

- Locations that have a high bicycle/pedestrian crash and fatality rate,
- Along the corridor with existing or planned non-motorized infrastructure, and
- Urban space, as well as trails that have high bicycling and walking activities.

2.2.4 Agencies' expected support from TDOT

All of the interviewees responded that they need some form of support from TDOT. RPOs, who were interested in nonmotorized count programs, responded that they need both financial and technical support. Some of the transportation agencies said that they generally want technical assistance on bicycle and pedestrian count efforts. Agencies in the major cities had some technical expertise for count efforts and programs and better financial capabilities. The most frequent expectations of agencies in major cities from TDOT are as follows:

- Support for best practices of bicycle and pedestrian count methods,
- A robust system with an institutionalized data repository similar to vehicular counts, and
- Regional collaboration to understand what other agencies are doing.

2.3 Scan of non-motorized activities

While it is relatively easy to locate motorized traffic activities because of proper monitoring and database infrastructure, the spatial distribution of bike and pedestrian activity is often not measured with good accuracy and precision. Emerging third-party data sources can provide the basic spatial distribution of bicycling and walking activities. However, these data should be interpreted with caution as they are likely to be biased for specific demographics and contexts. In particular, data from Strava tends to focus on physically active population groups who frequently go mountain biking and hiking outside the city area.

A visualization of bicycling and walking activities throughout Tennessee from Strava is shown in Figure 8 and Figure 9, respectively. In the figures, red represents segments with high use, while blue represents lower use. Walking activities are clusters around cities, while bicycling have larger geographical coverage than walking.

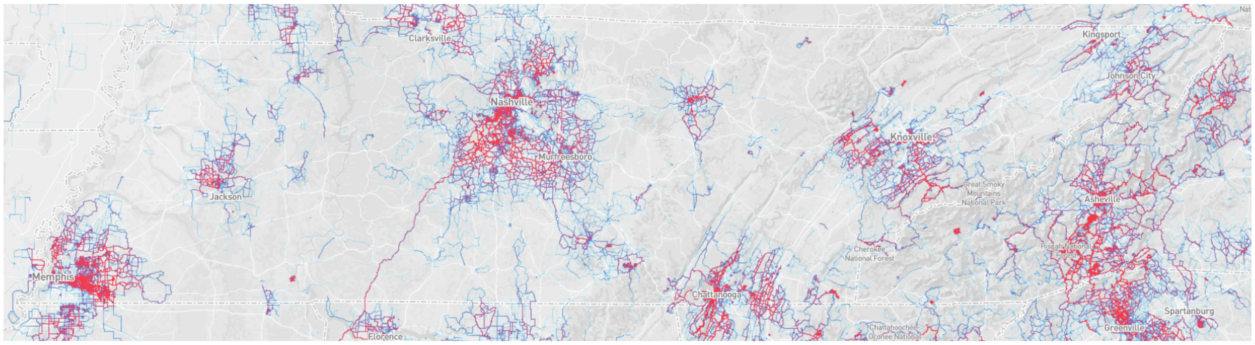


Figure 8: Bicycling activity in TN (Source: https://www.strava.com/heatmap)

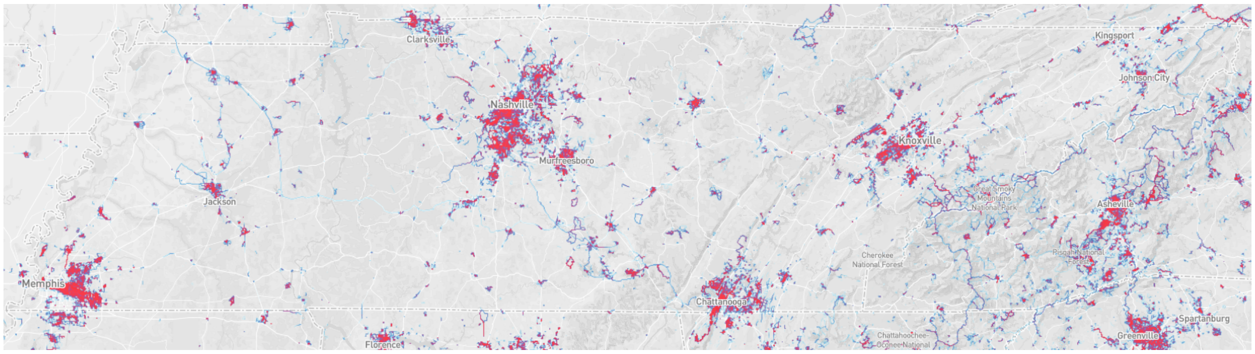


Figure 9: Walking activity in TN (Source: https://www.strava.com/heatmap)

2.4 Challenges and gaps

Based on the interviews with representatives of transportation agencies in Tennessee, there are few noteworthy concerns related to bicycle and pedestrian count programs. These are summarized in the following paragraphs.

1. **Resources for a count program**

   Almost all of the respondents said that they need assistance to implement and/or improve bicycle and pedestrian count programs. Technical and financial limitations were often mentioned as significant reasons not to have count programs. In general, MPOs have better technical and financial capabilities than RPOs. However, even when some agencies have sufficient financial resources, they often do not have sufficient technical knowledge to establish a thorough bicycle and pedestrian count program.

2. **Knowledge of best practice and technologies**

   A critical gap in the existing non-motorized count programs relates to the best practices of counting methods and technologies. Although agencies are using a wide range of counting technology and methods, there is room for improvement to leverage the benefit of these technologies fully. Some agencies have started to consider emerging technologies, like Strava, for estimating bicycle and pedestrian volumes; these emerging bicycle and pedestrian counting methods might be a cost-effective approach for a state-wide count program.

3. **Data quality**

   Among the existing count programs in Tennessee, validation of data was done only on a few occasions. Moreover, none of the transportation agencies that were interviewed had a rigid framework for quality assurance during data collection. Based on the count programs in other states, accuracy is likely an issue in the existing counts. Count validation should be a part of the data collection process for bicycle and pedestrian counting, and the validation process should also be well documented.

4. **Data management**

   Bicycle and pedestrian count datasets do not have a data repository like vehicular counts. Thus, they lack consistent file format, have data duplication issues, and lack metadata. Therefore, better documentation and data management can improve the reliability of bicycle and pedestrian count programs.

Chapter 3: Existing and emerging technologies and methods

Bicycles and pedestrians can be counted by using several technologies and methods. Early count programs used manual methods, while automated counters are also available with proper documentation on the best practices. Recent use of widespread smartphones has enabled innovative ways to collect data on bicycling and walking. This chapter discusses manual, automated, video-based, and emerging count technologies for counting bicyclists and pedestrians.

3.1 Manual Count Technologies and Methods

Manual counts are collected by human beings either physically in the field at a specified site or through video recordings and subsequent manual observations. These counts can be targeted users who either pass a point (screen line count), navigate an intersection (intersection count), or use a crosswalk. Screen line counts are preferred for manual counts (Nordback, Johnstone, & Kothuri, 2017). Manual counts can be recorded using paper sheets, traffic count boards, "clicker" counters, or smartphone apps. They can also be used to count bicycle parking occupancy, transit boardings, gender, age, and other attributes. Manual counts are the most familiar type of data collection for many agencies and jurisdictions (FHWA, 2016).

Manual counting can provide data that are difficult or impossible for machines to detect, such as perceived gender, age, ethnicity, helmet use, use of assistive devices, and abnormal behaviors. However, it is difficult for a single human to count longer than two hours at a time accurately. Manual counts are useful for collecting data from a wide geographic area, and if using volunteers. A well-organized count program can be relatively inexpensive to implement (Johnstone, Nordback, & Lowry, 2017). Many manual counts are collected at intersections, and most automated counts are collected on-road segments because this is a simpler environment to count nonnotarized road users with equipment (Nordback, Johnstone, et al., 2017).

Manual counts are also a good starting point for new count programs, both because of low start-up costs, with the only high cost being labor, and to help in prioritizing sites for installing automated counting equipment. Manual counts are also needed for validating automated counting equipment as they are considered the ground truth (Ryus et al., 2014b). Nevertheless, manual counts only provide a brief snapshot of daily and weekly patterns of travel patterns. They are practical and low-cost for periodic short-term counts but are not sustainable for continuous monitoring purposes due to required labor and associated costs (FHWA, 2016).

Before collecting counts, the site should be assessed to determine the specific location(s) at which the manual counter(s) should be positioned to most easily view and record users. Based on the anticipated user volumes and the kinds of information that will be collected, more than one person may be needed (Ryus et al., 2014b). Data collectors in the field should be trained to be aware of their surroundings and to be careful in and around traffic. It is also recommended that counters bring a letter or some form of official documentation that describes the counting effort. It is essential to remember locations with higher user volumes or a greater mix of pedestrians, and bicyclists often require more data collectors (Ryus et al., 2014b).

The next sections provide additional detail on specific types of manual counting methods, beginning with manual in-field counting.

3.1.1 Manual in-field counting

Pedestrians can be counted in the field by observers using data collection sheets, clickers, or count boards. In the last few years, smartphone applications have also emerged for manual pedestrian counts. Manual in-field counts are typically used to collect short-duration counts and can yield very accurate information if the data collectors are well trained. They are often used to validate automated count data.

In comparing different manual count techniques, manual counts using sheets or clickers underestimated pedestrian volumes by between 8 and 25 percent (Diogenes, Greene-Roesel, Arnold, & Ragland, 2007). They also found that accuracy was worse during the beginning and end of the data collection period, which could perhaps be attributed to a lack of familiarity in the beginning and fatigue at the end.

Disadvantages of manual in-field counts are its limitation to short-term counts only and that they are labor-intensive. At high-volume locations, additional personnel is needed, which can make this methodology expensive.

Methods for manual in-field counting include tally sheets, mechanical counting devices, and electronic counting devices.

- *Tally sheets* are the cheapest way to gather manual data and can be used for both on-site counts and video counts. Volunteers are generally provided with a standard paper form on which they can record counts and observations. Tally sheets can often lead to errors when observers take their eyes off the study area to record their counts. This method performs best in areas with light count volumes or where a small number of user attributes are being recorded (Schweizer, 2005).
- *Mechanical counting devices* can be used by observers to keep track of their counts and reduce errors by allowing observers to record users without taking their eyes off the study area (Ryus et al., 2014b). Hand tally counters, which are available in both analog and digital models, are the most common type of mechanical counting devices. Observers press the clicker every time a user travel past.
- *Electronic counting devices* come primarily in two forms: electronic counting boards, and tablet/smartphone apps. They can be used for either screen line counts or intersection counts. The counting board creates a data point with a timestamp for each observation recorded. Counts are recorded by pushing the appropriate button, and the data are automatically tallied. Tablet and smartphone apps have become more widespread and user-friendly in recent years with a variety of options on the market. These technologies offer a strong advantage over tally sheets and mechanical counting devices in their ability to process data, provide advanced analysis, and graphically represent outputs (Ryus et al., 2014b).

3.1.2 Manual counts from video

Manual counts can also be collected from video footage with a temporarily or permanently installed camera. Videos are reviewed on a monitor after they are collected manually by a human data collector using a paper sheet, a handheld counter, or a computer. Specialized keyboards that can be plugged directly into a computer are available commercially. Manual counts from the video are considered the most accurate way of collecting data counts and are often used to find ground truth counts, given the ability if needed to re-watch or pause video data or slow down playback speed (Ryus et al., 2014b).

Manual counts on video are essentially the same as manual counts in person. However, a difference is some individual characteristics, like gender and helmet usage can be difficult to discern on video counts due to low-resolution video images or images taken from a distance. Still, specific behaviors such as wrong-way riding, traffic control device compliance, and sidewalk-riding can be observed where most automated technologies would neglect such behaviors (Ryus et al., 2014b). Greene-Roesel, Diogenes, Ragland, and Lindau (2008) found very little difference between counts obtained manually in the field versus from video when the count data to collect was simple.

According to NCHRP 797 (Ryus et al., 2014b), video cameras should be installed inconspicuously and 10+ feet above ground to avoid theft and vandalism. The camera's location should allow the detection zone to be recorded, being aware of possible tree branches moving in the wind or stopped trucks obscuring the view. Typically, every 2 to 3 days, a site visit is required when a video is collecting to ensure the camera is working correctly, swap memory cards, and replace batteries if needed.

Manual counts from the video are limited to short-duration counts. Other disadvantages are that data reduction is labor-intensive, frequent field visits may be required for swapping batteries and storage cards, and equipment may be susceptible to theft or damage.

The cost of manual counts can vary depending on the quality of the camera, the monitor or computer for video playback, and the computer software. Labor costs include camera set-up, maintenance, take-down, and periodically conducting quality-assurance. It is site-dependent whether video or in-field manual counting is more efficient. In rural and/or remote sites with light traffic and simple configurations, manual counts from the video were most cost-effective. However, in more complicated and crowded sites, manual counts from the video will typically cost more but be more accurate (Ryus et al., 2014b).

3.1.3 Surveys

Surveys can be conducted via a travel diary, GPS device, interview, or web-based questionnaires to collect pedestrian and bicyclist data, such as activities, travel details, origin-destination, and mode share information. Mode shares can then be extrapolated to establish total cyclist and pedestrian volumes for a larger area, such as within a traffic analysis zone. Estimations made in this manner cannot serve as a suitable means of gathering count data due to the relatively small sample size in comparison with a relatively large sample area (Ryus et al., 2014a).

Common survey methodologies are travel surveys, stand-alone GPS based surveys, intercept surveys, and web-based surveys. These are described below.

- **Travel surveys (e.g., National Household Travel Survey)** help to grasp how people move from place to place for different types of trips and answer questions related to mode split (Johnstone et al., 2017). Two commonly known travel surveys are the U.S. Census American Community Survey (ACS) and the National Household Travel Survey (NHTS). These surveys provide contextual information (i.e., trip purpose, income level, and resident status), which are significant parameters in estimating travel behaviors. However, considerable preparatory work and post-data processing are required for the nationwide data, which could result in high costs and small sample sizes at the local level that might be particularly troublesome for non-motorized travel monitoring (Schweizer, 2005).
- **Stand-alone global positioning system–based surveys** are conducted by giving survey respondents a handheld GPS device that records their location over a few days. GPS based surveys are potentially more accurate and require less work from the respondents than traditional paper surveys. Travel patterns are becoming increasingly varied in time and space due to many factors (i.e., spatial fragmentation and automation), and because of this increasing complexity of travel behavior, GPS based surveys can provide more detailed information about travel patterns (Bohte & Maat, 2009).
- **Intercept surveys** can be used to understand better who is using a given facility and for what purposes. Intercept surveys stop cyclists and pedestrians so they can answer a few questions about their trip. These surveys are best for collecting qualitative data about a user’s experience in a facility. Fieldwork has confirmed that intercept surveys are likely the only way to determine how users accessed a given facility or station. However, with an intercept survey, there could be a considerable margin of error due to imprecision in identifying a catchment area of access or what qualifies as a user (i.e., pedestrian, cyclist) (Schweizer, 2005).
- **Web-based surveys** have been increasing in popularity and use over the years because web-based surveys are often cheaper and easier to conduct. However, web-based surveys are scarcely used for count programs (Spitz, Niles, & Adler, 2006).

3.2 Automated Count Technologies

Automated counting devices can continuously record traffic flow. They are either collected by timestamp or in distinct time bins such as 15 minutes or hour-long time intervals (FHWA, 2016; G. Lindsey et al., 2014). Automated count devices may be portable/temporary or permanent (Nordback, Johnstone, et al., 2017).

For short-duration automated counts, the FHWA Traffic Monitoring Guide (TMG) recommends a total of 14 days and a minimum of 7 days to account for each day in the week. Automated count technologies have many benefits in terms of reducing costs per hour counting and allow for longer periods of data collection (Nordback, 2019). Various technologies to conduct automated counts are described in the following paragraphs.

3.2.1 Pneumatic tubes

Pneumatic tubes are implemented by stretching one or more tubes across a desired path or roadway (see Figure 10). When a bicyclist or vehicle passes over a tube, a pulse of air moves through the tube to a detector, which records the pulse of air as a count. Specialized bike-specific counters can solely count cyclists even if vehicles are passing over the tubes, whereas general-purpose counters count both vehicles and bicyclists (Ryus et al., 2014b).

Figure 10: Bicyclist riding over pneumatic tubes (Source: Karla Kingsley, Kittelson & Associates, Inc. (Ryus et al., 2014b)

Pneumatic tubes are effective when bicyclist data are needed to be collected over multiple days and up to multiple weeks. Tubes are most appropriate on paved surfaces with little pedestrian use. They should not be used at temperatures below freezing because tubes may not maintain their properties and deteriorate.

Limitations of pneumatic tubes are that they are only capable of counting bicycles. Tubes pose a tripping hazard to pedestrian trail users and have a higher risk of vandalism. Pneumatic tubes should not be used in the winter.

Relative to other technologies, the level of effort and cost for setting up pneumatic tubes is low. In many cases, jurisdictions are familiar with the setup process due to their frequent use for counting vehicles. Tubes are installed across the path where bicyclists are unlikely to stop. While minimizing exposure to motor vehicles, tubes should adequately cover the travel path of bicyclists. Pneumatic tubes are often used as part of a bicyclist count program.

In one study, the accuracy of bicycle-specific pneumatic tubes showed an undercount by an average of 19.8 percent. In testing different products from three different vendors, it was found that the total deviation from the actual counts was 22.2 percent on average (Ryus, Butsick, Proulx, Schneider, & Hull, 2016).

3.2.2 Inductive loop detectors

Inductive loop detectors are wires installed under (embedded) or above (temporary) the surface of the pavement (see Figure 11). A magnetic field is formed with a light electrical current passing through the wires. Sensors are then able to detect changes in the magnetic field when metal parts of a bicycle pass over, such as frame, spokes, and pedals. Loop detectors generally are intended for permanent (embedded) count locations and are used to detect screen line counts. They are typically used on paved facilities but can be used on unpaved paths too.

Figure 11: Technicians installing temporary inductive loop detectors (Source: Katie Mencarini, Toole Design Group)

Inductive loop detectors are recommended to be placed on mid-segment channels to conduct screen-line counts where bicyclists are unlikely to stop or bypass the detectors. If the loops are embedded, pavement cuts are required, which can take considerable lead time if permits are necessary. Temporary loops are attached to the ground with adhesive tape (Ryus et al., 2014b). For example, Eco Counter's inductive loop technology is battery-powered with two-year battery life (Eco Counter).

The level of effort and cost can vary greatly depending on if there is in-house expertise as compared to hiring a contractor. Relative to other counting technologies, the effort and cost for installing embedded loops are high, and installing temporary loops is medium. Inductive loop detectors only count bicycles. The in-pavement installation is complicated and requires a professional installer. The technology is susceptible to electrical interference.

Embedded loops are more common than temporary loops. Both are commercially available, and many transportation agencies are familiar with loop detectors given their abundant use in vehicle detection at intersections (Ryus et al., 2014b). According to Eco Counter technologies, inductive loops have high accuracy on shared roads and dedicated bicycle lanes with heavy traffic (Eco Counter). Research has shown that inductive loop technology has a high degree of accuracy and consistency for counting the bicyclists. In one study, the total deviation from the actual counts was 10.5 percent (Ryus et al., 2016).

3.2.3 Passive infrared

Passive infrared devices can detect cyclists and pedestrians by differentiating the background temperature from the heat and infrared radiation emitted by people passing by the front of the sensor (see Figure 12).

Figure 12: Passive Infrared Sensor for Counting Pedestrians and Bicyclists (ADOT).

Passive infrared devices are typically used to collect counts for several weeks or permanently. They are unable to differentiate between bicyclists and pedestrians, so most are used in conjunction with bicycle-only counting devices like inductive loops or piezoelectric strips, which are commercially available. When combined counts are used, pedestrian counts are identified based on the difference between total user counts and bicycle counts (Ryus et al., 2014b).

The relative effort to install a passive infrared detector is low, and the cost per device is medium compared to other counting technologies. The placement of a passive infrared device is essential in collecting accurate results. Sensors should be placed on one side of the corridor facing a fixed background (e.g., wall) at a vendor specified height, typically 2-3 feet (Ryus et al., 2014b). According to Eco Counter, their technologies cost between $2,325 and $3,825 for no direction detection and between $2,925 and $4,425 for bidirectional detection (Eco Counter).

