CCRPC Bicycle Count Data Analysis and Count Program Design Strategies

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Prepared by:

Dr. Gregory Rowangould, Eliana Fox, Rose O'Brien and Julia Clarke
University of Vermont Transportation Research Center
25 Colchester Avenue, Burlington, VT 05405
www.uvm.edu/cems/trc

Prepared for:

Chittenden County Regional Planning Commission
10 West Canal Street, Suite 202
Winooski, Vermont 05404

THE UNIVERSITY OF VERMONT
TRANSPORTATION
RESEARCH CENTER

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1 INTRODUCTION

In 2017, the Chittenden County Regional Planning Commission (CCRPC) completed the most recent update of the region's Active Transportation Plan (ATP) with the goal of creating "a safe, comfortable, and connected regional network of pedestrian and bicycle routes that appeal to all ages and abilities". Developing a "robust" bicycle count program was one of the key non-infrastructure recommendations in the ATP (CCRPC, 2017). The UVM Transportation Research Center ("TRC") was contracted to evaluate current bicycle data collection efforts in the region, identify gaps and limitations and make recommendations on how to develop a comprehensive bicycle count program that could better support the region's bicycle planning objectives.

The TRC conducted three primary research tasks:

1. We conducted a review of current best and potentially innovative bicycle count practices. This included a review of bicycling counting methods and technology, regional data collection strategies, and related data analysis methods. The review was performed by completing a literature review of published government studies and peer reviewed academic and professional journal articles. We supplemented the literature review with information about current practice gathered through interviews with bicycle count program staff at five regional and state transportation agencies.
2. We collected as much historical bicycle count data as we could identify in Chittenden County. This was accomplished by reaching out to the project's advisory committee, CCRPC staff, VTrans and Local Motion. We identified data from four sources (CCRPC ATR and TMC data, Local Motion, and a VTrans Bicycle Data Portal) dating back to 2011. These data were then evaluated for their spatial and temporal coverage and what they could reveal about bicycling trends in the region. We focused on identifying critical gaps and limitations that could be addressed by applying best practices and innovations identified in our literature review.
3. We developed recommendations based on our review of current best practices, guidance and research and our analysis of currently available data. Our recommendations provide CCRPC with a roadmap for creating and implementing a more robust and comprehensive bicycle count program that we believe is cost effective and feasible if implemented in stages.

Our research was focused on developing a more robust regional bicycle count program. There are other methods to collect information about bicycling that can provide additional information to inform planning decisions and modeling efforts. Bicycle traffic counts provide information about how much bicycling is occurring at a specific time and place. These data can be used to track how levels of bicycling change over time and space. Changes in bicycle traffic counts can also be used to evaluate how various projects, programs and policies affect the amount of bicycling on a facility or in the region. The data are also useful for measuring the performance of long range transportation and bicycle plans. Additional data, typically collected with questionnaires, are used to understand how and why people choose to make trips on a bicycle and their preferences for particular routes and facility designs. Data collected from travel diaries are often used to understand trip making patterns (origins and destinations) and trip purposes. These data are generally used for creating demand forecasting models. While other types of bicycle data should be considered to better understand how plans can better encourage bicycling in the region, these are beyond the scope of the current study. A robust bicycle count program serves as a useful foundational data source that is relatively inexpensive and can support a wide range of planning decisions and program evaluation.

The TRC research team received input on bicycle count program needs and current practices from a project advisory committee made up of transportation planners from municipal governments in the region, the Vermont Agency of Transportation, the region's transportation management organization,

and a regional bicycle advocacy organization. We also received input from the project advisory committee on our initial set of recommendations. The project advisory committee included:

- Nicole Losch – Senior Transportation Planner, City of Burlington
- Jonathon Weber – Program Manager, Local Motion
- Jon Kaplan – Bicycle and Pedestrian Program Manager, Vermont Agency of Transportation
- Cymone Haiju – Director of Planning and Development Review, Town of Milton
- Sandy Bender – Program Coordinator, Local Motion
- Kim Furtado – Transportation Analyst, Chittenden Area Transportation Management Association