Passive infrared counters have been tested in research and are commercially available. In the United States, these sensors are one of the main automated counting technologies used (Ryus et al., 2014b).

Passive infrared counters have good accuracy rates; however, many studies have found that passive infrared sensors increasingly undercount as user volume increases. The sum of the under- and over-counting amounts to a 22.5 percent deviation from the actual (Ryus et al., 2016).

Eco Counter states that their passive infrared technology has a high level of accuracy when counting cyclists traveling at high speeds (Eco Counter). Passive infrared technology cannot distinguish between bicyclists and pedestrians. It is difficult to use for bike lanes and shared lanes and cannot be used for crosswalks. Extreme ambient temperature may affect accuracy. Eco Counter offers "Pyro Box" as a passive infrared technology and is the company's most popular pedestrian counter. The Pyro Box uses passive-infrared, pyroelectric technology, and a high-precision lens. It is battery operated. According to Eco Counter, it has a high level of accuracy when counting cyclists traveling at high speeds.

3.2.4 Active infrared

Active infrared devices count by emitting an infrared beam from a transmitter to a receiver located on the opposite side of the pathway (see Figure 13). An object crossing the path breaks the beam for a specified time to record a count. Active infrared devices are typically used to collect screen line counts for several weeks or permanently. However, they are unable to differentiate between bicyclists and pedestrians. Thus, active infrared devices are used in conjunction with bicycle-only counting devices like inductive loops or piezoelectric strips (Ryus et al., 2014b).

Figure 13: Active infrared counter installation at a test site. Source: Tony Hull, Toole Design Group (Ryus et al., 2014b).

The level of effort is medium compared to other automated technologies requiring the setup of a transmitter and a receiver and finding suitable locations. The equipment cost is high, but installation costs are medium compared to other technologies (Ryus et al., 2014b). The transmitter and receiver should be installed facing each other with a clear line of sight. Finding appropriate mounting locations on each side of the pathway can pose challenges. Active infrared technology cannot distinguish between bicyclists and pedestrians. It is not suitable for on-street monitoring. It requires fixed objects or poles on either side of the path or trail.

Active infrared counters have been tested in research and are commercially available. They are used throughout the United States, but in low numbers (Ryus et al., 2014b). In one study, Ryus et al. (2014a) tested the accuracy of a single infrared detector to find them precise, but they undercounted as the count volume increased. The under- and over- counting rate is a 7.3% deviation from the actual volume (Ryus et al., 2016).

3.2.5 Piezoelectric strips

Piezoelectric materials emit an electric signal when they are physically deformed (see Figure 14). Counters consist of two strips embedded in pavement across the traveled pathway. An electric signal is emitted when a bicycle crosses the strips. The piezoelectric strips provide information on the direction and speed of bicyclists. Piezoelectric strips are used for collecting bicycle counts at permanent count sites. They are typically used on paved multi-use paths or cycle tracks (Ryus et al., 2014b).

Figure 14: Bicyclist rising over piezoelectric strips. Source: Tony Hull, Toole Design Group (NCHRP 797).

The level of effort is high relative to other technologies and requires careful installation. The equipment cost is medium relative to other technologies, but the overall installation cost is high compared to other technologies. Pavement cuts are necessary to install piezoelectric strips. A data logger is typically stored in a utility box next to the facility. Lead time is probably required to obtain permits, hire a contractor, and schedule installation (Ryus et al., 2014b).

Piezoelectric strips are not widely used (Ryus et al., 2014b). According to another prior study, two sets of piezoelectric strips were tested, and both sensors were found to be highly accurate, with an undercount rate of only 4.5 percent and a total deviation of only 4.5 percent (Ryus et al., 2016).

3.2.6 Radio beams

Radio beam counters use a transmitter and receiver positioned on opposite sides of the facility (see Figure 15). The transmitter sends a radio signal to detect an object if a beam is interrupted. Radio beam counters are used for screen line counts on sidewalks, pathways, and cycle tracks and can be used in both short-term and permanent counting applications. As with other beam-type technologies, they are subject to occlusion errors (Ryus et al., 2014b).

The level of effort is medium relative to other technologies and requires finding suitable locations to mount a device on both sides of the facility. The equipment cost is high relative to other technologies, but the overall installation cost is medium. The devices can be mounted on existing infrastructure or installed in a post, so the device is completely hidden from sight. As with other beam-type technologies, locations, where pedestrians or bicyclists are likely to linger, should be avoided (Ryus et al., 2014b).

Figure 15: Completed radio beam counter installation. Source: Karla Kingsley, Kittelson & Associates, Inc. (Ryus et al., 2014b).

Radio beam devices are commercially available. However, according to a survey, they are not widely used in the

United States. There has not been much testing of radio beams. Some research that was done on radio beams suggests that they undercount by 11.5 percent and that they have a high correlation with manual counts (Ryus et al., 2016).

3.2.7 Pressure and acoustic pads

Figure 16: Pressure pad (Source: Linetop Ltd.)

Pressure and acoustic pads are installed in the ground, either flush or under the surface (see Figure 16). Pressure pads detect a change in weight on the pad. Pressure and acoustic pads are primarily used to count pedestrians on unpaved trails. Pressure pads can also count bicyclists, while acoustic pads can only count pedestrians. Pressure pads can distinguish the pressure from bicyclists separated from pedestrians. These devices are mostly used on unpaved multi-use paths and off-road trails where they can be buried and concealed. Users should pass directly over the sensor to be counted. If users are traveling side-by-side, multiple pads can be placed side-by-side and linked. Pressure and acoustic pads are typically used for long-term or permanent installations.

The level of effort is high compared to other technologies and requires installing the pads in the ground. Installation costs are expected to be high compared to other counting technologies since the pads need to be installed in the ground. Pads should be placed where users are expected to be moving. The number of pads should match the facility width. Placement consideration should be given to travelers' anticipated behavior. Pads can be installed in paved locations, but pavement would have to be removed and reinstalled. The use of pressure and acoustic pads is common in other countries but not in the United States.

3.2.8 Magnetometers

Figure 17: Magnetometers Source: TRAFx (Ryus et al., 2014b)

Magnetometers detect bicycle activities through changes in the average magnetic field as a bicycle's metal parts pass by (see Figure 17). Magnetometers are more commonly used as part of vehicle detection systems to detect the presence and movement of vehicles. While it may be possible to use existing motorized traffic magnetometers for counting bicyclists, the installation and configuration may not be optimal, and they are not designed for this purpose (FHWA, 2016).

Magnetometers are best suited for rural locations because the device is highly sensitive to ferrous objects. They are typically used to count bicyclists on rural bike paths or mountain bike paths. The level of effort is high compared to other technologies and requires installing the device in the ground. Installation requires an unpaved area or removing pavement from a bicycle facility, followed by replacement. They are not appropriate for locations with ground freezes. The accuracy of this technology has not been widely tested.

3.2.9 Fiberoptic pressure sensors

Fiberoptic pressure sensors detect changes in the amount of light transmitted through an embedded fiberoptic cable based on the amount of pressure (weight) applied to the cable. The sensitivity of the device can be adjusted to reflect the minimum or maximum weight desired to be counted. Fiberoptic pressure sensors can be used for permanent count stations. The technology could be applied to exclusive bicycle facilities, pathways, mixed-traffic roadways, and sidewalks.

The level of effort is high and requires installing a fiberoptic cable in the pavement and associated traffic control. Installation requires excavating a slot in the pavement and placing a fiberoptic cable in the slot. Avoid locations where users would be likely to congregate or linger to avoid multiple detections of the same user. Bicycle counters using fiberoptic pressure sensor technology are commercially available, mostly in Europe. Therefore, the accuracy of this technology has not been widely tested in the United States.

3.2.10 Multiple technologies: an inductive loop with an infrared detector

While each individual count technologies have its pros and cons, several technologies can be used in combination to improve the bicycle and pedestrian count activities. This section provides a brief overview of such popular combinations.

Combination of induction loop and infrared detector

An inductive loop sensor and a passive infrared sensor are installed at a single location to detect bicyclists and pedestrians and classify movements by mode. The passive infrared detector is used to obtain a combined count of pedestrians and bicyclists. The loop detector is used to obtain a bicycle-only count. Pedestrian counts can be derived by subtracting the bicycle-only number from the combined number. This technology is used for continuous counts and can be used for shared use paths. The combination inductive loop/infrared detectors are best in locations with predictable paths of travel for mixed traffic.

Eco Counter has a dual technology referred to as Multi Range (Urban Multi and Multi Nature). This system combines their passive infrared sensor (Pyro Box) and ZELT inductive loop. Their intelligent subsystem, the Smart Connect, analyses the signal from both sensors to classify users and analyze the direction of travel. The Urban Multi is optimized to count large groups of pedestrians and cyclists with high accuracy making it ideal for high-volume multi-use paths. The multi-range technology is battery operated with two-year battery life, and it works in all weather conditions (Eco Counter).

Inductive loops and infrared detectors require little maintenance, which makes them cost-effective; however, the installation cost is high. Eco Counter quotes $4,650 for bidirectional detection (Eco Counter). According to Eco Counter, the accuracy rates for multiple technologies are high, and cyclists can be detected with a 97 percent accuracy (Eco Counter).

The limitations are that multiple technologies can be costly because of using two technologies at the same time. Installation costs are high as it requires a work crew to do pavement cuts as well as perform post-installation maintenance for sensor and logger.

Combination of pneumatic tubes and infrared detector

A combination of a short duration automated count program is to pair pneumatic tubes with infrared sensors. Although the mechanism to distinguish bicycle and pedestrian is similar to the combination of induction loop and infrared detectors, the combination of pneumatic tubes and infrared detectors is portable and easy to install and is also relatively low cost. On the other hand, the limitation of the pneumatic tube applies to the combination. For instance, pneumatic tubes are prone to vandalism and theft and are not appropriate in snowy conditions. One of the commercially available products of this combination is Mobile Multi from Eco counters.

3.3 Review of video-based count technologies and methods

Video cameras can be one of the effective methods for the continuous as well as short term counts of bicycles and pedestrians. Although agencies implement short term manual counts from archived video, the operating costs can be high because of the labor-intensive process. Thus, automated counting from video using algorithms has been gaining popularity in recent years to reduce the cost as well as make the technology feasible for permanent counts.

3.3.1 Automated video count technologies

A recent development in video (imagery) technology can count bicyclists and pedestrians using computer algorithms, such as the Miovision Scout device depicted in Figure 18 (Source: Miovision). They can distinguish the travel modes of walking and bicycling from motorized transport like cars and heavy vehicles. Some of them can even detect the travel direction, speed, and other attributes. One of the exciting applications of this technology is from a company called Placemeter, which claims to detect pedestrians, bicycles, and car movements from any video camera, including a cell phone.

Figure 18: Miovision Scout device (Source: Miovision)

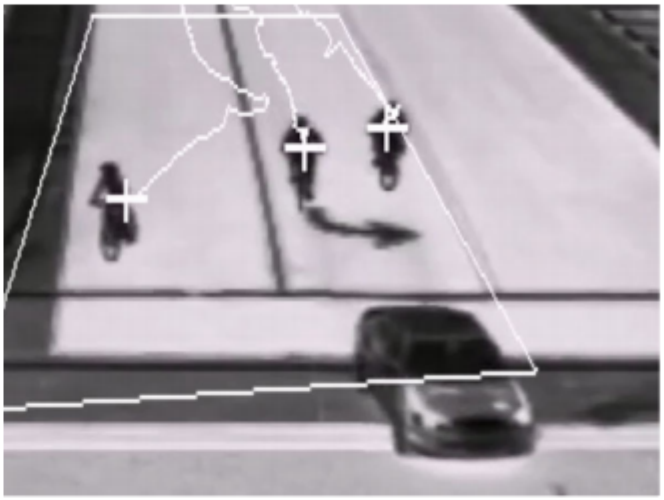


Figure 19: Thermal detection technology (Source: Louch, Davis, Voros, O'Toole, and Piper (2016))

A system of video camera device(s) can be installed at the intersection or segment of the road to collect input data to count pedestrians and bicyclists. Although these devices can be stand-alone devices dedicated just for non-motorized modes, these counts can also be integrated with the vehicular traffic monitoring system. Both short- and long-term counts can be done with automated video-based count methods. Depending on the technology implemented, additional information like direction and speed can also be collected at those locations.

In general, automated video-based count technologies require minimum human time to count non-motorized volumes both at intersections and at mid-block locations. Video playback can also be used to evaluate user behavior like the use of a helmet while riding a bicycle. In most cities, existing vehicular traffic monitoring cameras can be upgraded to count pedestrians and bicyclists (see, e.g., Iteris's SmartCycle). Louch et al. (2016) prepared a white paper that has more detail about this technology.

One of the limitations of video-based counting is that this method is useful only in good lighting conditions. Further, the commercial product could be limited to the detection of either bicycles or pedestrians, and the data processing can be costly. The validation of the count accuracy is also unknown for this technology and vendors.

3.3.2 Thermal imaging cameras

Thermal devices generate infrared images by detecting body heat (see Figure 19). They work similarly to passive infrared counters but are mounted above the detection area. This positioning allows thermal devices to monitor the movement of persons and not just count the number of persons to pass the device. Thermal sensors are not affected by changes in ambient light, so they can be used to capture pedestrians at night.

Since the detection of objects is not affected by the lighting condition, thermal cameras can potentially be a good option for long term counts in a poorly lighted environment. Thermal sensors can be used for presence-detection applications (e.g., traffic signal detectors and monitoring intrusions into restricted areas). Thermal sensors would most likely be used for permanent count locations. Figure 19 illustrates the detection of vehicles and bicyclists from a thermal camera.

There are currently two thermal cameras commercially available. "TrafiOne" is an all-around detection sensor for traffic monitoring and dynamic traffic signal control. It uses thermal imaging and Wi-Fi tracking technology to provide high-resolution data on vehicles, bicycles, and pedestrians. "ThermiCam" is an integrated thermal camera and detector for a vehicle, bike, and pedestrian detection. The intelligent ThermiCam can distinguish between vehicles and bicycles.

This technology is relatively new in the field of pedestrian and bicycle counting, and its performance is still unknown. Some of the advantages of the devices are that it can work in a poorly lighted environment, have a wider detection area, and could be easy to install. However, the validation of thermal devices is still unknown. Also, detection capabilities can be affected by weather conditions.

3.4 Comparison of manual and automated count technologies

Table 5-Table 7 illustrates the comparison of manual and automated count technologies on user and site characteristics, count capabilities, and resources. Appendix C contains more detailed comparison of manual and automated count technologies.

Table 5: Comparison of common pedestrian and bicycle counting methods: user characteristics and site characteristics (Source: (Ryus et al., 2014b))

Characteristic	**Passive Infrared**	**Active Infrared**	**Pneumatic Tubes**	**Inductive Loops**	**Piezoelectric Sensor**	**Passive IR + Inductive Loops**	**Radio Beam (One Frequency)**	**Radio Beam (High/Low Frequency)**	**Automated Video[1]**	**Manual Counts[2]**
Type of users counted										
All facility users	Yes	Yes				Yes	Yes	Yes	Yes	Yes
Pedestrians only						Yes		Yes	Yes	Yes
Bicycles only			Yes	Yes	Yes	Yes		Yes	Yes	Yes
Pedestrians vs. bicycles						Yes		Yes	Yes	Yes
Bicycles vs. automobiles			Yes	Yes					Yes	Yes
Characteristics collected										
Different user types						Yes		Yes	Yes	Yes
Direction of travel[3]	Yes	Yes	Yes	Yes	Yes	Yes		Yes	Yes	Yes
User characteristics[4]									Yes	Yes
Types of sites counted										
Multiple-use trail segments	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sidewalk segments	Yes	Yes				Yes	Yes	Yes	Yes	Yes
Bicycle lane segments			Yes	Yes	Yes				Yes	Yes
Cycle track segments		Yes	Yes	Yes	Yes			Yes	Yes	Yes
Shared roadway segments			Yes	Yes					Yes	Yes
Roadway crossings (detect from median)5		Yes	Yes	Yes	Yes		Yes	Yes	Yes	Yes
Roadway crossings (detect from end of crosswalk)									Yes	Yes
Intersections (identify turning movements)										Yes

Notes:

(1) Existing “automated video" systems may not use a completely automated counting process; they may also incorporate manual data checks of automated video processing.
(2) Includes manual counts from video images.
(3) Technologies noted as “Yes" have at least one vendor that uses the technology to capture directionality.
(4) User characteristics include estimated age, gender, helmet use, use of wheelchair or other assistive device, pedestrian and bicyclist behaviors, and other characteristics.
(5) Roadway crossings at medians potentially have issues with overcounting due to people waiting in the median. Median locations were not tested during this project.

Table 6: Comparison of common pedestrian and bicycle counting methods: volume, width, and duration capabilities (Source: (Ryus et al., 2014b))

Characteristic	**Passive Infrared**	**Active Infrared**	**Pneumatic Tubes**	**Inductive Loops**	**Piezoelectric Sensor**	**Passive IR + Inductive Loops**	**Radio Beam (One Frequency)**	**Radio Beam (High/Low Frequency)**	**Automated Video[1]**	**Manual Counts[2]**
User volume[3]	++	+++	++	++	+	++	++	++	+++	++
Detection zone width[4]	++	+++	+	+ +	++	++	++	+	+++	+++
Count duration[5]	+++	+++	++	+++	+++	+++	+++	+++	+	+

Notes:

(1) Existing “automated video" systems may not use a completely automated counting process; they may also incorporate manual data checks of automated video processing.

(2) Includes manual counts from video images.

(3) +: provides consistent counts (although some accuracy adjustment may be necessary) up to approximately 200 users per hour, ++: up to 600 users per hour, +++: beyond 600 users per hour. These are approximate ranges under typical conditions. The range also depends on specific site characteristics (e.g., average user group size, mix of pedestrians and bicyclists, detection zone width). The maximum user volume range for manual counts assumes a single data collector is counting one type of user and no additional characteristics. Multiple manual data collectors can count more than 600 users per hour. Counts can be adjusted at user volumes above these levels.

(4) +: typical detection zone width narrower than 4 meters (13 feet), ++: narrower than 6 meters (20 feet), +++: 6 meters (20 feet) or wider. In the case of automated video and manual counts, the detection width may be 25 meters (82 feet) or wider.

(5) +: typically used for 48 hours or less, ++: typically used for non-permanent short- or longer-term counts, +++: often used for permanent count sites. Most inductive loops are installed in the pavement, but there are also varieties that can be installed on top of the pavement for up to 6 months.

Table 7: Comparison of common pedestrian and bicycle counting methods: resources (Source: (Ryus et al., 2014b))

Characteristic	Passive Infrared	Active Infrared	Pneumatic Tubes	Inductive Loops	Piezoelectric Sensor	Passive IR + Inductive Loops	Radio Beam (One Frequency)	Radio Beam (High/Low Frequency)	Automated Video[1]	Manual Counts[2]
Equipment cost[3]	$$	$$$	$$	$$	$$	$$$	$$$	$$$	$$	$
Preparation cost[4]	$$	$$	$$	$$$	$$$	$$$	$$	$$	$$	$
Installation time[5]	🕓	🕓🕓	🕓	🕓🕓🕓	🕓🕓🕓	🕓🕓🕓	🕓🕓	🕓🕓	🕓	N/A
Hourly cost[6]	$	$	$$	$	$	$	$	$	$$$	$$$$
Data collector training time[7]	🕓	🕓	🕓	🕓	🕓	🕓	🕓	🕓	🕓	🕓🕓🕓
Mobility[8]	+++	++	+++	-	-	-	++	++	+++	+++
Pavement cuts	No	No	No	Yes	Yes	Yes	No	No	No	No

Notes:

N/A: not applicable

This table presents generalized information specific to particular counting technologies. Other aspects of counting products, such as battery life and communication interfaces, are also important to consider but are highly vendor-specific. See the text following this exhibit for more details.

(1) Existing “automated video" systems may not use a completely automated counting process; they may also incorporate manual data checks of automated video processing.

(2) Includes manual counts from video images.

(3) $: equipment (not including permitting and installation) typically cost less than $1,000 as of 2013, $$: typically costs between $1,000 and $3,000, $$$: typically costs more than $3,000. The cost of most counting technologies is subject to economies of scale, so the per site cost can be reduced by purchasing more counters.

(4) Fewer dollar signs ($) indicate that it takes less time (and therefore fewer financial resources) to find an appropriate site and to obtain any required permits to install the counting product. Preparation can range from less than one day for manual counts to several months for technologies with more restrictive installation requirements.

(5) More clocks (🕓) are given to methods that require more installation time (e.g., cut pavement, secure the data logger, test and adjust the equipment). Installation can range from no time for manual counts and less than 30 minutes for passive infrared to more than half a day for inductive loops.

(6) More dollar signs ($) indicate that the method is more costly for an average hour of counts, given the typical count duration for a particular method. These costs can range from a few cents per hour for automated technologies (the full equipment, preparation, and installation cost is spread across months of counts) to more than $50 per hour for manual counts (including training preparation time, management, and on-site labor costs).

(7) More clocks (🕓) indicate that more time is needed to prepare field data collectors to implement the counting method. A single data collector can be trained how to install or download data from a particular automated technology in less than 30 minutes, but it often takes more than one hour to thoroughly train data collectors to collect accurate manual counts.

(8) More pluses (++) indicate that a counting technology is easier to move after it has been installed. A minus sign (-) indicates that the technology is generally not intended to be used in more than one location based on the installation being permanent.

3.5 Review of the emerging smartphone app and GPS technologies and methods

While traditional pedestrian and bicycling count methods have a high cost, emerging technologies that use location data offer the prospect of collecting data using relatively fewer resources. These devices can be any mobile devices that have the capability of recording the location like mobile phones, smartphones, or fitness gear. Since the use of mobile devices is almost ubiquitous, they provide an opportunity to collect a broader and diverse sample of pedestrian and bicyclist populations in a shorter time using fewer resources. Thus, these technologies have been attracting a lot of attention from the researchers as well as commercial companies. However, these methods are still in the development phase, and much of the potential is yet to be realized.

Lee and Sener (2017) did a comprehensive literature review of these emerging technologies to classify them into two categories based on the input (interaction) of the traveler and data collection mechanism. They are:

- Passive data: Requires no or little input (interaction) from the pedestrian and bicyclist
- Active data: Requires input (interaction) from the pedestrian and bicyclist

These two categories are discussed in detail in the following sections.

3.5.1 Passive data sources

Spatio-temporal data of the travelers are collected by wireless technologies like cellular service providers and apps from smartphones. Lee and Sener (2017) categorized these data sources into three types with respect to location precision and technologies used: Mobile Phone Positioning (MPP), Global Positioning System (GPS), and Location-Based Services (LBS). The categories are defined as follows:

1. Mobile Phone Positioning (MPP): The cellular network providers collect cellphone's spatio-temporal information for operations purposes
2. Global Positioning System (GPS): GPS-enabled devices record the traces of travel from satellite data at a specific time interval
3. Location-Based Services (LBS): Location data are collected by smartphone apps, even when those apps are not running in the foreground (as long as the app has permission to access location data in the background)

The features and applications of these data sources are summarized in Table 8 below:

Table 8: Passive emerging data types (Source: Lee and Sener (2017) and modified by authors)

Data Description/Data types	**Mobile phone positioning (MPP)**	**GPS**	**Location-Based Services (LBS)**
Monitoring point	When mobile phones connect to cellular operator's networks	When mobile phones receive signals from satellites	When the LBS app is initiated (in the foreground), and the device begins moving (in the background) by Wi-Fi and assistive-GPS (A-GPS) (varies based on technology)
Locational precision	200 to 1,000 m	5 m	From 5 m (A-GPS) to 50 m (Wi-Fi)
Detection coverage	Up to the traffic analysis zone (TAZ), census block, or road on which the device is located	Up to a small road or parking lot	Up to most parking lots, TAZs, and blocks
Example vendors	AirSage (www.airsage.com)	INRIX (inrix.com), TomTom (www.tomtom.com), and HERE (here.com*)*	StreetLight (www.streetlightdata.com), Cuebiq (www.cuebiq.com), Ridereport
Possible data	Aggregate origin-destination (OD), trip purpose (imputed), home/work location (imputed), and speed	Aggregate OD, trip purpose (imputed), home/work location (imputed), and speed	Aggregate OD, trip purpose (imputed), home/work location (imputed), and speed

The application of these data sources depends on the precision of the data. For example, Wang, Calabrese, Di Lorenzo, and Ratti (2010) argued that AirSage's MPP could not be used for very short trips since its data precision can be higher than the average walking distance of 400 m (Cervero, 2001). GPS and LBS data sources, on the other hand, can be used to impute useful information related to walking and bicycling. Thus, the coarse precision data sources (MPP) can only be used for origin-destination analysis, whereas detailed analysis is possible from GPS and LBS data sources.

Data aggregators companies, like Streetlight, purchase the raw data and resell the data after some data processing. These commercial data include origin-destination, trip attributes (travel distance, time, speed, purposes, and such), infrastructure evaluation (route choice), and attributes of the traveler (demographics, home, and work location, and such).

However, Lee and Sener (2017) claimed that these data have several limitations. They lack the contextual information about the traveler. Age, gender, income level, and similar information could be missing for the trip data collected from location-based data sources. Also, data aggregator companies anonymize and aggregate the data due to privacy concerns. Furthermore, the data might have sampling bias that would only collect information from the population who uses these devices and exclude the population without such devices.

3.5.2 Active data sources

These data sources collect the movement of users/devices when they are willing to participate in the data collection to some extent. For example, a user might use a fitness tracking app to record data of their physical activity. Thus, the collection of data for walking and bicycling is more targeted for a specific user group than the passive data sources.

Lee and Sener (2017) categorized four types of data sources for active data. They are:

1. Regional bicycling tracking: Bicycling tracking apps that are developed by public agencies to collect bicycling patterns.
2. Fitness/activity tracking: Tracking apps developed by private companies to quantify and record the physical activities of users (that includes walking, running, bicycling, and other daily activities).
3. Bike-share programs: Travel data collected by bike-sharing services to trace their devices as well as use pattern. The GPS trace might be collected by linking to users' smartphones as well as installing a stand-alone GPS device on the bicycle.
4. User-feedback-based map inventory: A public input platform to collect safety issues and facility demand feedback from users.

A descriptive summary of these data sources is shown in Table 9 below:

Table 9: Active emerging data types (Source: Lee and Sener (2017) and modified by authors)

Data Description/Data types	**Regional bicycling tracking**	**Fitness/activity tracking**	**Bike-share programs**	**User-feedback-based map inventory**
Description	Tracking app to collect bicycling travel pattern by public agencies	Fitness and activity tracking app developed by private companies	Apps developed by companies to	Inventory map to collect public input data like crash location
Technology in use	GPS, Smartphone Apps	GPS, fitness device, Smartphone Apps	Smartphone Apps, bicycle equipped with GPS	Smartphone Apps, Website
Example vendors	CycleTracks, Cycle Atlanta, Mon RésoVélo	Strava, Fitbit, Endomondo	Capital Bikeshare, CitiBike, BIXI Montreal	Bikemaps.org, MySidewalk
Possible data	GPS trace, rider demographics,	GPS trace, traffic volume, traffic flow,	Trip OD, GPS trace, trip	cycle crash incident

	trip purpose, trip frequency, and rider experience data	average speed, calories burned, and step counts	distance and time, and user demographics	details, walking path (available and missing), and infrastructure closure status
Applications	Route choice modeling, comfort level modeling, bicycling trip profile	Bicycle volume estimation, data comparison, visualizing bicycling flow, evaluate new facility performance, and estimate injury risk and exposure	Route choice, analyzing the impact on transit use, and bike-share user analysis	Analyzing crash factors

Most of the applications of these data sources are focused on bicycling than walking. Since most of the users have created a profile before using the service, the data might be enriched with socio-demographic information like age or gender. Some of the popular applications of these data sources include route modeling, comfort level modeling, data comparison among different sources, bicycle volume analysis, exposure estimation, and evaluation study.

Similar to passive data sources, Lee and Sener (2017) argued that these data sources also have several limitations. First, there is evidence of high sampling bias for specific user groups, especially towards males, young generations, and commuting population groups (Blanc & Figliozzi, 2016; Charlton, Sall, Schwartz, & Hood, 2011; Hochmair, Bardin, & Ahmouda, 2019; Hood, Sall, & Charlton, 2011; Jestico, Nelson, & Winters, 2016; Zimmermann, Mai, & Frejinger, 2017). Second, the personal information of the user profile can potentially be a privacy issue, and there might be limitations using the data at an individual level (Romanillos, Zaltz Austwick, Ettema, & De Kruijf, 2016). Finally, passive data sources might have sample size limitations since many users might not use the smartphone app during all of their travel.

3.5.3 Evaluation and application of emerging technologies

At the time of this review, the authors found limited documentation on using these emerging technologies for statewide non-motorized count programs. Some commercial companies, like Streetlight and Strava, claim to have a methodology to count bicyclists and pedestrians, but they are yet to be validated.

Lee and Sener (2017) claimed that most of the applications of emerging smartphone technologies are focused on bicycles, not pedestrians. Molina (2014) found five distinct applications of these emerging technologies through literature review and semi-structured interviews of ten case studies. There are:

1. Bicycle facility demand: identify demand level of bicycling
2. Network planning: preparing short- and long-term plan and policy for bicycling infrastructure and safety

3. Suitability/bicyclability metrics: assessing bicycle network for perceived comfort, safety, route preference, and such
4. Route choice modeling: analyze bicyclist travel behavior
5. Safety: estimate exposure for safety analysis and map crash or near-miss information related to bicycling

Bicycle volume estimation using the crowdsourcing data is evolving rapidly in the past few years. One such example is the fusion of Strava Metro data with bike-share program data, manual and automated counts, and demand models to develop a method to estimate a network-wide bicycle volume in San Francisco (Proulx and Pozdnukhov 2017).

Different route choice and longitudinal analyses of trip volumes have established a strong correlation between temporal elements (e.g., time of the day), weather conditions, topographic attributes as well as built environment attributes (e.g., residential density, bicycle infrastructure) (G. P. Griffin & Jiao, 2019; Hochmair et al., 2019; Morency, Trépanier, Faucher, Páez, & Verreault, 2017). Many commercial companies have some metrics for pedestrian and bicycle travel based on their data.

McCahill and Sundquist (2017) made following recommendations on using these emerging data sources to inform decision-making:

1. Familiarize oneself with a range of data sources and their capabilities as well as limitations
2. Ask specific questions to address the planning requirements
3. Consult the right people to interpret the data
4. Aggregate data appropriately to make better sense of patterns in travel activity

Chapter 4: Emerging technologies for pedestrian and bicycle counting

Counting pedestrian and bicycle volumes can be more challenging than motorized vehicles for several reasons, as discussed in Chapter 1. Some non-motorized count technologies and methods have well-documented best practices, accuracy, and capabilities, as well as limitations (refer to Chapter 3 of this report for more detail). However, improving the current accuracy and coverage of traditional count methods and technologies can be expensive. Therefore, researchers and product developers are exploring innovative methods to estimate walking and bicycling volumes that would require less financial and human resources. While they are conceptually viable, most of them are still in the research and developmental phase.

These emerging technologies can be broadly classified into two categories: prospective and imminent count methods/technologies. The prospective class includes techniques that can potentially be implemented for pedestrian and bicyclist counts but have not been used on a large scale so far. The use of current traffic signals with pedestrian actuation phases as a proxy for the pedestrian volume is one example of prospective count methods. As of now, the literature does not have sufficient documentation of performance, accuracy, limitation, and best practices to implement these methods in practice. However, we can expect some progress in the coming years.

Some methods are imminent, but the timeframe of adoption is highly uncertain. For example, pedestrian and bicyclist detection technology for Connected and Autonomous Vehicles (CAV) is developing independently of video-based non-motorized counts. Given the resources being invested in autonomous vehicles research, we can assume that a breakthrough in that technology can benefit pedestrian and bicyclist counts too. However, we cannot confidently predict how these technologies can be adapted to estimate walking and bicycling volume. For instance, autonomous vehicle developers are still exploring visible-light cameras (VLC), Light Detection and Ranging (LiDAR), or radar to detect pedestrians and bicyclists but do not have consensus on the best technology, so far. Regardless, these technologies can supplement the existing count methods to scale the program to broader spatial and temporal coverage.

Table 10 presents a summary of the evaluation of such emerging technologies. These technologies are discussed in more detail in the subsequent sections, beginning with Wireless MAC id technology from smartphones.

Table 10: Summary of evaluation of emerging technologies for non-motorized volume count

No	Technology	Category (prospective or imminent)	Opportunities	Limitation	The critical component for implementation
1	Wireless MAC id for pedestrian activity	Prospective	Suitable for public places with large crowds, like an airport terminal	Lack of validation	Detection method based on Wi-Fi signal works better than Bluetooth
2	Bikeshare as a probe for bicycle count	Prospective	Expansion of bicycle counts on temporal and spatial attributes	Bikeshare trip records should have GPS trace data	Bikeshare should be a representative sample of bicycling activity in the city
3	Transit Automated Passenger Count (APC) for pedestrian activity	Prospective	Evaluation of pedestrian activity hot-spot with no added cost for pedestrian detection equipment	APC data could have errors and inconsistencies	APC counter data at the stop level
4	Using data richness of shared micromobility system	Prospective	Understand trip information and vehicle status	Lack of contextual information about trips, like trip purpose	Data sharing standards, like Mobility Data Specification (MDS)
5	Push button to estimate pedestrian	Prospective	Minimum cost to collect data from the existing signal system	All approaches should have pedestrian actuation phase	Advanced Transportation Controller (ATC) controller and Automated Traffic Signal Performance Measures (ATSPM) logging
6	Pedestrian and bicyclist mapping through CAV	Imminent	Potentially leverage the use of Vehicle-to-Pedestrian (V2P)	Technology adoption rate	Standardization of data sharing of CAV

	detection technology		communication to collect data		
7	Smart city infrastructure for monitoring mobility	Imminent	Monitoring of urban mobility using multiple types of equipment, such as infrared and automated video counters	Development of technology	Capital investment in smart city infrastructures

The section below describes each of the methods in detail.

4.1 Smartphone probe data

The advancement in communication technology and the widespread adoption of smartphones has enabled new ways to collect mobility data. The emerging technology based on smartphones generates a large amount of data that can supplement traditional pedestrian and bicyclist counts. Section 3.5 has a detailed review of such emerging technologies.

We explored two novel concepts that use a smartphone as a probe to detect walking and bicycling activities. We used Bluetooth MAC detectors to measure pedestrian volume while we also explored the possibility of using bikeshare GPS trace data as a surrogate for bicycle volumes.

4.1.1 Wireless MAC ID for pedestrian activity

Counting the flow of pedestrians in large public spaces, like train stations, can be challenging due to the high cost of implementation of devices such as video camera and image processing. However, most people use smartphones that have wireless communication mechanisms, like Bluetooth and Wi-Fi, and the detection of these signals is relatively easier and cheaper. Therefore, we hypothesize that counting unique Bluetooth and Wi-Fi-enabled devices can be used as a measure of pedestrian activity.

4.1.1.1 Conceptual description

Smartphones periodically scan for Bluetooth and Wi-Fi signals by sending out device information through a unique device ID known as MAC address. Assuming each MAC address belongs to one person, the same MAC address at two different locations indicates the movement of a pedestrian. As a proof of concept, we counted the number of unique MAC addresses of pedestrians between two roadway segments and compared them with the ground truth from a manual count. We installed SMATS Bluetooth, and Wi-Fi scanner devices at Cumberland Ave between 16th and 17th St from 9:30 to 10:30 am on a typical weekday (Figure 20). We also manually counted the number of pedestrians walking each direction in the same period. If a MAC address appeared on both scanners, we calculated the travel time and the average travel speed between two scanners.

Figure 20: Location of SMATS Bluetooth and Wi-Fi scanners

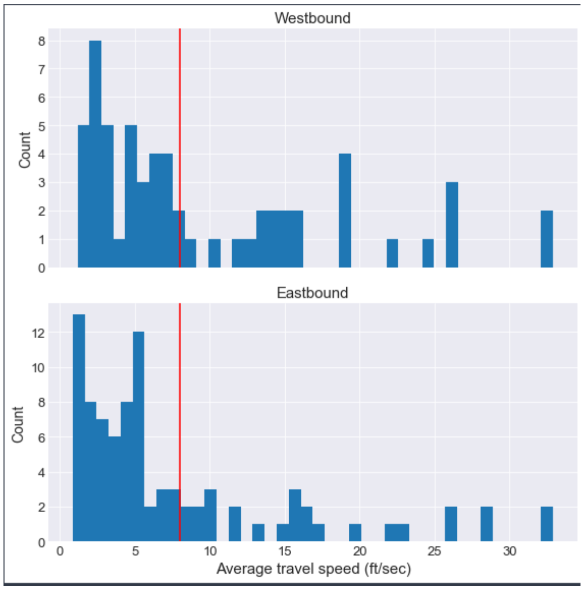


Figure 21: Histogram of average travel speed between two scanner locations

Figure 21 presents the histogram of the average travel speed of people moving in both directions of travel between the two scanner locations. Assuming the maximum walking speed of a pedestrian is 8 ft/s, and the traffic in the street is free-flowing without congestion, MAC addresses that have moved at a speed less than 8 ft/s are probably pedestrians. The Bluetooth and Wi-Fi scan represented 51.5% of actual westbound pedestrian traffic, while the eastbound movement accounted for 30.2% of actual pedestrian traffic. It is also likely that the device could not detect pedestrians for reasons such as they did not have a smartphone or turned off their Bluetooth and Wi-Fi signal. We can conclude that Bluetooth and Wi-Fi scanners can represent some measure of pedestrian traffic in public spaces, although further analysis is necessary.

4.1.1.2 Opportunities

The opportunities of this methods are the following:

1. Bluetooth and Wi-Fi scanners are a relatively cheaper method of detecting travelers, even for a high volume of pedestrian flow.
2. This method can estimate additional travel information like travel time and average travel speed.

4.1.1.3 Limitations

The limitations of using Bluetooth and Wi-Fi scanners as a proxy for pedestrian activities are the following:

1. Although it is fair to assume every person has Bluetooth and Wi-Fi-enabled phones, people might carry multiple devices, or not every device actively enables their wireless communication all the time. A validation study of what proportion of MAC address represents the actual population is necessary.
2. The scanner does not identify the mode of travel.

4.1.1.4 Implementation

There are limited studies on the application of Bluetooth and Wi-Fi signals as count methods. We recommend the following key issues to implement this method:

1. A few prior studies have found that Bluetooth has a lower detection rate than Wi-Fi technology (Lesani & Miranda-Moreno, 2018; Schauer, Werner, & Marcus, 2014). Therefore, Wi-Fi detection technology is recommended for monitoring pedestrian and bicyclist activities.
2. Installation of scanners in a controlled environment, such as a bikeway, can ensure the detection of pedestrians and bicyclists only.
3. A validation of scanners by comparing to manual count could correct for the sampling bias.

4.1.2 Bikeshare as a probe vehicle

According to NACTO, 36.5 million trips were completed using station-based bikeshare in 2018, while 9 million trips were made on dockless bikeshare in the United States (NACTO, 2019). These bikeshare systems are usually equipped with a Global Positioning System (GPS) tracking mechanism that allows these trips to serve as probe vehicles for bicycling. Researchers have used the probe data to track and map the use of bikes (Broach, Dill, & Gliebe, 2012; Le Dantec, Asad, Misra, & Watkins, 2015), evaluate route choice decisions (Hood et al., 2011; Khatri, Cherry, Nambisan, & Han, 2016), and perform bikeability assessment of road sections (Krykewycz, Pollard, Canzoneri, & He, 2011).

We analyzed the GPS trace data of bikeshare, and short-term bicycle counts with a hypothesis that bikeshare data can be a proxy for bicycle counts in an urban area.