Finally, while this report makes specific recommendations about strategies for developing a more comprehensive bicycle count program, implementation will require further fine-tuning and including key stakeholders and partners in key decision making steps. While we have provided a strategy that is based on best practice and supported by both federal guidance and academic research, implementation will also need to consider tradeoffs between a more comprehensive understanding of bicycle traffic patterns and trends in the region and program costs. Development patterns and land use in the region vary from a relatively dense and mixed-use urban core in Burlington and Winooski to suburban communities and rural settlements with small town centers. A cost-effective strategy should aim to collect data that supports the bicycle planning needs of these various communities recognizing that in places with low bicycle volumes, the cost of a comprehensive bicycle count program that achieves a reasonable level of accuracy over a large geographic area becomes increasingly expensive. We therefore recommend a hybrid approach where a comprehensive program is developed for municipalities (or portions of them) where the potential for moderate to high bicycle volumes is greatest. Communities that currently have low bicycle volumes could be included in the comprehensive program if plans call for area-wide changes expected to result in substantial increases. A more targeted program is recommended for communities where the overall potential for bicycling is low or confined to specific corridors. In these communities, count programs would target specific roadway or bicycle infrastructure projects, locations where bicyclist safety concerns have been identified, and specific corridors that have higher potential to attract bicyclists. The region's bicycle count program can be developed in phases to limit costs associated with purchasing and installing count equipment and collecting additional data to refine the design of the program.

2 LITERATURE REVIEW

We reviewed recent guidance documents and peer reviewed academic research studies to identify best practices and emerging methods for creating effective regional bicycle count programs. While bicycle counts can be used for a wide range of purposes, we focused on information most relevant to creating a regional bicycle count program designed to monitor changes in bicycle traffic volumes over time, between facilities and across different geographic locations. Many of the recommendations and strategies identified in our literature review also apply to special purpose counts with a more limited geographic scope and study length. Our search for relevant documents turned up well over 100 reports and journal articles related to the design of bicycle count programs published since 1996 through 2020. Included are two comprehensive guidance documents that consider much of this literature through 2016. The first is a National Cooperative Highway Research Program (NCHRP) report "Guidebook on Pedestrian and Bicycle Volume Data Collection" and the second is chapter 4 of the Federal Highway Administration's (FHWA) most recent "Traffic Monitoring Guide" (FHWA, 2016c; TRB, 2014a). Considered together, these two documents provide comprehensive guidance for designing regional bicycle traffic volume count programs. In our review we discuss the main takeaways from these guidance documents and supplement them with information drawn from more recent studies as well as several older studies that provide additional implementation guidance.

2.1 General Framework

With few exceptions, the most recent guidance from FHWA and the NCHRP study along with more recent academic studies have converged on the recommendation of a strategy that employs a combination of long-term continuous counts and repeated short-duration counts (FHWA, 2016c; Nordback et al., 2019; TRB, 2014a). Long-term continuous counts are observed by fixed, usually permanent, automatic counters. The technology used for long-term continuous counts is relatively expensive to install, since it typically requires construction to install detectors (e.g., placing inductive wire loops within a roadway) and house the recording equipment (typically in a cabinet, vault or post on the side of the facility). The expense of installing continuous counters means that it is typically impractical from a budget and time perspective to install a large number of them and observe bicycle traffic in a wide range of settings across a large region. Therefore, the prevailing guidance is to supplement long-term continuous counts with a large number of short-duration counts using relatively inexpensive and portable counting equipment. With just a few portable counters, bicycle traffic can be observed at a large number of sites within a region over the course of a year. Since short-duration counts only provide a snapshot of bicycle traffic, data from continuous counters are used to expand or "factor" short-duration counts into an estimated annual average daily bicycle (AADB) count or other period averages (El Esawey et al., 2013; FHWA, 2016c; Nordback et al., 2013; TRB, 2014a).

This strategy uses continuous counts to collect information on temporal traffic volume patterns and short-duration counts to collect information on spatial traffic volume patterns. It is a strategic and cost effective strategy because it maximizes the use of inexpensive short-duration counts and relies on a relatively small number of more expensive continuous count sites. The role of continuous count sites in this strategy is primarily to collect data for generating short-duration count correction factors, rather than serving as a standalone source of regional traffic volume data. Combining data from each count type allows for a much greater understanding of regional bicycle traffic volume patterns than relying on either count type alone.