4.1.2.1 Conceptual description

Local transportation agencies usually do short-term bicycle counts at specific locations, while the bikeshare system (usually) records a trace of all the trips in a specific service area with GPS locations and timestamps. We can identify the bikeshare trips passing through the bicycle count locations by overlaying the GPS trace during the time of the count. The bikeshare data can be a surrogate of bicycling activity if trips of bikeshare consistently represent the count.

As proof of concept, we examined the relationship of short duration bicycle counts and bikeshare data for Knoxville. The Knoxville Regional Transportation Planning Organization performed 2-3 hours of bicycle counts at 20 different locations during the fall of 2018. The visual examination of 11,098 Pace bike routes from April 2018 to April 2019 identified eight prospective count locations (out of 20 counts in Knoxville) for our analysis. We counted the number of Pace bike trips recorded within a 100 ft. radius of the count locations during the time of bicycle counts. Only two count locations had Pace bike trips with one trip at each location. The low match rate of bikeshare trips at count locations indicates that Pace bike data cannot be used as a surrogate of bicycle activity in Knoxville.

The Pace bike is a station based bikeshare system, and its users might not be regular bicyclists in Knoxville. This could explain why the only two Pace bike trips were identified at the bicycle count locations. However, the hypothesis should still be tested further for a densely built environment with high bikeshare usage, like New York City.

4.1.2.2 Opportunities

The potential opportunities for bikeshare data as a proxy for the bicycle counts are as follows:

1. Bikeshare data does not require any additional costs for count devices.
2. Depending on the bikeshare company data sharing policy, sociodemographic information of users, such as age, gender, and membership type, could be available.
3. The bikeshare trips represent a substantial proportion of bicycle trips in dense urban areas. Thus, the data generated by the bikeshare system can still represent a significant part of the bicycling activity in some cities.
4. Factoring time variations (time of the day and day of the week) between bikeshare data and bicycle counts could help expand the temporal and spatial coverage of bicycle monitoring in urban areas.

4.1.2.3 Limitations

The limitations of the concept are as follows:

1. Bikeshare data do not appear to represent the actual bicycling activity in small/medium size cities like Knoxville.
2. Bikeshare companies might not record GPS trace data because of privacy issues or technical limitations.
3. Further research is needed for the validation and implementation of this method.

4.1.2.4 Implementation

Some of the critical issues for the implementation of bikeshare data as a measure of bicycle activities are as follows:

1. The city should already have some basic level of bicycle count program.
2. The bikeshare system should reflect the overall bicycling in the city.
3. The GPS trace data are essential for this method.

4.2 Using transit and other shared mode data

4.1.3 Transit Automated Passenger Count

An Automated Passenger Counter (APC) is a device installed in the transit vehicles to count the boarding and alighting of passengers. Transit agencies in the United States started deploying APC devices in the 1970s (Attanucci & Vozzolo, 1983). There is extensive literature on the use of APC data to study passenger boarding and alighting behavior. This data is also used to report ridership for the National Transit Database. Since transit users are generally pedestrians before and after using transit, the APC count data could be a proxy for pedestrian activity. However, such research is lacking in the literature.

4.1.3.1 Conceptual description

As a proof of concept for the use of APC data as a proxy for pedestrian activity, we analyzed stop level data for 33 routes operated by Chattanooga Area Regional Transportation Authority (CARTA). The transit agency provided the research team with one week of APC data from February 1-7, 2020, that was aggregated at the stop and trip level. Since the spatial distribution of pedestrian activities is of interest, stop level aggregated data were used to identify the location of passengers boarding or alighting the bus. Figure 22 is a heat map of passengers alighting the bus, which shows some areas with a higher number of passengers getting off the bus.

Figure 22: Heat map of passenger alighting at bus stops

Figure 23: Hot spot analysis of passenger alighting at the bus stops

A higher number of pedestrians were expected at specific locations like the downtown area, with nearby bus stops boarding/alighting (spatially) correlated with each other. Consequently, a hotspot analysis of the average number of passenger alightings at each bus stop was performed, and the results are presented in Figure 23. A bus stop is labeled as a hot spot if the particular stop, as well as surrounding bus stops, have a higher number of passenger alighting on average (shown as red dots in the figure). Downtown Chattanooga, Eastgate Town Center area and the intersection of Highway 64 and Bonny Oaks Dr were deemed hot spots. These hotspots corresponded to commercial areas, where a high number of pedestrian activities was expected.

4.1.3.2 Opportunities

APC data are already used in transit demand analysis and for recording ridership for the National Transit Database. The opportunities for using APC as a proxy for pedestrian activities are as follows:

1. Since transit riders are usually pedestrians before and after using the bus, APC data could be a surrogate of pedestrian activity.
2. This method can be implemented at no additional cost, as most transit agencies have already deployed APC devices.

4.1.3.3 Limitations

This method has the following limitations:

1. APC count data has errors and inconsistencies (Berrebi, Gibbs, Joshi, & Watkins, 2020).
2. The research on APC data as a proxy for pedestrian activity is still missing in the literature.

4.1.3.4 Implementation

The critical issues for the implementation of using APC data as a measure of pedestrian activities are the following:

1. Locations with a higher transit ridership rate are likely to predict pedestrian activity using APC data more accurately.
2. The validation of APC data with actual pedestrian and passenger counts could correct the errors and inconsistencies of data.

4.1.4 Shared micromobility data

The number of shared micromobility devices, particularly electric scooters, has increased exponentially over the last two years (NACTO, 2019). Shared electric scooter systems collect a massive amount of data on trips and the location of devices. This section describes the potential use of such data conceptually, opportunities, and issues related to micromobility data.

4.1.4.1 Conceptual description

GPS-enabled micromobility devices allow service providers to collect location and status (e.g., battery level) of each vehicle and information about trips (e.g., start and end location, route data, and such). These data usually follow standard data formats such as the Mobility Data Specification (MDS) and the General Bikeshare Feed Specification (GBFS) (Lempert, 2019). The MDS standard was initiated by LADOT that builds upon GBFS by including additional information such as trip trajectory/route information and the status of vehicles unavailable due to redistribution, maintenance, or low batteries.

Calculating summary statistics of MDS data can provide basic information on trip distribution, such as the number of trips starting at specific locations and times as well as the distribution of available vehicles within the city. Linking MDS data with other datasets, like land use, can also explain travel behavior. For instance, the trip purpose is an essential piece of information to assess the impacts of e-scooters. However, the trip purpose is not available in data standards such as MDS. The research team applied unsupervised machine learning to infer trip purposes on 79,009 e-scooter trips in Nashville, Tennessee, during March of 2019 (Shah, 2020). The model identified nine distinctive clusters of scooter use patterns by supplementing land use data at start and end locations, such as population and employment density, land use type, and parking capacity (Figure 24).

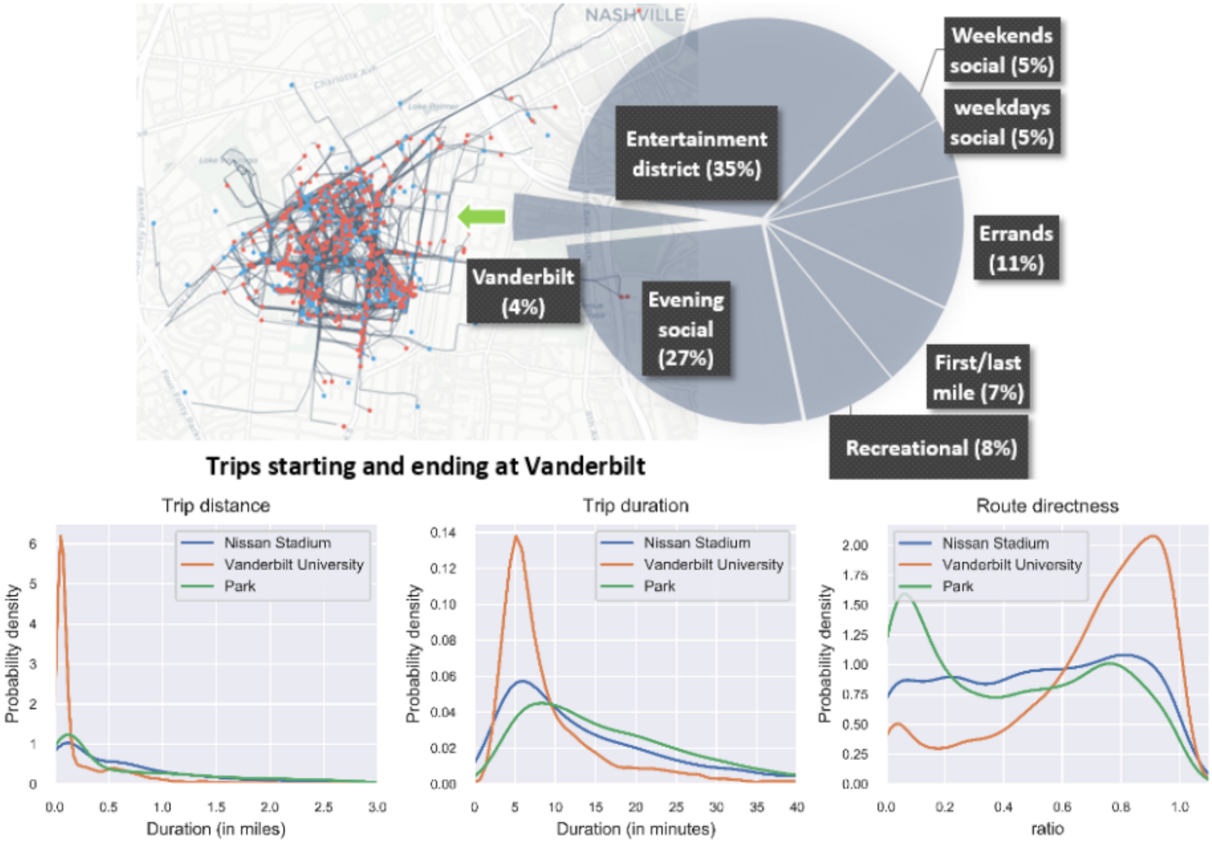


Figure 24: Market segmentation of e-scooter use in Vanderbilt University, Tennessee (Source: (Shah, 2020))

Figure 24 also illustrates the trip characteristics of Vanderbilt University as one of the identified clusters. Although the university attracts 4% of all scooter trips in Nashville, it is distinctive in its e-scooter trip patterns in that these trips are shorter in time and distance.

4.1.4.2 Opportunities

The opportunities for data generated by micromobility are as follows:

1. Micromobility data, such as from shared e-scooters, can leverage information about where and when these devices are being used.
2. The data can enable us to understand the distribution of micromobility devices across various neighborhoods in the city.
3. Revealed preference models can provide insights on travel behavior, system operation, and other aspects of shared micromobility systems.

4.1.4.3 Limitations

Some of the limitations are as follows:

1. The data generated by micromobility devices do not have contextual information, like trip purposes; however, some of this could be inferred using techniques such as machine learning.
2. Micromobility data could contain Personally Identifiable Information (PII), which should be handled with caution to protect privacy.

4.1.4.4 Implementation

Critical issues for the implementation of micromobility data are as follows:

1. The city transportation agency should thoroughly discuss data licensing during the regulation and licensing of micromobility service providers.
2. Data handling might require expert skills and dedicated hardware.

4.3 Push-button traffic signals

Several studies have explored the possibility of using pedestrian push button actuation as a proxy for pedestrian volumes at signalized intersections. This section will discuss the concept, opportunities, limitations, and implementation of this method to estimate pedestrian volumes at a signalized intersection.

4.3.1 Conceptual description

In a typical intersection, there are two main types of pedestrian signal phasing configuration:

1. Pedestrian phase on recall mode: Individual pedestrian movements on a signalized intersection can be automatically granted a phase every cycle, regardless of activation of the push-button by a pedestrian.
2. Pedestrian phase by actuation of a push-button: The pedestrian phase is served only when the pedestrian button is pushed. Figure 25 shows a typical pedestrian push button.

With the implementation of Automated Traffic Signal Performance Measures (ATSPMs), agencies can collect data on the number and time of activations of pedestrian pushbuttons, as well as the time of service of a pedestrian interval. Figure 26 is an example of ATSPMs data demonstrating pedestrian activity and pedestrian delay throughout 24 hours.

Figure 25: Pedestrian phase actuation button. Source: pedbikeimages.com - Dan Burden (2006)

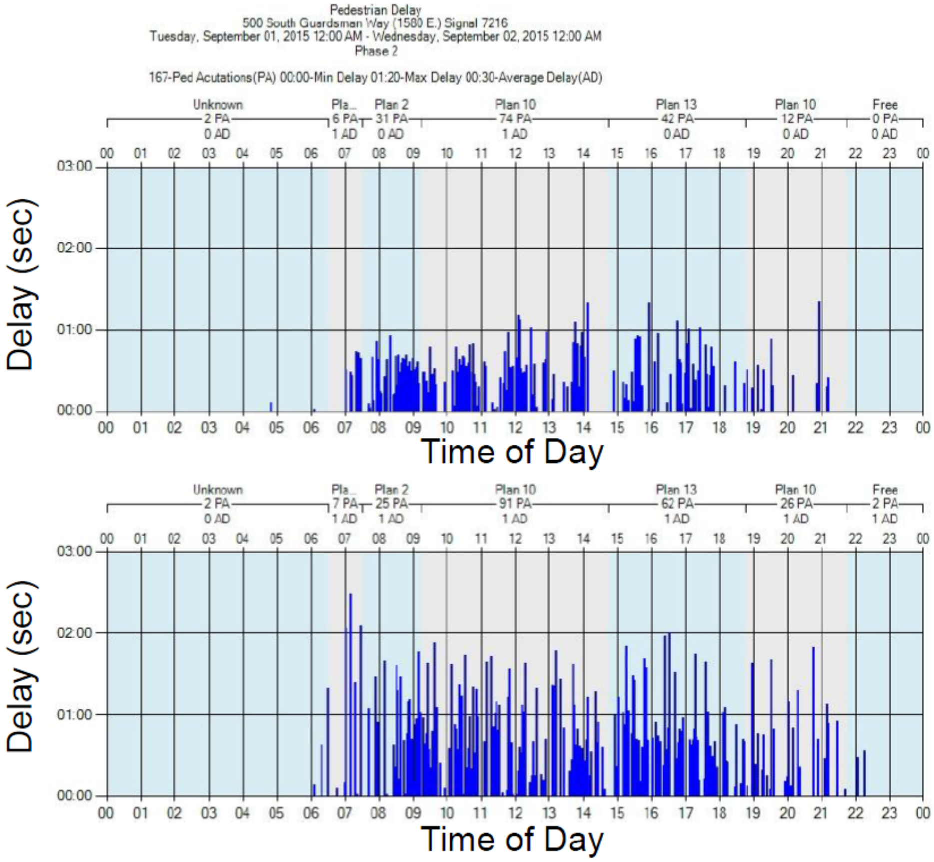


Figure 26: Pedestrian push-button activation on a typical intersection

The servicing of a pedestrian phase by pushing an actuation button implies that there is a presence of a pedestrian. Thus, the actuation of the pedestrian phase can be a surrogate for the presence of a pedestrian in an intersection.

4.3.2 Opportunities

The idea of using the actuated pedestrian phase as a proxy for the pedestrian volume is a relatively new concept in the literature. Although this idea still requires validation in the field, this approach can be one of the more cost-effective methods because of the low cost of collecting pedestrian phase logs. Further, this method can be scaled to leverage existing traffic signal infrastructure to estimate pedestrian activity in many areas.

Several studies have found a strong correlation between pedestrian volume and actuation frequency (Blanc, Johnson, Figliozzi, Monsere, & Nordback, 2015; Day, Premachandra, & Bullock, 2016; Kothuri, Nordback, Schrope, Phillips, & Figliozzi, 2017). Day et al. (2016) also evaluated the influence of time of day/week/year variation, temperature and precipitation, and special events (like sports games) at the signalized intersection at Purdue University campus.

4.3.3 Limitations

The pedestrian phase actuation can be used as an estimate of pedestrian activity only if the pedestrian phase is actuated. Blanc et al. (2015) summarized the lessons and limitations of a 24-h pilot study conducted in Oregon, which is as follows:

1. The pedestrian phase is a good approximation of pedestrian volume if the push button is present and working well, with each pedestrian crossing after they activate the push button.
2. The pedestrian volume could be overestimated when a pedestrian pushes two different buttons for two directions at the same corner. This will grant and log two pedestrian phases for one actual actuation
3. Depending on the pedestrian group and flow rate, the approximation of pedestrian activity could be biased. For example, a group of pedestrians could underestimate the total number of pedestrians.
4. The pedestrian volume could be overestimated if bicyclists use the pedestrian push button at an intersection.

4.3.4 Implementation

Signalized intersections equipped with modern signal systems usually have some logging mechanism built in their signal controller. Thus, theoretically, the pedestrian activity can be detected at those intersections. Some of the critical criteria for the application of this technique are as follows:

- The signal controller should be able to record the pedestrian actuation.
- All approaches should have a pedestrian actuation phase.
- Consideration of site-specific factors (like surrounding land use and demographics) could affect pedestrian activity level and group size.

- Consideration of geometric design of the intersection that could influence pedestrian movement (for example, a pedestrian using two crosswalks at the same intersection) or use of the push button by a bicyclist needs to be assessed.
- The model should be calibrated to adjust location-specific characteristics and temporal variation of pedestrian activity.

4.2 Emerging technologies

4.2.1 Leveraging pedestrian detection technology of CAV

Connected and Automated Vehicles (CAVs) (also referred to as connected and autonomous vehicles or driver-less cars) are regarded as evolving technologies with the potential to reduce traffic accidents and improve the efficiency of the transportation system (Elliott, Keen, & Miao, 2019). CAVs are also equipped with pedestrian and bicyclist detection technology to avoid collision and safely maneuver the vehicle in mixed traffic. Subsequently, the data generated by the detectors can be used to measure walking and bicycling activities.

4.2.1.1 Conceptual description

CAVs have wireless connectivity for communicating with the internal and external environment. They have an in-vehicle information system to inform vehicle performance as well as sensors for situational awareness of surrounding vehicles and pedestrians. Furthermore, each CAV can be considered a building block of the Internet of Vehicles (IoV), which is a dynamic communication system that collects, shares, processes, computes, secures information, and enables Intelligent Transportation System (ITS) (Liu, 2011). CAVs can support vehicle-to-sensor on-board (V2S), vehicle-to-vehicle (V2V), vehicle-to-road infrastructure (V2R), vehicle-to-pedestrian (V2P), and vehicle-to-internet (V2I) communications (Lu, Cheng, Zhang, Shen, & Mark, 2014), as shown in Figure 27. Detection of pedestrians or bicyclists by any CAV could potentially be shared among other CAVs as well as with a central database. Therefore, the pedestrian and bicycle detection system of CAVs could potentially be used to monitor walking and bicycling activities.

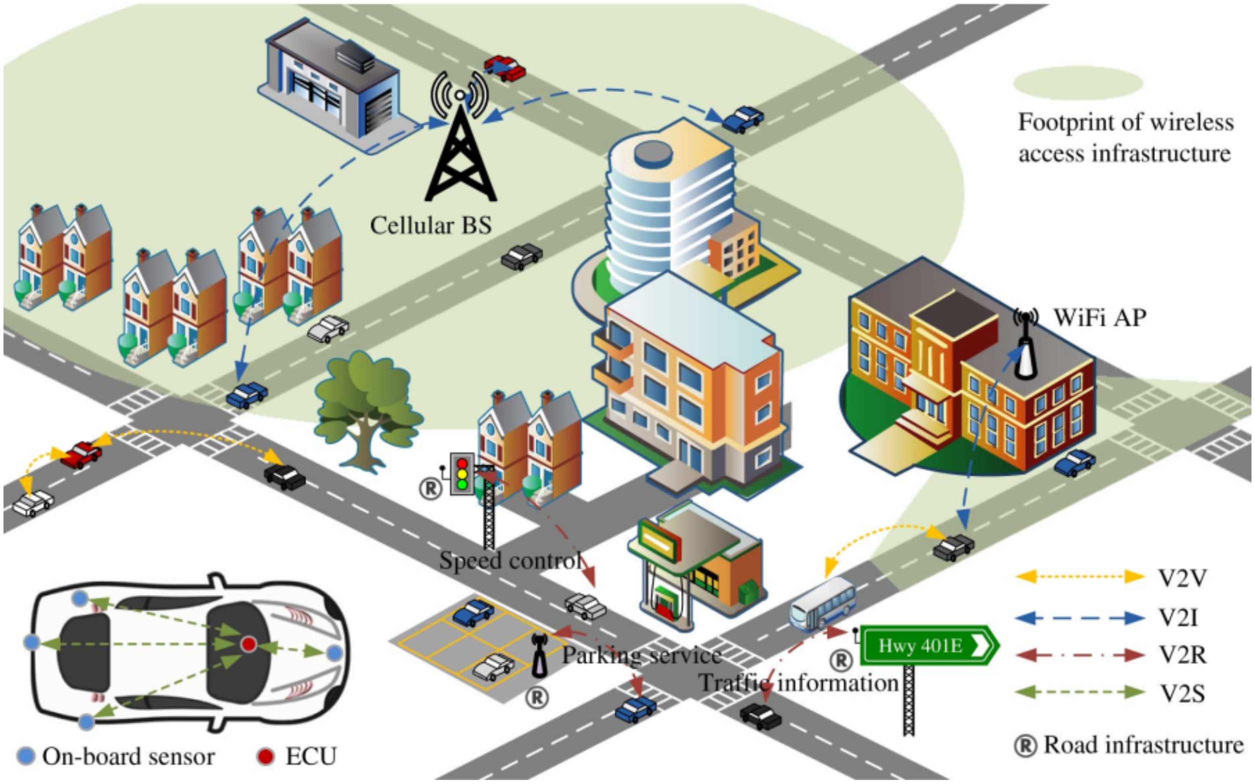


Figure 27: Communication framework of CAV (Source: Lu et al. (2014))

4.2.1.2 Opportunities

While pedestrian and bicyclist monitoring is a byproduct of data generated by CAVs, the opportunities for such techniques are as follows:

1. The data from CAVs can be one of the components of a broader pedestrian and bicyclist monitoring system that does not require additional sensors or equipment.
2. The data collected by this method could be useful for safety analysis, such as pedestrian-vehicle or bicycle-vehicle interaction for crashes and near misses.
3. Depending on the system design, the monitoring of non-motorized activities could be real-time.

4.2.1.3 Limitations

The limitations of using the data generated by CAVs to measure walking and bicycling activities are as follows:

1. The idea of using sensors from CAVs to monitor non-motorized volumes is conceptual, as CAV technology is still in a developmental phase.
2. Geographical coverage of data collection could be limited to CAVs movements. For example, the technology might not be able to detect people and bicycles in wide sidewalks nearby.

4.2.1.4 Implementation

A few of the fundamental implementation issues for this method are as follows:

1. Data standards should have sufficient information on pedestrians/bicyclists, such as detection location and time, that would allow for the monitoring of non-motorized modes.
2. The data source should be validated to understand any biases, errors, and inconsistencies.

4.2.2 Analysis of emerging smart city infrastructure

Smart cities are a growing idea that relies on sensor technologies, as well as data transferring and processing. Caragliu, Del Bo, and Nijkamp (2011) defined smart cities "when investments in human and social capital and traditional (transport) and modern (ICT) communication infrastructure fuel sustainable economic growth and high quality of life, with a wise management of natural resources, through participatory governance."

The integration of Information and Communication Technologies (ICT) and devices connected in a network (Internet of Things (IoT)) can help to improve the efficiency of operations and services in the city (Hammi, Khatoun, Zeadally, Fayad, & Khoukhi, 2017). Smart city technology is also capable of monitoring active transportation modes like walking. This section is a review of pedestrian counting methods using smart city infrastructure.

4.2.2.1 Conceptual Description

Smart city infrastructure can count people using technologies such as video cameras, thermal cameras, radio frequency identification (RFID), and Wi-Fi probe requests. Cities around the world like Melbourne, New York, Auckland, and Barcelona are already implementing these technologies to monitor pedestrian movements. For example, visualizations of hourly pedestrian data for Melbourne can be accessed through the following link: http://www.pedestrian.melbourne.vic.gov.au/. These sensors are equipped with wireless communication so that the logged data are transferred to a central server every 10-15 minutes (Carter et al., 2020).

Smart city infrastructure aims to provide a complete picture of mobility by supplementing pedestrian counts with other data sources like parking and transit. Figure 28 illustrates the data flow of smart city infrastructure. The data collected from sensors requires appropriate processing and aggregation to quantify the movement of people and vehicles. Further, the numbers are simplified into visualizations, which is easier to process and use to make informed decisions.

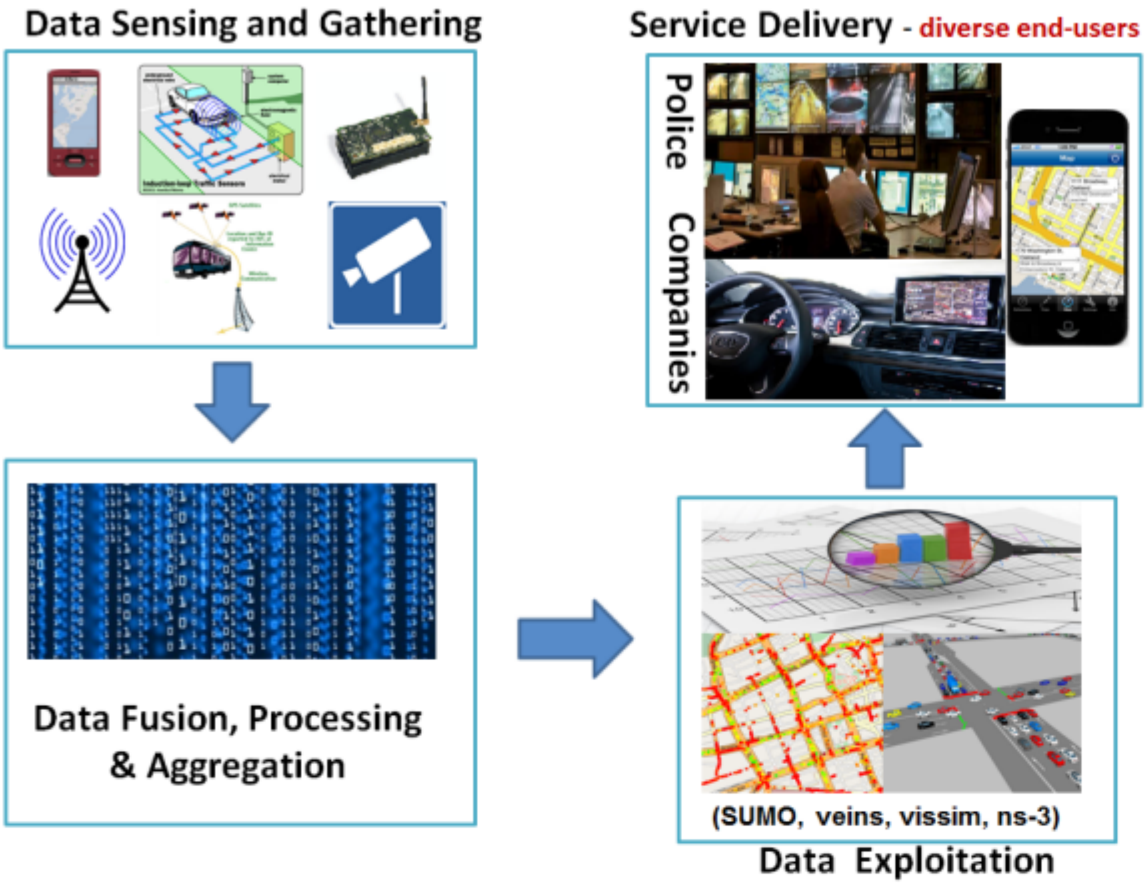


Figure 28: Flow of data in smart cities (Source: Djahel, Doolan, Muntean, and Murphy (2014))

4.2.2.2 Opportunities

The data generated by smart city infrastructure are massive; subsequently, a Big Data approach should be taken to support data generation, processing, and applications. Some of the opportunities for these technologies are as follows:

1. Smart city technologies are capable of handling and processing massive data in nearly real-time to facilitate effective data-driven decisions.
2. The data generated could potentially overcome the barriers of traditional data. For example, a continuous data collection of the pedestrian activities can explain time variations more accurately than short-duration counts.
3. Additional data sources, such as social media, could add contextual information about mobility. For instance, Twitter and Facebook data are already popular among business analytics to understand the marketing behavior of consumers.

4.2.2.3 Limitations

While smart cities have the potential to quantify mobility in urban areas, some of the limitations are as follows:

1. An incoherent smart city infrastructure could be "data-rich and information poor," where the vast amount of data does not necessarily add additional value.
2. Data privacy and security are a primary concern as these technologies can collect Personally Identifiable Information (PII), such as facial attributes from a video camera.
3. Smart city infrastructure requires a significant capital investment to enable detection, transferring, and processing of extensive amounts of data.
4. The implementation of these technologies is still in the developmental phase, and further exploration of the method is ongoing.

4.2.2.4 Implementation

A few issues for implementation of smart city infrastructure are as follows:

1. High bandwidth communication and a large storage system are required to handle and archive data generated by smart city infrastructure.
2. All the detection technologies should collect similar data in the same format. For instance, bicycling data collected by a video camera and infrared counter should (at least) collect detection time, while a video camera can also collect additional information like the speed of a bicycle.

Chapter 5: Integrating technologies for count program

Accurate, easily accessible travel data is an essential resource for any public transportation agency that wants to build a clear understanding of travel patterns, preferences, and behaviors. This data is used to identify safety and capacity deficiencies, prioritize future infrastructure investments, and inform transportation policies. Procedures to gather, process, and share travel data on the movement of automobiles, trucks, and other road-going vehicles are well-established.

The science of gathering and aggregating bicycle and pedestrian count data into a cohesive dataset that describes non-motorized travel over large areas, regions, or states is not yet mature. While every state has a vehicle count program that conforms with uniform federal criteria, most states either had no statewide non-motorized counting program or were in the early stages of assembling such a program as recently as 2018 (Ohlms et al., 2018). The Tennessee Department of Transportation should carefully consider available counting and data options, prioritize these options to meet its needs and resources, and establish a comprehensive plan that combines multiple data sources into a single data system that provides accurate and appropriately-detailed information to transportation decision-makers and stakeholders across the state.

This chapter will discuss the factors that should be considered in this process, building on the information presented in earlier sections if this report and setting the stage for the recommendations detailed in the concluding Chapter 6 and accompanying implementation guide.

5.1 Developing Approaches to Scale Existing Bicycle and Pedestrian Count Data for Tennessee

A wide range of non-motorized count data technologies and sources are available to transportation agencies. In general terms, these options include manual counts, automated counts, crowdsourced data, and emerging technologies. The cost, quality, coverage, and resolution of these datasets vary widely among these options. Proulx and Pozdnukhov (2017) identify six dimensions, or characteristics, of bicycle travel data that should be considered for individual data sources. These dimensions include population scope, trip aggregation, temporal scale, temporal resolution, spatial scale, and demographics (Proulx & Pozdnukhov, 2017).

Differences among these characteristics can create an incoherent dataset, meaning that it is difficult or impossible to combine or make direct comparisons between individual data sources. Organizations using multiple sources of non-motorized travel data should first identify these incompatible characteristics and then develop a plan to adjust, or scale, data in such a way that these differences are eliminated.

5.1.1 Overview of Cost, Resolution, and Coverage of Bicycle and Pedestrian Count Technologies

Bicycle and pedestrian count data sources cover a wide range of geographic coverage, data resolution, and cost. Even at the city level, no single technology presents an economically feasible solution for high-resolution, high-coverage travel data. Budget and time limitations typically force organizations to gather detailed data at a limited number of locations or rely on a mix of data sources to cover their area of interest.

At one end of the spectrum, point-based counts (manual and automated) provide high-resolution data with limited geographic coverage. Permanent count stations, using video, pneumatic tubes, inductive loop detectors, passive or active infrared, piezoelectric strips, radio signals, pressure, and acoustic pads, magnetometers, fiber optic pressure sensors, or a combination of technologies, are capable of providing detailed data that is very close to the ground truth. Permanent counters continuously monitor bicycle and/or pedestrian traffic 24 hours per day, seven days per week, 365 days per year. They capture variations in traffic associated with the time of day, the day of the week, climate and weather conditions, holidays, and other special events. However, permanent count stations are expensive to purchase and install and require regular maintenance, often by skilled professionals. For this reason, permanent counters are typically used only at locations of importance or to establish patterns that can be used to adjust short term counts at other locations.

Short-term high-resolution counts can be conducted manually or using automated counters. Manual counts are effective in locations where it is difficult to deploy automated counters or to separate bicycle and pedestrian traffic from vehicle traffic. Trained observers can capture demographic data, track movements at intersections, helmet use, and compliance with traffic regulations and traffic control devices. Manual counts can be conducted on location or after the fact of using video recordings. Manual counts are easy to implement, but they are labor-intensive. Most individuals begin to tire after two hours of counting. This fatigue affects the accuracy of the count. To reflect this issue, manual counts should be ended after two hours, or the individual performing the count should be relieved after two hours.

Manual counts from the video are generally considered more accurate than manual counts in the field. Video recordings give observers the ability to pause or replay footage to ensure that the count is accurate and complete (Ryus et al., 2014a). While accuracy is often improved with video, these counts do require cameras, additional labor to install cameras, replace batteries, and retrieve data, and may require special software for playback and count data capture. As with permanent count stations, manual counts provide high-resolution count data. Unlike permanent counters, manual counts provide data in a limited period that can range from an hour to a few weeks.

Automated short-term counts are gathered using many of the technologies described for permanent count stations. While automated counters do not require constant monitoring, organizations should have trained personnel available to install, remove, and maintain count equipment. Individual counters range in cost from several hundred dollars to several thousand dollars. For large geographic coverage, the investment in this technology can be significant. Counters may be damaged or stolen, adding to count program costs. Not every detection technology is appropriate to all locations, meaning that the organization may need to have multiple count technologies available. In general, automated counters provide high-resolution data over two weeks or less.

At the other end of the spectrum, travel surveys, passive data collection from cellphone signals, Bluetooth, and Wi-Fi, and active data from smartphone apps, fitness and activity trackers, and bikeshare programs provide transportation organizations with datasets that capture a large number of travelers in a wide area. These datasets can be purchased from commercial data aggregators or obtained from bike-share operators or other data owners, providing wide coverage at a relatively low cost compared to permanent count stations or field counts. While these sources provide high-coverage data, they typically do so at a reduced resolution. Additionally, many sources capture only a subset of pedestrians and bicyclists (e.g., bikeshare riders, not other bicyclists). Travel surveys often capture origin-destination, trip purpose, mode splits, and even route selection. While surveys provide useful insight regarding travel patterns and preferences, their relatively small sample sizes are not useful in establishing count data.

Passive travel data sources use technology such as mobile phone positioning (MPP), GPS, and location-based services (LBS) This data is attractive in that a majority of travelers carry cellular telephones as they move from location to location during the day. Passive technologies require no action or even consent from individual travelers, meaning that the data collected from these sources include a high percentage of the traveling population. Passive datasets also cover large geographic areas. Datasets typically include origin-destination, travel distance, average speed, trip purpose, and route choice. Some datasets, such as AirSage's MPP travel data, may have insufficient resolution to capture walking trips. Other datasets may not distinguish trips by mode, particularly in conditions where bicycles may travel at speeds similar to those of vehicles on the same route. Some travelers may not carry a cell phone as they travel, and some datasets rely on travelers activating phone features or granting permissions to applications. Passive data is aggregated to protect personal information, including demographic information that may be of interest to transportation organizations. Organizations should purchase these datasets from commercial data aggregators, including Streetlight, INRIX, and AirSage.

Active data sources, including those collecting travel information from fitness and activity-tracking applications and devices and bike-share programs, collect detailed information for a specific subset of travelers. As the name implies, these travelers should take action to contribute to these datasets. For information from fitness tracking apps, such as Strava, users should initiate tracking using a smartphone application. This data is recorded and aggregated. Bike-share tracking relies on users that pay single-use or subscription fees to use shared bicycles. Bike-share data may be representative of all bicycle trips within the company's service areas, but trips can be limited by the location of bicycle docks and program pricing schemes. Datasets such as Strava Metro should be purchased from private companies and could include flows on links and is potentially representative for specific segments of the bicycling population. Bikeshare (or scooter share) data may be available from service providers at no cost as a condition of their business licensing or permit agreements with local or state governments.

5.1.2 Potential Approaches to Scale Count Data for Higher Temporal and Geographic Coverage

Agencies using a combination of the count technologies and resulting data described in the previous section should devise a plan to combine disparate datasets into a single, coherent system. Proulx and Pozdnukhov (2017) describe this process of bringing datasets into compatible terms as “homogenation.” Traditional scaling approaches, such as the process described in the Federal Highway Administration’s *Traffic Monitoring Guide* (2016), use temporal patterns identified at permanent count stations to expand short-duration counts conducted at sites with similar characteristics. Recently, researchers have explored scaling methods that blend high-coverage, low-duration datasets such as Strava Metro with short-duration count data or other high coverage datasets (such as Bikeshare and travel data) to produce high-coverage datasets with increased accuracy.

These scaling efforts should address both the geographic and temporal coverage of the count data. This process typically results in estimated or predicted traffic volumes on a specific segment across the transportation network, often in terms of average annual daily bicycle traffic (AADBT) or average annual daily pedestrian traffic (AADPT).

The simplest form of scaling for higher geographic coverage involves creating a set of temporal adjustment factors that are applied to short-duration counts based solely on a limited set of characteristics of the count site. These characteristics may describe the location of the count location (urban versus rural, for example), the type of facility (e.g., street versus trail), or adjacent land uses (e.g., commercial versus residential). Patterns are established from data gathered at permanent count stations with a specific subset of these characteristics. These patterns are assumed to be accurate for all short-duration count locations with similar characteristics. These count factors are easy to calculate and apply but are often less accurate than other methods.

High-coverage, low-resolution datasets can be used as the primary input for a predictive statistical model. One example of this approach is found in a 2019 study by Roy, Nelson, Fotheringham, and Winters (2019). The researchers used Strava Metro data as the basis of a predictive model that would calculate predicted Average Annual Daily Bicycle Traffic (AADBT) counts for every street in Tempe, Arizona. Strava data were correlated to high-resolution demographic, socio-economic, travel, and land use datasets. The model was “trained” using count data from 44 locations across Maricopa County (where Tempe is located) and validated using count data from 60 locations in Tempe. Ultimately researchers found that the model was useful in adjusting for the biases inherent to the Strava dataset, resulting in predicted counts that were within a margin of ± 100 average annual bicyclists at 86% of the Tempe count sites (Roy et al., 2019).

A final approach for geographic scaling of data is to use a data fusion method were multiple high-coverage datasets are merged to create a new dataset with increased accuracy. A 2017 article by Proulx and Pozdnukhov (2017) describe their experience in using an approach they named “Geographically Weight Data Fusion” to merge multiple datasets into a single model used to predict directional bicycle volumes on all network links for a specific period. This effort combined data from manual counts, two travel demand models, a bike-share program, and Strava Metro. Their approach compensates for spatial biases in the individual datasets by changing model parameters to fit a specific location. The researchers concluded that the resulting predictive model was more accurate than any of the individual datasets or a combination of the datasets using a single set of corrections (Proulx & Pozdnukhov, 2017).

Temporal scaling is used to expand short-duration counts to reflect expected traffic over a longer period. Temporal adjustment factors, typically derived from permanent count station data, include the time of day, day of the week, and month or season of the year (FHWA, 2016). Some research has shown that day of the year factoring is more effective than the traditional day of week and month of year adjustments because it captures the effects of changing weather conditions (Hankey, Lindsey, & Marshall, 2014). These temporal adjustments will be described in greater detail in Chapter 5.2.