As the FHWA guidance explains, many aspects of designing a bicycle count program and appropriate factor groups are not nearly as well understood as they are for vehicle traffic counts. Bicycle traffic is significantly more variable owing to lower overall volumes, the use of lower volume and residential streets (more network area to monitor), multiple and often non-transportation trip purposes, and is

significantly more impacted by climate and weather conditions which also have strong seasonal patterns (FHWA, 2016c; Tin Tin et al., 2012). FHWA guidance and some relatively recent research provides useful, although still evolving guidance for making the above decisions.

2.2 How Many Continuous Counters are Required?

One of the first decisions to implement the above strategy is to determine how many continuous counters are needed. Unfortunately, guidance on this question is still evolving and is also dependent on a count program's objectives and regional characteristics. The main starting point is understanding the count program's objectives. If the objective is understanding bicycle traffic on recreational paths within a particular municipality or urban region, then only a few continuous counters may be needed. If the objective is to understand traffic volume patterns on streets and recreational paths for all types of possible bicycle trip purposes, then more continuous counters will be needed. If the count program will span across regions with significantly different land-use and development patterns, even more continuous counters are likely needed.

A number of studies have converged on the recommendation of at least 2 continuous counters per "factor group." Factor groups are sets of bicycle traffic patterns that are similar in their temporal patterns (over the course of a year, a week and/or a day). Factor groups are typically defined through some combination of trip purpose and development pattern/land use. Many count programs identify two distinct trip types used for defining factor groups: commute trips (to work and school) and recreation and utilitarian trips (excluding utilitarian commute trips) (FHWA, 2016c; Miranda-Moreno et al., 2013; Nordback et al., 2013). The factor groups combine trips together that display similar temporal patterns. Commute trips display maximum volumes in morning and evenings while recreational and utilitarian trips may have a single peak in the afternoon or no peak at all. Since some or possibly many facilities have a mixture of commute, recreational and utilitarian trips, it is also common to include a "mixed" factor group. Additional factor groups may be required to account for region-specific factors that affect the temporal patterns of bicycle traffic volumes including different types of land use or development patterns or special traffic generations such as colleges and universities.

The most straightforward method for identifying how many factor groups are required is by plotting existing continuous or short-duration count data from the study region and identifying sites that have similar patterns throughout the year, week and over the course of a day. Local knowledge of the region will also be important in determining appropriate factor groups to account for special traffic generators and differences in land-use and development patterns that may impact traffic patterns. It may become necessary to add factor groups and additional continuous count sites as a count program evolves and new data becomes available for evaluating temporal patterns. If continuous count data are not available (likely when developing a new count program) short-duration counts can be collected for different facility types and in places with different land-uses to determine an initial set of factor groups to guide longer-term investment in continuous count sites. Statistical techniques have also been developed to automatically classify traffic patterns into commute, recreation/utilitarian or mixed factor groups (Miranda-Moreno et al., 2013). A second alternative is to use commercially available passively collected mobility data such as that available from Strava to identify factor groups by viewing spatial volume patterns and creating time series plots. Machine learning techniques have also been developed to automate the selection of factor groups from these large passively collected mobility datasets (Brum-Bastos et al., 2019). The direct use of passively collected mobility data is not recommended as a replacement for an on-the-ground bicycle count program since the data are unlikely to be representative of all (Brum-Bastos et al., 2019; Lee & Sener, 2020b; Nelson et al., 2020). Additionally, passively collected bicycle traffic data can be very expensive ($100,000s per year to license from private

vendors), may have limits on how it can be shared, and may raise privacy concerns with some community members (Lee & Sener, 2020a; Nelson et al., 2020).

In most applications, a minimum of 2 or 3 factor groups is likely which translates to at least 6 continuous count locations. However, the actual number of continuous counters may need to be double this, 4 per factor group, to provide redundancy to account for counter maintenance, malfunction and vandalism which should be expected to occur at some point. FHWA recommends 3 or 4 continuous counters per factor group as a "rule of thumb" (FHWA, 2016c). However, more recent research suggests that the benefits of adding additional counters beyond 2 (plus 2 additional for redundancy) declines sharply. According to a recent study that evaluated data from 102 continuous counters in 6 different cities, the benefits of expanding from 1 to 2 counters per factor group are large, on average about a 20% reduction in AADB error (Nordback et al., 2019). The same study shows that further reductions in error are achieved with additional counters, but the gains are relatively small.