5.2 Methods for Time-of-Day, Day-of-Week, Month-of-Year, and Day-of-Year Factoring for Count Data

A key consideration in a bicycle and pedestrian count program is the development of temporal factor groups and assignment of short duration count (SDC) locations to the correct factor group. This process can be complicated because we rarely know the long-term patterns at SDC locations. One approach is to identify the travel pattern at the count site using a crowdsourced dataset. For instance, we could have a permanent bike counter that follows a weekend-dominant pattern, and the crowdsourced data at that location also follows a weekend-dominant pattern. We then can assume that other locations with a weekend-dominant pattern in the crowdsourced data follow that pattern overall. Therefore, SDCs at those locations can be adjusted using the weekend-dominant factor group.

5.2.1 Review of factoring methods

In the early stages of developing a count data program, the organization should consider travel patterns and site characteristics that may affect bicycle and pedestrian traffic across the city, region, or state. At least one (and preferably more) continuous count stations should be established for each possible combination of factors. The resulting temporal adjustment factors will be used to expand SDC data to the desired annual average daily traffic estimate at each count location.

5.2.1.1 Factor Grouping

The Traffic Monitoring Guide (TMG) (FHWA, 2016) identifies travel patterns as the most critical element in factoring count data. The TMG divides non-motorized travel patterns into three categories: commuter and work/school-based trips, recreation/utilitarian, and mixed trip purposes. The TMG also discusses the role of facility type and adjacent land use but concludes that trip purpose is the best predictor of time-of-day and day-of-week patterns. Ideally, each factor group will have three to five permanent count stations. Continuous counting locations should be representative of travel patterns, allow for accurate and separate counts of bicyclists and pedestrians, and possess characteristics that favor the selected detection technologies (FHWA, 2016).

The Washington State DOT’s bicycle and pedestrian counting guide describe their approach to creating and applying factoring groups. Sites are first classified by travel patterns (Commute, Multipurpose or Mixed, and Non-Commute or Noon Activity). Factor groups also consider the region of the state (for this purpose, Washington is divided into four regions: Coast Range, Puget Lowland, Cascades, and Eastern Washington) and the mode of travel (bicycle or pedestrian). Each combination of factors describes a different set of travelers, trip purposes, weather conditions, and terrain. WSDOT also recommends that permanent count locations have a moderate bicycle and pedestrian volumes (more than 100 but less than 1,000 per day) and suggest that pinch points such as bridges are ideal locations to capture representative samples of travel in a given area (Johnstone et al., 2017). The Minnesota DOT Bicycle and Pedestrian Counting Program identify four travel patterns: commuter, mixed-commuter, multipurpose, and multipurpose-mixed (Greg Lindsey, Petesch, & Hankey, 2015).

Permanent count locations should be selected carefully to ensure that expected travel patterns are present. WSDOT recommends conducting a short duration count at candidate sites to verify travel patterns before the permanent count equipment is installed. If the SDC indicates a different travel pattern than expected, the organization should consider another site that represents the intended pattern. If permanent count stations do not collect representative data, the organization will not be able to produce accurate estimates of AADBT or AADPT (Johnstone et al., 2017).

Finally, the WSDOT bicycle and pedestrian counting guidebook also stress the importance of applying the correction adjustment factors to SDC data. The authors present an example where count data from a site in Eastern Washington with a non-commute travel pattern are adjusted using factors from a count station in the Puget Lowland region with a commuting pattern. The example demonstrates the magnitude of error in AADT estimates resulting from the application of incorrect adjustment factors. In this case, 21 of 24 hours would result in absolute estimation errors of 25% or greater, and 14 hours would result in errors of 50% or greater (Johnstone et al., 2017).

5.2.1.2 Temporal Factoring

Once factor groups are established, permanent count station and crowdsourced data can be used to develop temporal adjustment factors for each group. Traditional factoring approaches such as those shown in the FHWA TMG, develop individual adjustment factors for the day of the week and the month or season of the year. Some agencies, such as the Washington State DOT (Johnstone et al., 2017) and the Minnesota DOT (Greg Lindsey, Hankey, Wang, & Chen, 2013), also produce the time of day adjustment factors that allow organizations to expand very short counts collected during expected peak hours to AADBT or AADPT.

In their simplest form, these adjustments are applied as expansion factors that expand count data from a short period to a longer period. Expansion factors are calculated from permanent count station data using the formula shown in Figure 29.

$$\gamma_t = \frac{\sum_{i=1}^{N} Volume_i}{Volume_t}$$

where

γ_t = the expansion factor for time period t,
$Volume_i$ = the volume during time period i,
$Volume_t$ = the volume during time period t, and
N = the set of all time periods i.

Figure 29: Expansion Factor for Short Duration Count Data (Ryus et al., 2014a)

This expansion factor can be used to expand from a single hour to a single day, from a single day to a complete week, or from a month to a year (Ryus et al., 2014a).

It is more common for state data programs to develop adjustment factors that convert a daily count total to estimated annual average daily bicycle traffic (AADBT) or annual average daily pedestrian traffic (AADPT). This approach may separate adjustment factors for the day of the week and month of the year or a single adjustment factor specific to the day of the week in each month. The FHWA *Traffic Monitoring Guide* presents a detailed example of how continuous count data is used to adjust SDC counts at a nearby location with similar characteristics. Correction factors for the day of the week are a ratio of average traffic on a specific day (e.g., Thursday) to monthly average daily traffic (MADT). In this example, a different set of day-of-week factors is calculated for each month. The second correction factor (month) is set by the ratio of MADT to AADT. As with the day-of-week adjustment, each month has its correction factor. For SDC, including data from multiple days, the day-of-week adjustment is applied using an average correction factor for the days of the count and average daily traffic throughout the count (FHWA, 2016).

In some cases, mainly where manual count data is collected, SDC may cover less than a complete day. Agencies can also develop expansion or adjustment factors to expand a count as short as one hour to an equivalent daily total, which is then expanded to produce an estimate of AADT or to adjust directly from the hourly count total to AADT. These hour-of-day adjustments may use a single set of values for factor groups on all days. Hour-of-day adjustments also may be tailored to specific travel patterns, mode, day of the week, weekdays versus weekend, or month of the year. Nordback, Marshall, Janson, and Stolz (2013) found that the use of one-hour coverage counts produced AADT estimates with average estimation errors as high as 54% (using any hour between 7:00 am and 7:00 pm on any day of the week). The average error was reduced somewhat (to 42%) by using one hour between 7:00 am and 7:00 pm on a Tuesday, Wednesday, or Thursday (TWorR) or a single TWorR peak hour (Nordback et al., 2013).

Recent research suggests that using day-of-year scaling factors produces less estimation error than the traditional use of day-of-week and month-of-year factors. Nosal, Miranda-Moreno, Krstulic, and Eng (2014) compared four methods of estimating AADBT from 24-hour SDCs. These methods included a traditional approach using separate adjustment factors for day-of-week and month, a traditional approach using a single adjustment factor that combined the effects of day-of-week and month, a weather model method that applies an additional correction factor for weather conditions during the count, and a “Disaggregate Factor Method” that uses the day of the year to calculate an expansion factor. The authors found that the day-of-year method produced the lowest average error in AADBT estimates and that the method’s advantages were most significant for 24-hour counts. Average errors from all four methods began to converge as count duration approached 14 days (Nosal et al., 2014).

Hankey et al. (2014) compared day-of-year scaling to traditional methods and also found that the day-of-year technique produced significantly less error in estimated AADT levels. The authors identified three limitations of the day-of-year scaling approach. First, day-of-year is only useful where the continuous count station and the coverage count location are relatively close. This ensures that the weather at each site is similar. Second, day-of-year scaling factors only apply to the year from which the continuous count data is taken. Finally, day-of-year factors cannot be applied to SDC data in real-time. The data required to develop these factors are only available at the end of the year, and AADT estimates from individual counts cannot be calculated during the year in which the data is collected (Hankey et al., 2014).

5.2.2 Recommendations for Factoring Groups in Tennessee

TDOT should consider the topic of factoring groups early in the process of establishing a bicycle and pedestrian counting program. Several vital references, including the TMG (FHWA, 2016), NCHRP Report 797 (Ryus et al., 2014a), and guides for statewide bicycle and pedestrian counting programs in Minnesota (Greg Lindsey et al., 2013) and Washington State (Johnstone et al., 2017), identify non-motorized travel patterns as a critical factoring group. In the early stages of Tennessee's program, this may be the only grouping factor that can be supported. Considering most count programs identify at least three distinct travel patterns and that the *TMG* recommends a minimum of three to five continuous count stations per factor group (FHWA, 2016), this would mean that TDOT would need to establish between nine and 15 permanent counters across the state.

However, as the program grows (or if initial resources are sufficient to install additional continuous count stations), TDOT may wish to consider additional factoring groups. Additional factoring groups could include population density (urban versus rural), facility type (street versus trail), and region or climate (possibly using Tennessee's three grand divisions of East, Middle, and West or TDOT Regions 1 through 4). Additional consideration could be given to specific locations where patterns, populations, infrastructure, and traffic may vary, including central business districts, tourist areas, and areas near colleges and universities.

5.3 Statewide Bicycle and Pedestrian Data

The data collected by different methods have a different resolution (frequency of data collection as well as information). For example, a pneumatic tube can only collect the number of bicyclists or pedestrian crossing at a point, while a crowdsourcing method can collect route data (at link and polygon level) as well as general demographics of a small sample of bicycle users.

The implementation of statewide bicycle and pedestrian count using is a single method is unfeasible. An agency needs to rely on multiple data sources that complement each other. This section describes the standardization of traditional count data and the expansion of temporal as well as the geographical scale of count program using novel data sources like crowdsource GPS data.

5.3.1 Standardizing Count Data Using Traffic Monitoring Analysis System (TMAS)

The Traffic Monitoring Analysis System (TMAS) is a national database initially developed by the Federal Highway Administration and currently maintained by the Bureau of Transportation Statistics. TMAS is a national repository of traffic count data from continuous counting stations. TMAS establishes a standardized set of sites and counts data attributes to ensure that all count data is consistent regardless of which state submits the data. The 2013 *Traffic Monitoring Guide* introduces standardized TMAS data fields and codes for non-motorized traffic. These codes were updated in the 2016 *Traffic Monitoring Guide* (Laustsen et al., 2016).

Non-motorized (bicycle and pedestrian) count data submitted to TMAS requires two record formats. The Count Station Description Record includes 32 data fields that describe the count location, facility type, direction of travel, factor groups, primary count purpose, and other descriptive site characteristics. This record includes 15 critical, or required, data elements and 17 optional data elements. The non-motorized Count Record contains up to 312 data fields that location, facility type, type (mode) of the count, helmet use, demographic information, sensor technology, weather, time of the count, and counts by time interval (as small as five minutes). 15 of the 24 non-count fields are critical (FHWA, 2016).

5.3.2 Expanding temporal and geographical coverage

Bicycle and pedestrian volume can be counted only for a short duration (a few hours to weeks) due to the cost of data acquisition. These counts are further limited to specific links or intersections of the network. The short duration counts can be expanded on the temporal and geographical scale by applying adjustment factors, as described in Section 5.2. The temporal adjustment factor considers the difference of volumes by hour-of-day, time-of-week, and month-of-year, whereas the geographical adjustment factor accounts for variation in counts by a trip pattern such as commuting and recreational.

Another approach to expand the geographical coverage is the use of models that complement short counts and travel surveys with novel third-party datasets, such as crowdsourced GPS trace and bikeshare data. Studies have used random utility models to evaluate travel activities of individuals, direct demand models of facilities (Kuzmyak et al., 2014), and spatial regression models (Proulx & Pozdnukhov, 2017). These models should be calibrated and validated as the third-party data sources represent only a portion of travel activities. The count implementation guide attached as an appendix to this report has further detail on the calibration and validation of third-party data sources.

Chapter 6: Goals and Recommendations for a Statewide Bicycle and Pedestrian Counting Program in Tennessee

This chapter presents an overview of the recommended practices for bicycle and pedestrian volume data collection and management by TDOT and its partners, including metropolitan planning organizations (MPOs), rural planning organizations (RPOs), local agencies (cities, towns, and counties), and private organizations. Program elements are linked to a series of preliminary count program goals and associated recommendations. A detailed discussion of these goals and recommendations is included in the TDOT Bicycle and Pedestrian Count Program Guidance Manual.

6.1 Bicycle and Pedestrian Count Program Processes

Bicycle and pedestrian count programs consist of a series of related processes, which are shown in Figure 30. They include data collection, data management, analysis, and reporting, and sharing. Count program goals and recommendations are linked to these processes in the following sections.

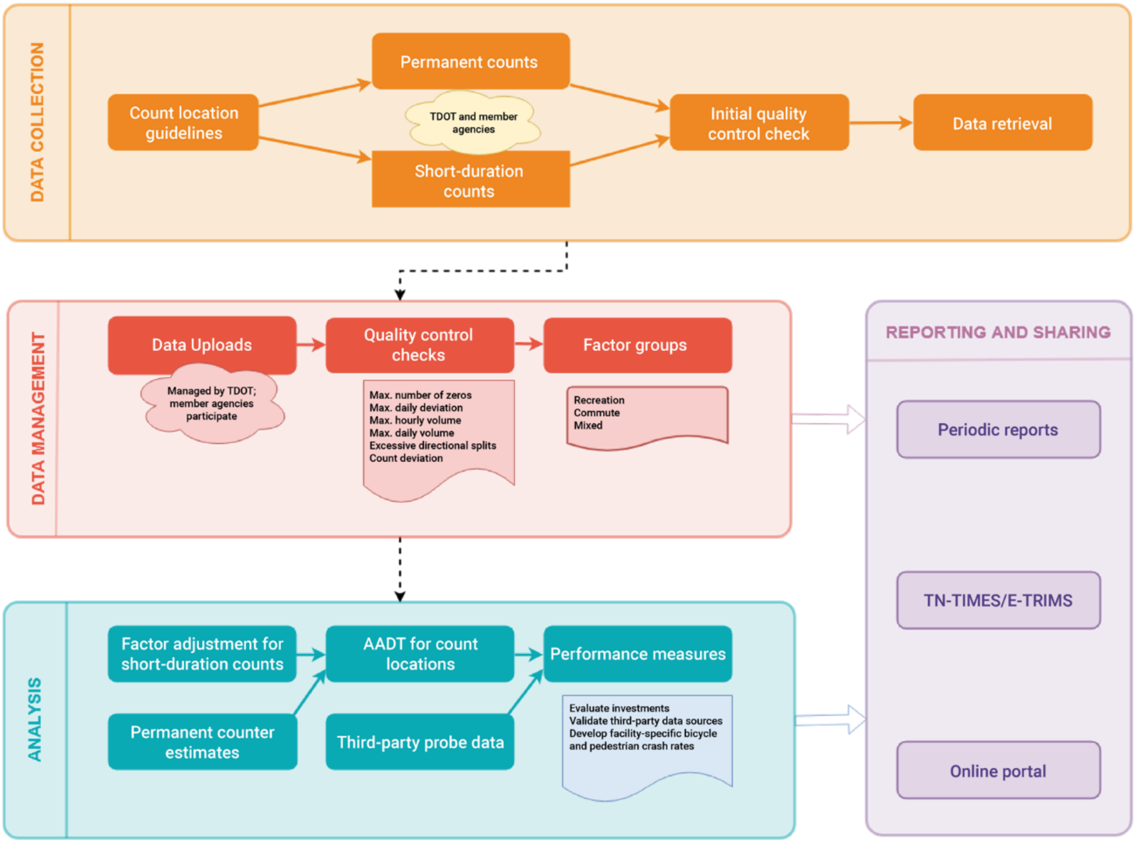


Figure 30: TDOT's Bicycle and Pedestrian Volume Program Structure

6.2 Nonmotorized Count Program Goals and Recommendations

Input from TDOT staff, interviews with local and regional partners, best practices from other statewide bicycle and pedestrian count programs, and a review of current count technologies were used to develop the following five goals for TDOT's statewide nonmotorized count program:

1. Establish a routine pedestrian and bicycle count data collection protocol.

2. Establish and implement a process for data to be consistently uploaded to a centralized database maintained by TDOT.
3. Develop analytical methods and processes for reporting performance measures.
4. Share data with stakeholders.
5. Institutionalize and build capacity for pedestrian and bicyclist monitoring within TDOT and across Tennessee.

Each goal is accompanied by specific recommendations that will ensure that useful bicycle and pedestrian volume data is collected in a consistent and coordinated fashion. Partner agencies that follow these recommendations will benefit from greater consistency with other jurisdictions and enhanced data management and analysis capabilities. Additionally, these recommendations recognize that member jurisdictions and agencies have varying levels of expertise, resources, and capacity to collect and manage count programs.

6.2.1 Goal 1: Establish a Routine Pedestrian and Bicycle Count Data Collection Protocol

TDOT should identify factor groups, assign permanent count sites to appropriate factor groups, convert short-duration count sites with known travel patterns to permanent count sites, and identify Short Duration Count (SDC) locations where counts will be conducted regularly. In the long term, TDOT should add new permanent count sites as factoring groups are expanded or refined and implement and maintain SDC equipment and locations. This goal and accompanying recommendations are focused on the Data Collection process and the Factor Groups element of the Data Management Process shown in Figure 31.

TDOT should evaluate and select preferred count technologies to gather accurate information in a wide variety of situations. This effort will guide subsequent equipment purchases by TDOT and its partners. These choices will cover both permanent counters and portable, short-duration automated counters. A summary of recommended count technologies by context and duration is provided in Table 11.

Table 11: Recommended Count Technologies by Context and Duration

Context	Permanent	Short-Duration Automated
Bicycles in Bicycle Lane	» Induction Loops » Piezoelectric Strips » Automated Video**	» Pneumatic Tubes » Automated Video**
Bicycles in Mixed Traffic*	» Piezoelectric Strips » Automated Video**	» Pneumatic Tubes » Automated Video**
Pedestrians on a Sidewalk	» [Passive/Active] Infrared » Automated Video**	» Passive Infrared » Active Infrared » Automated Video**
Pedestrians in a Crosswalk	» Automated Video**	» Automated Video**
Bicycles and Pedestrians on Multi-Use Trail (separate counts)	» Passive Infrared + Induction Loops » Passive Infrared + Piezoelectric Strips » Automated Video**	» Passive Infrared + Pneumatic Tubes » Automated Video**
Bicycles and Pedestrians on Multi-Use Trail (combined counts)	» Passive Infrared » Active Infrared	» Passive Infrared » Active Infrared

*Bicycle volume data collection in mixed traffic conditions should be limited to low-volume sites with 5,000 motorist ADT or less.

** Due to the proprietary nature and need for third party processing, the full accuracy and effectiveness of the automated video for bicycle and pedestrian counts is still being tested.

TDOT should invest in automated count equipment for use by the Department and its partners. This investment will include the program’s initial permanent automated counters. Using the FHWA *Traffic Monitoring Guide* (2016) recommendations, TDOT should establish 3-5 permanent count stations per factor group. Combined with the initial recommendation for three factoring groups (Recreation, Commute, and Mixed as detailed in Section 6.4), this means that TDOT should plan to install between nine and 15 permanent counters to support the statewide program adequately. TDOT should work with local partners to identify suitable locations and ensure ongoing support for permanent counters. Locations with high volumes of bicycle and pedestrian traffic are ideal for permanent counters.

Short duration count sites should cover a wider variety of locations and volumes than the sites selected for permanent counters. SDC locations should not be limited to high-volume locations to ensure that the overall volume and VMT estimates are not biased. The minimum duration of SDCs should be 24 hours, with one to two weeks as the ideal duration. If shorter counts are necessary, TDOT should consider a mix of one mid-week day (Tuesday, Wednesday, or Thursday) and one weekend day (Saturday or Sunday) to capture the weekday/weekend split at the location. Results are also improved by conducting counts in warm, dry weather when biking and walking activity is common.

Development of TDOT-specific factor groups and associated adjustment factors is an iterative process that will evolve as more data is collected and evaluated. As a starting point, TDOT should categorize sites into three groups, according to their activity patterns. Activity patterns identified from collected data will indicate whether the site is characterized by recreation, commute, or mixed trip types. More specifically, the following metrics are used to determine the activity pattern of a given site (Miranda-Moreno et al, 2013).

- AM peak-to-midday index (AMI). The average hourly volume during weekday morning commute periods (7 am to 9 am) divided by the average midday volume (11 am to 1 pm).
- Weekend-to-weekday index (WWI): The average weekday volume divided by the average weekend volume.

The combination of hour-of-day and day-of-week metrics suggests an overall activity pattern for the site. The specific thresholds for 'commute' and 'recreation' activity patterns should be defined based on a review of data collected from several sites. Initially, suggested thresholds are offered below in Figure 31.

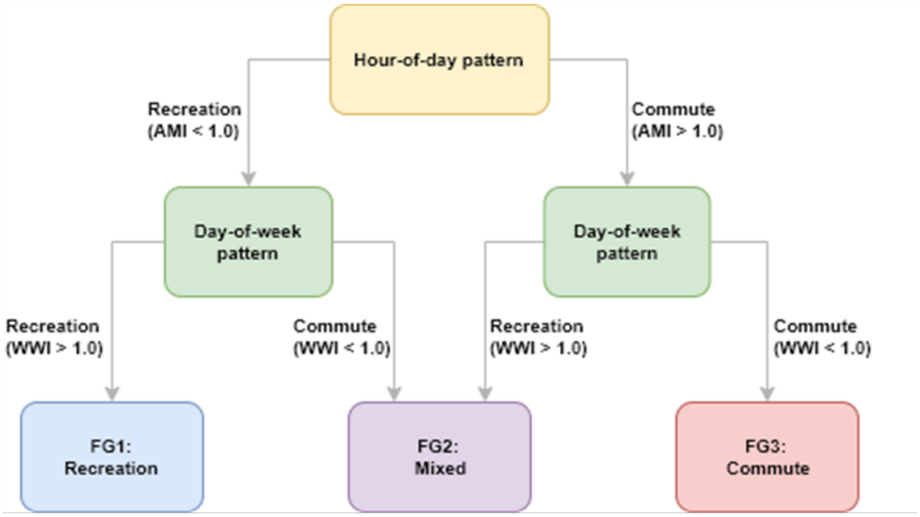


Figure 31: Initial Recommended Factor Group Assignment Thresholds

In addition to reviewing the hour-of-day and day-of-week patterns, TDOT should consider seasonal variation in its factor groups. For sites with a full year of data, a seasonal distribution metric may be calculated using the Warm Month Index. Including the seasonal distribution would introduce an additional layer to the factor group assignment process, resulting in a total of six-factor groups (assuming two seasonal patterns are identified). Factor groups should be reevaluated annually.

6.2.2 Goal 2: Establish and Implement a Process for Data to Be Consistently Uploaded to a Centralized Database Maintained By TDOT

TDOT should adopt a standard count data format (such as TMG), establish minimum data requirements, and implement quality controls for the statewide database. In the long term, TDOT should provide its partners with access that will allow them to upload counts directly to the database. This goal and accompanying recommendations are focused on the Data Uploads and Quality Control Checks elements of the Data Management process shown in Figure 31.

TDOT should develop quality control procedures that will allow the Department and its partners to identify corrupted data and to identify and adjust for systematic under- or over-counting. Corrupted data has many possible causes, including equipment malfunctions, improper installation of count equipment, and damage or vandalism of count equipment. Several quality control rules are proposed. Implementation of these rules will help TDOT identify corrupted data, make appropriate adjustments, or order recounts at affected locations. Systemic undercounting is uniform across all devices using a specific technology or configuration. Undercounting can be corrected using adjustment factors that are determining through short-duration manual counts.

Count data may also capture atypical but non-erroneous data that results from unusual conditions at the count location. Special events may produce unusually high count totals, while unfavorable weather may produce unusually low totals. Using atypical data from short-duration counts may skew the resulting estimate of annual or average daily traffic at these sites.

6.2.3 Goal 3: Develop Analytical Methods and Processes for Reporting Performance Measures

TDOT should develop a reliable factoring process for estimating Annual Average Daily Traffic (AADT) from segment SDCs, develop and test a method for estimating intersection volumes from turning movement counts or other intersection SDCs, and identify a benchmarked set of count locations for long-term trend monitoring. In the long term, TDOT should explore the feasibility of developing a statewide estimate of bicycle miles traveled (BMT) and pedestrian miles traveled (PMT) using count, survey, and crowdsourced data. TDOT should also explore the feasibility of developing statewide safety performance functions for bicyclists and pedestrians using count data as input. This goal and accompanying recommendations are focused on the analysis process shown in Figure 31.

TDOT's analysis of bicycle and pedestrian count data should include the development of count adjustment factors and preparation of guidance and training on the use of these factors, collection of before and after nonmotorized counts to measure the effect of infrastructure projects, and development of bicycle and pedestrian crash rates and safety performance functions. The use of bicycle and pedestrian volume data and generated AADT estimates are essential for determining a project's overall safety impact, as bicycle and pedestrian facility improvements may lead to higher bicycling and walking volumes in addition to changes in crash numbers.

Two factoring approaches are provided in the Factoring Approaches section in Appendix A of the guidance manual, either of which would be appropriate for future use in Tennessee. The first factoring option, the conventional method outlined in the FHWA Traffic Monitoring Guide, is based on motor vehicle traffic monitoring principles. It requires the application of three types of expansion factors: seasonal factors, day-of-week factors, and hour-of-day factors. In the second factoring option, the day-of-year method, each day of the calendar year's daily traffic is evaluated against the AADT for the site, providing an adjustment factor for each calendar day. This approach replaces the seasonal and day-of-week factors in the conventional approach and has been shown to outperform that method when working with permanent counters in relative proximity to the SDC sites. It remains to be seen whether the day-of-year factoring approach translates well to the state level. Ideally, TDOT should compare the two methods to determine which one produces more reliable estimates and under what conditions.

Third-party probe data is quickly emerging as an essential element of traffic monitoring approaches, including for bicycle and pedestrian volume monitoring. Probe data can work in tandem with count data, providing a more comprehensive understanding of bicycle and pedestrian volume throughout the network, and as a reference source for relative volume estimates when before counts were not conducted (assuming no changes in conditions or bicycle or pedestrian volumes). Additionally, probe data can be used to generate volume estimates along well-counted roads as the collected count data can be used to validate and calibrate the probe data. Leveraging probe data in this way will allow TDOT and its partner agencies to expand its count database by "freeing up" counters for new un-counted locations.

Probe data hold the potential for helping TDOT understand bicycling and walking patterns and to calculate the above-discussed performance measures but requires careful validation and calibration to be effective. The collection, management, and analysis processes associated with probe data differ significantly from conventional count data. If TDOT chooses to use probe data in its bicycle and pedestrian count program, the Department must select and apply data calibration and validation techniques.

Calibration of third-party data sources is critical, as these data sources only represent a sample of the traveling public. They are expected to provide estimates that offer insight into relative volumes, such as between two segments in the same area. Third-party activity estimates need to be compared to ground-truth data to identify a calibration factor that scales the estimate so that it is consistent with verified use. The *TDOT Bicycle and Pedestrian Count Program Guidance Manual* detail several options to calibrate these third-party probe data sources. In increasing order of complexity, these options include the Naïve Approach, the Stratified Approach, and the recommended Advanced Approach. A comparison of these calibration methods is presented in Table 12.

Table 12: Calibration Approaches for Third-Party Probe Data Sources

Approach	Pros	Cons	Considerations
Naïve	» Simple to implement and easy to explain. » Fewer ground-truth data points are required compared to other approaches.	» Overall low accuracy. » Accuracy varies across locations.	» The level of variation across locations should be documented before pursuing this method to determine if it is an acceptable approach.
Stratified	» Accounts for inconsistent relationships between third-party and observed activity estimates across location types. » Location types may align with factor grouping methodology. » The method can be implemented incrementally, such as by starting with 2 to 4 location types and expanding over time.	» Cumbersome data requirements for identifying and applying location types. » Requires exploratory data analysis and/or ongoing review of results to determine the appropriateness of location types. » Requires a larger number of ground-truth data points.	» Thresholds for differentiating location types would be needed.
Advanced	» Likely to provide the most accurate segment estimates. » The approach accounts for different contexts. » Data requirements may be lower than the stratified approach outlined above after scaling factors are developed.	» Cumbersome data requirements for initial model development. » Significant statistical modeling expertise is required to develop a model. » Difficult to explain.	» The suggested model functional form is a log link.

Validation is needed to determine how reliable the data is and to identify potential problems with third-party data sources. The primary purpose of validation is to understand how third-party data can be used and when it should not be relied upon. Ground-truth validation of third-party data should use separate data from that used for calibration. The program guidance manual details four options for probe data validation, including Root Mean Square Error and Percent Root Mean Square Error, Scatterplots, Model Comparison, and Trip Length and Temporal Distributions.

The count data used to calibrate and validate third-party data sources should be of the highest quality. Generally, permanent count data that have followed recommended quality control procedures are suitable for use in calibration and validation activities. Importantly, these counts are expected to have been calibrated to minimize equipment errors, to track bicyclists and pedestrians separately, and to record directional information. Short-duration automated counts may also be used in validation if they contain this information. The use of factored counts for validation is not preferred but may be acceptable if limited permanent count data is available for validation.

6.2.4 Goal 4: Share Data with Stakeholders

TDOT should develop templates and standard count report formats, provide annual statewide summary reports, and provide a process to share raw data with partner agencies and stakeholders via an online data management system. In the long term, TDOT should develop an online interactive map to share data with stakeholders and the public. This goal and accompanying recommendations are focused on the Reporting and Sharing process shown in Figure 31.

Periodic reports on an annual or biannual basis would help organize the efforts of the count program and communicate the program's findings to the public. The reports should focus on the program's progress toward its key objectives with supporting details on the program's performance measures and high-level analysis findings. Developing a program report for the first time may require a significant effort but should be considerably less time-intensive to update in subsequent years. These reports should be targeted toward a general audience consisting of local agencies, bicycling and walking organizations, and TDOT committees and staff.

Through the Enhanced Tennessee Roadway Information Management System (E-TRIMs) platform, authorized users can export roadway datasets to support their analysis needs. TDOT should work to integrate annualized bicycle and pedestrian count data into E-TRIMs (or equivalent platforms) in similar ways as existing motorized count data. Incorporating these bicycle and pedestrian data elements into the same database will enable users to perform comprehensive multimodal analyses with limited additional processing required.

There are a variety of ways the data might be shared, and TDOT should consider how to best share bicycle and pedestrian data with a broad group of potential users, including MPOs/RPOs, local agencies, internal committees and staff, researchers, advocacy organizations, developers, and members of the public. From the perspective of a non-TDOT data user, the most accessible method may be to post the data on a website in a standard format (e.g., CSV, shapefile). As the program grows and additional MPOs, RPOs, and local agencies begin to collect count data, TDOT may decide to use a third-party data management and sharing service. The use of an accessible data management platform for external users will benefit the TDOT in the long-term and will improve the ease of sharing AADT with MPOs/RPOs, local agencies, and other non-TDOT stakeholders.

TDOT may also wish to consider partnering with MPOs/RPOS, local jurisdictions, or park departments to install public-facing real-time displays at automated count locations. Such displays can encourage bicycling by letting bicyclists know they count and by conveying to other roadway users that bicyclists are welcome and expected. Public-facing real-time displays are most appropriate in high-profile locations that already have significant bicycle volumes.

Open data websites provide another channel for TDOT and its partner agencies to highlight and promote their pedestrian and bicyclist counting efforts. The websites can also be used to support partnerships with local planning agencies, non-profits, and research institutions through data sharing and website hosting services. Shared open data websites can also function as a data collection and reporting portal among partner agencies who do not have access to TN-TIMES or E-TRIMs and as data access and visualization tool for interested community members. Data selection and visualization tools such as forms to query data, interactive maps, charts, and graphs are particularly helpful for community members with limited access to data analysis tools and expertise. The program guidance manual presents several case studies to highlight open data pedestrian and bicyclist count websites hosted by metropolitan planning organizations from across the nation.

6.2.5 Goal 5: Institutionalize and build capacity for pedestrian and bicyclist monitoring within TDOT and across Tennessee

TDOT should develop clear roles and responsibilities for the statewide count program, develop educational materials and training for partnering agencies, and provide funding for partner agencies to purchase a bicycle and pedestrian counter programs. In the long term, TDOT should secure funding to maintain or expand the nonmotorized count program to meet the state’s needs and integrate count data into planning and project development processes. This goal and accompanying recommendations apply to all four count program processes shown in Figure 31.

Beyond providing financial support and program guidance, TDOT should work to coordinate count efforts among its local agencies and to share best practices and lessons learned from data collection and equipment maintenance activities. Included in these efforts is the development of data collection and quality assurance measures. These measures include following all vendor specifications and recommendations when installing counters and selecting count locations to mitigate bypass errors. TDOT and its partners should also validate data from permanent counters using short-duration manual or video counts. If accuracy is found to be lower than 80 percent, TDOT should work with the equipment vendor to identify error sources and improve accuracy. If observed accuracy is greater than 80%, SDC counts can be used to develop an adjustment factor for recorded volumes.

Understanding the impacts of TDOT’s infrastructure investments requires monitoring usage along state project-funded corridors. While TDOT can expect to see different impacts from bicycle and pedestrian facility projects based on the facility type and local land use context, over time, TDOT can use the findings to compare the effectiveness of different investment decisions and to evaluate the likely impact of future funding proposals.

TDOT can take immediate steps by working with MPOs/RPOs and local communities on grant-awarded projects to collect “before” bicycle and pedestrian volume data on essential upcoming bicycle and pedestrian facility projects, and “after” counts on high-profile, recently completed projects. In the long-term, TDOT can use a wide variety of before-and-after data to measure and track changes in bicycling ridership and walking levels, vehicle speed, traffic volumes, traffic crashes, and economic activities at state-funded project locations and along nearby vital corridors.

6.3 Conclusions

Bicycling and walking are essential components of multimodal transportation. Although Tennessee has a statewide motor vehicle count program, this report recommends integrating bicyclist and pedestrian counts into the existing program. The recommendations included in this chapter will help TDOT create an effective statewide nonmotorized count program that produces data for the Department and its partners. The resulting nonmotorized count volume data can be used for resource prioritization, facility design decision and performance evaluation, safety analysis, and trend monitoring. Metrics on bicycling and walking also support performance-based planning and accountability.

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Appendix

Appendix A. Schedule of interviews

SN	Organization	Interviewees	Remarks
1	Knoxville TPO	Ellen Zavisca	
2	City of Memphis	Nick Oyler	
3	Memphis MPO	Zylavian Watley	
4	City of Nashville	Jason Radinger	
5	WalkBike Nashville	Nora Kern	
6	Chattanooga TPO	Cortney Geary and Jonathan Gibbons	
7	Bristol MPO	Rex Montgomery	
8	Clarksville MPO	Stan Williams	No response
9	Cleveland MPO	Greg Thomas	
10	Jackson MPO	James Matthews	Email response
11	Johnson City MPO	Glenn Berry	
12	Kingsport MPO	Bill Albright	
13	Lakeway MPO	Rich DesGroseilliers	
14	East Tennessee RPO North	Don Brown	Email response
15	East Tennessee RPO South	Don Brown	Email response
16	First Tennessee RPO	Russ Davis	No response
17	Middle Tennessee RPO	Karyssa Helton	No response
18	West Tennessee RPO	Jasmine Champion	No response
19	Northwest Tennessee RPO	Ben Bradberry	
20	South Central East RPO	Lisa Cross	
21	South Central West RPO	Lisa Cross	
22	Southeast Tennessee RPO	Chad Reese	Email response
23	Southwest Tennessee RPO	Shelton Merrell	
24	Center Hill RPO	Virginia Solimine	Joint interview with Mark Dudney
25	Dale Hollow RPO	Mark Dudney	Joint interview with Virginia Solimine

Appendix B. Interview questionnaire

Estimated conversation duration: 30 minutes

Part I: General background about the count program

1. Has your locality/organization conducted any counts of pedestrian and/or bicycle volumes since 2014?
    - Purpose of data collection
    - Who oversees the count program (e.g., Parks and Recreation or Public Works)?
    - Any non-governmental organization conducting count (like cycling club or other non-profit)?
    - Do you think we need to talk with other people in your locality about the count program?
2. If you are not doing any bicycle/pedestrian counts, why not?
    - Potential topics to discuss include lack of institutional support/lack of funding, lack of interest, lack of technical knowledge, etc.
3. What was the counting duration and locations?
    - Continuously or periodically (for example, monthly or yearly),
    - Counting at the same location(s) or different
    - How did you select locations for counts?
4. How was counting done?
    - Method (manual or automatic counts)
    - Frequency
    - Season
    - Equipment(s) used (type, brand)
    - Who counts?
    - Use of third-party data sources like Strava, StreetLight, etc.
5. Do you think the counts were "successful?"
    - Did they accomplish their goal?
    - What worked well?
    - What did not work well?
6. How is data stored and used?
    - Format of the data (paper, excel, GIS shapefile)
    - Use of data services provided by the vendors of equipment or third-party software
    - Were outside entities involved in data management?
    - If doing short-duration counts, have you extrapolated to annualized volume estimates?
    - Is data validation done for quality assurance?
    - Is data shared outside of the organization?
    - How is the data used? (descriptive summary, models)
    - If data is not used, what would make you more likely to use it?

Part II: Bicycle and pedestrian count requirements

7. In your opinion, are there distinct locations on roadways or trails where continuous or periodic counts would be beneficial?
    - Location
    - season
    - Purpose of data

Part III: Interest in state-wide bike-ped count program

8. Do you use any other existing count data?
    - National-level: US Census Journey-to-Work, NHTS, National Survey of Bicycle and Pedestrian Attitude and Behavior
    - If so, what did you use it for?
9. If TDOT provided support for a bicycle-pedestrian count, would your locality/organization be interested in a count program?
    - What kind of support would you need? Support for financial and/or technical assistance
    - What would be the scope of the count program? (continuous or periodic)
    - How would your organization use the data?
    - Would you be interested in sharing a summary of your count data (with us for this research project)?

Appendix C. Inventory of count programs in Tennessee

We compiled the count inventory from the interviews of representative transportation agencies of major cities of Tennessee (Nashville, Memphis, Knoxville, and Chattanooga, as well as agencies with bicycle and pedestrian count efforts outside these cities. The inventory does not include locations whose transportation agencies do not have any count efforts or did not respond to our email regarding bicycle and pedestrian count efforts.

C.1 Nashville

The city of Nashville and Walk Bike Nashville, an advocacy group, conducted bicycle counts in Nashville. Walk Bike Nashville conducted counts on behalf of Nashville MPO, and the interviewees (from Walk Bike Nashville as well as the City of Nashville) mentioned that Nashville MPO does not conduct any counts by themselves. Therefore, we did not interview with representatives of the Nashville MPO. A detailed inventory is as follows:

City of Nashville

Questions	Past (since 2014 until April of 2019)	Present (since May of 2019 to July 2020)	Future plans (After August 2020)
1. General question			
Has/is/will your locality/organization conduct any counts of pedestrian and/or bicycle volumes?	• Data collection is done on a project need basis	• Nothing has happened	• Planning for case by case projects and some follow-up counts
Who (will) oversees the count program (e.g. Parks and Recreation or Public Works)?	• All of the counts that have been conducted are through MPO using consultants		
Any non-governmental organization conducting count (like cycling club or other non-profit)?			
How is/will the count data stored and shared with internal (e.g., city engineering) and external (e.g. public) stakeholders			
2. What was/is/will the counting duration and locations?			
Continuously or periodically (for example, monthly or yearly),			
How many location(s)?			
3. How was/is/will be counting done?			
Method (manual or automatic counts)	• automated		

How often did/do/will you do count in a year?	• Either a single day or a week-long count but stopped counting since 2017		
What time of the year (for example, summer, all year)			
Which equipment(s) used for the count (type, brand)?	• Eco counter (mobile counter) and video count for pedestrian		
Who counts? (volunteers, sub-contract, in-house)	•		
Use of third-party data sources like Strava, StreetLight, etc.	• occasionally but not often.		

Walk Bike Nashville

Questions	Past (since 2014 until April of 2019)	Present (since May of 2019 to July 2020)	Future plans (After August 2020)
1. General question			
Has/is/will your locality/organization conduct any counts of pedestrian and/or bicycle volumes?	• Did the counts for the MPO in 2013, 2014, 2015 • Agency didn't want to do it in 2017 • counted at an intersection that TDOT recently	• specific project (plan for bikelane) • evaluation of bike facilities (Woodland St and Commerce St, and 3rd Ave (maybe) • decline in overall bicycling during COVID	• No concrete plans and maybe project based
Who (will) oversees the count program (e.g. Parks and Recreation or Public Works)?	• MPO mostly	• Independent counts	
Any non-governmental organization conducting count (like cycling club or other non-profit)?			
How is/will the count data stored and shared with internal (e.g., city engineering) and external (e.g. public) stakeholders		• probably share with public	
2. What was/is/will the counting duration and locations?			
Continuously or periodically (for example, monthly or yearly),	• One day counts in September for MPO	• Exploring streetlight for time variations	
How many location(s)?	• 20-30 locations	• 2 or 3 locations	
3. How was/is/will be counting done?			
Method (manual or automatic counts)	• Manual counts for MPO • Manual counts intersection		
How often did/do/will you do count in a year?	• September (couple of times in the day)		

What time of the year (for example, summer, all year)			
Which equipment(s) used for the count (type, brand)?			
Who counts? (volunteers, sub-contract, in-house)	• ~50 volunteers		
Use of third-party data sources like Strava, StreetLight, etc.		• Working with Streetlight	

C.2 Memphis

Both City of Memphis and Memphis MPO conducted bicycle and pedestrian counts in Memphis. The inventory of such efforts is as follows:

Memphis MPO

Questions	Past (since 2014 until April of 2019)	Present (since May of 2019 to July 2020)	Future plans (After August 2020)
1. General question			
Has/is/will your locality/organization conduct any counts of pedestrian and/or bicycle volumes?	• In 2014 • In 2017	• No	• Working on bike-ped plan
Who (will) oversees the count program (e.g. Parks and Recreation or Public Works)?	• Memphis MPO		
Any non-governmental organization conducting count (like cycling club or other non-profit)?	• City of Memphis	• City of Memphis checked out counter once	
How is/will the count data stored and shared with internal (e.g., city engineering) and external (e.g. public) stakeholders			
2. What was/is/will the counting duration and locations?			
Continuously or periodically (for example, monthly or yearly),	• Periodic count in 2014 and 2017		
How many location(s)?	• 40 in 2014 • 3 in 2017 at same locations as 2014		
3. How was/is/will be counting done?			
Method (manual or automatic counts)	• manual in 2014 • automated in 2017		
How often did/do/will you do count in a year?	• 1 day in 2014 • 7 day in 2017		

What time of the year (for example, summer, all year)	• same season in both 2014 and 2017 • busiest day of the week		
Which equipment(s) used for the count (type, brand)?	• 3 passive infrared counters (Traffix) • 3 pneumatic tubes (to distinguish bicyclist and pedestrian)		
Who counts? (volunteers, sub-contract, in-house)	• in-house		
Use of third-party data sources like Strava, StreetLight, etc.	• No		

City of Memphis

Questions	Past (since 2014 until April of 2019)	Present (since May of 2019 to July 2020)	Future plans (After August 2020)
1. General question			
Has/is/will your locality/organization conduct any counts of pedestrian and/or bicycle volumes?	• yes	• did analysis of the data this year	• continue counts and partnership • increase counts in Wolf river greenway
Who (will) oversees the count program (e.g. Parks and Recreation or Public Works)?	• contracted counts – part of 2014 update to bike/ped plan	• Purchased through partnership of non-profit (parks)	• In process of purchasing new counter to be installed in 2-way cycletrack
Any non-governmental organization conducting count (like cycling club or other non-profit)?			
How is/will the count data stored and shared with internal (e.g., city engineering) and external (e.g. public) stakeholders	• Shared use path is maintained by a private entity and they use the data for grant funding to extend the shared use path.	• shared analysis of the data	
2. What was/is/will the counting duration and locations?			
Continuously or periodically (for example, monthly or yearly),	• 4 permanent counters installed in the city • periodic count for before/after project evaluation		
How many location(s)?	• 20 locations in 2014 • 2 combo bike/ped on a bridge (~2.5 years) • 1 bike-specific counter in-street loops (almost 2 years) (has been validated)	• about 10 count • 9 locations are in park • 1 on street	• at least additional 3 in Wolf River Greenway • 2-3 counters in Vollentine Evergreen neighborhood; planning to do 2 week counts at

	• 1 infrared combination counter on shared-use path (~5 years old) • 1 mobile bike counter (pneumatic tubes) – primarily used for before/after on projects		the end of September (either manual or automatic counters)
3. How was/is/will be counting done?			
Method (manual or automatic counts)	• combination of pneumatic and manual count in 2014 • automatic	• all permanent and one mobile	
How often did/do/will you do count in a year?	• not sure for the time of the year in 2014	• all year	
What time of the year (for example, summer, all year)	• all year for permanent counters?	• all year	
Which equipment(s) used for the count (type, brand)?	• Eco-counters	• Infrared • Eco counters • Pneumatic • video based counters	• extend using video based counters
Who counts? (volunteers, sub-contract, in-house)	• sub-contract and in-house	• in-house and contract	
Use of third-party data sources like Strava, StreetLight, etc.	• bikeshare data (b-cycle dash)		

C.3 Knoxville

Knoxville TPO conducted bicycle and pedestrian counts in Knoxville. The inventory is as follows:

Questions	**Past (since 2014 until April of 2019)**	**Present (since May of 2019 to July 2020)**	**Future plans (After August 2020)**
1. General question			
Has/is/will your locality/organization conduct any counts of pedestrian and/or bicycle volumes?	• yes	• Spring 2020 counts were canceled due to the pandemic, and fall 2020 counts will likely be canceled as well.	• We are evaluating the program, as the counts we've done in the past have not been put to much use, and the short-term counts aren't very meaningful.
Who (will) oversees the count program (e.g. Parks and Recreation or Public Works)?	• Counts have been collected manually by TPO/MPC staff. In some past years, volunteers have been recruited, but we later shifted to having our AmeriCorps member do most of the counts.	• Not being conducted in 2020 due to the pandemic changing travel patterns and also the risk to the person counting.	
Any non-governmental organization conducting count (like cycling club or other non-profit)?	• No	• No	• Not anticipated.
How is/will the count data stored and shared with internal (e.g., city engineering) and external (e.g. public) stakeholders	• Uploaded at http://www.ibikeknx.com/what-we-do/bicycle-and-pedestrian-traffic-counts/		
2. What was/is/will the counting duration and locations?			
Continuously or periodically (for example, monthly or yearly),	• Intersection counts of bicycle and pedestrian traffic are conducted twice a year at		

	various locations in Knox and Blount Counties - Continuous on greenway (not anymore; issues with counters from last year); not required for now - Intersection counts of bicycle and pedestrian traffic are conducted twice a year at various locations in Knox and Blount Counties - Continuous on greenway (not anymore; issues with counters from last year); not required for now		
How many location(s)?	- About 20 locations have been counted every time, with other locations counted less frequently, as staff are available.		
3. How was/is/will be counting done?			
Method (manual or automatic counts)	- manually by TPO/MPC staff. - some greenway locations were equipped with automated counters; those are no longer maintained - video counts have also been used in the past for 24-hour counts, with manual review		
How often did/do/will you do count in a year?	- two times a year per location - 7 - 9 a.m. and 4 - 6 p.m. unless otherwise noted on website		

What time of the year (for example, summer, all year)	• spring and fall, but some locations have been counted in summer to get additional information.		
Which equipment(s) used for the count (type, brand)?	• Greenway locations have been counted in the past using automated counters. The first brand used was Ivan Technologies, and the most recent was Trafx. We had problems with the data from both counter types, so those counters have not been maintained.		
Who counts? (volunteers, sub-contract, in-house)	• volunteers in past • currently, TPO/MPC staff (AmeriCorps member)		
Use of third-party data sources like Strava, StreetLight, etc.	• We've looked at these but haven't used them due to concerns about accuracy and whether the trips counted are representative of the community		

C.4 Chattanooga

Chattanooga does not have any past or present bicycle and pedestrian count, but the Chattanooga TPO is planning for one. The inventory of count efforts is as follows:

Questions	**Past (since 2014 until April of 2019)**	**Present (since May of 2019 to July 2020)**	**Future plans (After August 2020)**
1. General question			
Has/is/will your locality/organization conduct any counts of pedestrian and/or bicycle volumes?	• No exiting count programs	• No exiting count programs	• RFQ for consultant for 2050 RTP plan (planned for September 2020)
Who (will) oversees the count program (e.g. Parks and Recreation or Public Works)?			
Any non-governmental organization conducting count (like cycling club or other non-profit)?			
How is/will the count data stored and shared with internal (e.g., city engineering) and external (e.g. public) stakeholders			
2. What was/is/will the counting duration and locations?			
Continuously or periodically (for example, monthly or yearly),			• 24 hours a day for seven days
How many location(s)?			• 24 sites throughout the TPO area
3. How was/is/will be counting done?			
Method (manual or automatic counts)			• automated video counters
How often did/do/will you do count in a year?			• biannual basis

What time of the year (for example, summer, all year)			• spring and fall months
Which equipment(s) used for the count (type, brand)?			
Who counts? (volunteers, sub-contract, in-house)			• in-house operation or by retaining the services of a consultant
Use of third-party data sources like Strava, StreetLight, etc.			

C.5 Cleveland

The Cleveland MPO responded that they had some bicycle and pedestrian count efforts in the past. The details of the inventory are as follows:

Questions	**Past (since 2014 until April of 2019)**
1. General question	
Has/is your locality/organization conduct any counts of pedestrian and/or bicycle volumes?	• Yes
Who oversees the count program (e.g. Parks and Recreation or Public Works)?	• MPO leading volunteers of college intern
Any non-governmental organization conducting count (like cycling club or other non-profit)?	
How is the count data stored and shared with internal (e.g., city engineering) and external (e.g. public) stakeholders	
2. What was/is the counting duration and locations?	
Continuously or periodically (for example, monthly or yearly),	• 2 hours counts • Some of them frequent at locations • Maybe shorter in some location • Not very systematic
How many location(s)?	• Streets/intersections • Greenway (not used much)
3. How was/is be counting done?	
Method (manual or automatic counts)	• Pencil and paper • counts processed by them for bicyclist from Miovision
How often did/do you do count in a year?	• Tried to get diverse data, sometimes random times based on availability of interns during summer
What time of the year (for example, summer, all year)	

Which equipment(s) used for the count (type, brand)?	
Who counts? (volunteers, sub-contract, in-house)	
Use of third-party data sources like Strava, StreetLight, etc.	

C.6 Kingsport

The Kingsport MPO responded that they had some bicycle and pedestrian count efforts in the past. The details of the inventory are as follows:

Questions	**Past (since 2014 until April of 2019)**
1. General question	
Has/is your locality/organization conduct any counts of pedestrian and/or bicycle volumes?	• yes
Who oversees the count program (e.g. Parks and Recreation or Public Works)?	
Any non-governmental organization conducting count (like cycling club or other non-profit)?	
How is the count data stored and shared with internal (e.g., city engineering) and external (e.g. public) stakeholders	
2. What was/is the counting duration and locations?	
Continuously or periodically (for example, monthly or yearly),	• Bike/ped count projects
How many location(s)?	• green belt and project location
3. How was/is be counting done?	
Method (manual or automatic counts)	• radar counter
How often did/do you do count in a year?	
What time of the year (for example, summer, all year)	
Which equipment(s) used for the count (type, brand)?	
Who counts? (volunteers, sub-contract, in-house)	

Use of third-party data sources like Strava, StreetLight, etc.	

C.6 Bristol

The Bristol MPO responded that they had some bicycle and pedestrian count efforts in the past. The details of the inventory are as follows:

Questions	**Past (since 2014 until April of 2019)**
1. General question	
Has/is your locality/organization conduct any counts of pedestrian and/or bicycle volumes?	• Yes, in 2014
Who oversees the count program (e.g. Parks and Recreation or Public Works)?	
Any non-governmental organization conducting count (like cycling club or other non-profit)?	
How is the count data stored and shared with internal (e.g., city engineering) and external (e.g. public) stakeholders	
2. What was/is the counting duration and locations?	
Continuously or periodically (for example, monthly or yearly),	
How many location(s)?	• School area and project basis
3. How was/is be counting done?	
Method (manual or automatic counts)	
How often did/do you do count in a year?	
What time of the year (for example, summer, all year)	
Which equipment(s) used for the count (type, brand)?	
Who counts? (volunteers, sub-contract, in-house)	

Use of third-party data sources like Strava, StreetLight, etc.	

C.6 Johnson City

The Johnson City MPO responded that they had some bicycle and pedestrian count efforts in the past. The details of the inventory are as follows:

Questions	**Past (since 2014 until April of 2019)**
1. General question	
Has/is your locality/organization conduct any counts of pedestrian and/or bicycle volumes?	• Yes
Who oversees the count program (e.g. Parks and Recreation or Public Works)?	
Any non-governmental organization conducting count (like cycling club or other non-profit)?	
How is the count data stored and shared with internal (e.g., city engineering) and external (e.g. public) stakeholders	
2. What was/is the counting duration and locations?	
Continuously or periodically (for example, monthly or yearly),	• Continuous with counters
How many location(s)?	• Before and after evaluation of Twisty trail
3. How was/is be counting done?	
Method (manual or automatic counts)	• Manual with help of volunteers • counters
How often did/do you do count in a year?	
What time of the year (for example, summer, all year)	• 2 hours count on Friday and Saturday
Which equipment(s) used for the count (type, brand)?	

Who counts? (volunteers, sub-contract, in-house)	
Use of third-party data sources like Strava, StreetLight, etc.	

Appendix D. Comparison of count technology

Technologies	**Application**	**Strengths**	**Limitations**	**Accuracy**	**Cost/Labor**
Manual Counts In-Field	• Short-duration counts • Differentiates between pedestrians and bicyclists	• Portable • No installation costs • Can gather gender and behavioral information • Applicability to all sites	• Limited to short-duration counts only • At high-volume locations, additional personnel are needed • Labor-intensive	• Accuracy may depend on data collector training and fatigue • Undercounting rates between 8-25%	• $ - $$$ • At high-volume locations, additional personnel are needed, which can result in higher cost
Manual Counts from Video	• Short-duration counts • Differentiates between pedestrians and bicyclists	• Can gather gender and behavioral information • Video can be reviewed in the office, data collector can view the video at fast and/or slow speeds to extract counts •	• Limited to short-duration counts only • Data reduction is labor intensive • Frequent field visits may be required for swapping batteries and storage cards • Equipment may be susceptible to theft or damage •	• Higher accuracy of in-field counts and higher pedestrian flows	• $ - $$$ • If existing cameras are available, costs can be low
Automated Counts from Video	• Short-duration or continuous counts • Bicyclists and pedestrians separately	• Portable • Time effort is low • Video can be used for additional purposes	• Algorithm development still maturing	• Accuracy in dense, high-traffic areas over manual counts	• $ - $$ ($1,200 – 8,000)** • More expensive for exclusive installations

Pneumatic Tubes	• Short-term counts • Bicyclists only	• Portable • May be possible to use existing motor vehicle counting technology	• Capable of counting bicyclists only • Tubes pose tripping hazard to trail users • Greater risk of vandalism • Not for use in winter	• APD: -17.89%, AAPD: 18.50% • High accuracy	• $ - $$ • low cost • low level of effort to install • Jurisdictions are familiar with setup process • Eco-Counter: $2,275 (no direction detection); $2,800 (bidirectional detection)
Inductive Loop Detectors	• Continuous counts • Short duration counts • Bicycles only	• Uses traditional motor vehicle counting technology	• Only counting bicycles • Complex installation in-pavement • Susceptible to electrical interference •	• High accuracy when properly installed and configured • High error when detecting groups of bicycles • Detection Zone* APD: 0.55%; AAPD: 8.87# • Incl. Bypass Errors* APD: -14.08%; AAPD: 17.62%	• $$ ($2,000 - $3,000)** • The effort and cost for installing embedded loops are high, installing temporary loops is medium • Level of effort and cost depends on in-house expertise compared to hiring a contractor
Passive Infrared	• Short-term or continuous counts	• Portable and easy to install • Unobtrusive appearance	• Cannot distinguish between	• Good accuracy rates	• $ -$$ ($2,000-3,000)**

	• Bicyclists and pedestrians combined	• External power source not required	bicyclists and pedestrians • Difficult to use for bike lanes and shared lanes • Cannot be used for crosswalks • Extreme ambient temperatures may affect accuracy	• May have higher errors with groups • APD: -8.75%; AAPD: 20.11%	• Level of effort to install is low • Cost per device is medium • Eco-Counter: between $2,325-3,825 (no direction detection); between $2,925-$4,425 (bidirectional detection)
Active Infrared	• Short-term or continuous counts • Bicyclists and pedestrians combined	• Portable, easy to install • Unobtrusive appearance •	• Cannot distinguish between bicyclists and pedestrians • Not suitable for on-street monitoring • Requires fixed objects or poles on either side of path or trail	• Good accuracy rates • Occlusion errors with large groups of pedestrians are crossing simultaneously • APD: -9.11%; AADP: 11.61%	• $ - $$$ ($800 - $7,000)** • Level of effort is medium • Equipment cost is high • Installation costs are medium
Piezoelectric Strips	• Continuous counts • Only bicycles	• Provide information on the direction and speed of bicyclists • Used on paved multi-use paths	• Difficult to install, requires pavement cuts • Lead time is required to obtain permits, hire contractor, and schedule the installation	• APD: -4.0%: AAPD: 4.5%	• $1,600** • Level of effort is high and requires careful installation • Equipment cost is medium • Installation cost is high

Radio Beams	• Short-term or continuous counts	• Portable, easy to install • Does not need external power source	• Requires fixed objects or poles on either side of path or trail	• Occlusion errors with large groups of pedestrians • APD: -9.6%; AAPD: 9.7%	
Pressure and Acoustic Pads	• Continuous counts • Typically on unpaved trail or paths	• Less prone to vandalism due to in-ground installation • Some equipment may be able to distinguish between bicyclists and pedestrians	• Requires users to pass directly over the sensor • Requires installation under pavement	• Accuracy has not been tested	• $$ • Expensive for installation under pavement
Magnetometers	• Continuous counts • Bicycles only	• May be possible to use existing motor vehicle sensors • Used to count bicyclists on rural bike paths or mountain bike paths	• Not appropriate for locations with ground freezes	• May have high error with groups	• $ - $$ • High level of effort to install
FiberOptic Pressure Sensors	• Continuous counts • Permanent count stations • Counts bicyclists only	• Used for permanent count stations • Applied for exclusive bicycle facilities, pathways,	• Installation requires excavating a slot in the pavement and placing a fiberoptic cable in the slot		• Difficult to install

		mixed-traffic roadways, and sidewalks			
Combination Inductive Loop/ Infrared Detectors	• Continuous counts • For shared paths • Detects bicyclists and pedestrians	• Flexible use for obtaining bicycle and pedestrian data or bicycle only/ pedestrian only data	• Requires work crew to install (pavement cutting; post installation for passive IR sensor and logger)		• $$ - $$$ • May require permitting • Eco-Counter: $4,650 (bidirectional detection)
Combination Pneumatic Tubes/ Infrared Detectors	• Continuous counts • For shared paths	• Can distinguish bicycle and pedestrians • Relatively low cost, portable, and easy to install	• Not appropriate for locations with snow • Limitations of pneumatic tube applicable in this combination • The devices is subject to vandalism or theft		• $-$$ • Relatively low cost and easy to install

Notes: APD = average percentage deviation, AADP = average of the absolute percent difference (Source: NCHRP Project 07-19, Table 4-1)
*Detection zone results refer to the accuracy of the device with regards to the bicycle volume that passes through its detection zone. Errors are larger when comparing the device's count to the actual volume on the facility, including bicyclists that bypass the detection zone

Sources: Ryus et al., 2004. Minnesota Department of Transportation, 2017, Bicycle and Pedestrian Data Collection Manual. Exploring Pedestrian Counting Procedures. A review and Compilation of Existing Procedures, Good Practices, and Recommendations. May 2016.

**Cost figures retrieved from: http://bikepeddocumentation.org/application/files/3214/6671/7814/NBPD_Automatic_Count_Technology_overview.pdf