2.3 How Long are Short-Duration Counts?

Longer short-duration counts will produce more accurate AADB traffic estimates at the expense of being able to collect data from more sites with the same amount of equipment. This leads to the question of how long is long enough? It is common for counts to fall within the range of 15 minutes to 2 hours (e.g., a typical morning and evening peak period) but much longer durations are required to produce reasonable estimates. FHWA and NCHRP guidance recommend 4 to 7 continuous days as a minimum while a number of academic studies support a 7 day period, no more and no less, under most circumstances. The 7 day (1 week) recommendation for short-duration counts is derived from studies that have evaluated data from numerous continuous count sites. These studies compare estimates of AADB made from small samples of these continuous data to replicate what a short-duration count would have observed and compare the estimates to the actual AADB calculated from the full continuous dataset. These studies find that error in estimating AADB declines significantly as duration increases from a few hours to a week, and that in most cases durations that extend over a week show much smaller improvements in accuracy (Hankey et al., 2014; Nordback et al., 2013, 2019; Nosal et al., 2014). For example, Nordback et al. (2019) find an average 35% reduction in error when short-duration counts are extended from one day to one week using data from 102 continuous counters in 6 different cities.

If budget or personnel constraints prevent collecting longer, multi-day, short-duration counts, care should be taken to collect data during times when bicycle traffic volume is highest which may differ from typical vehicle traffic peak periods. Bicycle traffic often has less pronounced morning and evening peaks than vehicle traffic which means it is more important to conduct counts from morning to evening or for 24 hours. If 24 hours counts are not possible, a duration of 12 hours from morning to evening on Tuesdays, Wednesdays, or Thursdays is the next best option in terms of limiting error in AADB estimates. Even shorter durations should consider morning and evening peaks as well as the potential for a mid-day peak; however, error in AADB will likely be quite large (Nordback et al., 2013).

Since minimizing error requires multi-day, 24 hour, counts this generally excludes manual counting methods which are expensive due to high labor costs and become error prone as observation periods extend over 2 hours (FHWA, 2016c). Therefore, portable automated counters are generally required for short-duration counts that will support a regional traffic volume count program. Manual, short-duration counts still play an important role in other bicycle count applications including observing bicycle behavior outside of the roadway or bicycle facility (sidewalk riding and short cuts through parking lots), identifying operational issues for bicyclists at intersections, and for calibrating and validating automated count equipment.

Errors in AADB can also be minimized by considering when short-duration counts take place. Collecting data during time periods where bicycling volumes are near their highest or when they are around annual

average levels will both minimize error. High volume times generally correspond with less variability while counting during times when volumes are near the annual average level may result in less error during the factoring process (FHWA, 2016c; Jackson et al., 2015; Nordback et al., 2013). However, a more recent study by Nordback at al. (2019) finds that when data are collected had little impact on AADB error relative to count duration, the number of continuous counters included in a factor group, and the accuracy of the counting equipment. The optimal timeframe will also depend on the climate and possible special traffic generators. Counting during good weather can also reduce error, especially when shorter durations are used (TRB, 2014a).

2.4 Expansion Factors and Factor Groups

While short-term counts can cover a wider geography and larger selection of travel corridors than a small number of permanent continuous count sites, the data only provide a brief snapshot of traffic. Changes in traffic volumes at individual sites can be tracked over time if they are made at the same time of year and days of the week under similar weather conditions (TRB, 2014a), but this can be difficult to achieve in practice. By expanding short-term counts to annual averages, short-term counts are used to estimate AADB which can then be used to track regional trends in bicycle traffic and compare differences in trends across locations (FHWA, 2016c; TRB, 2014a). Expanding short-term counts to AADB requires identifying appropriate adjustment factor groups and collecting data to estimate the factors.

The development of factor groups was reviewed in section 2.2. Here we discuss the different methods for creating and using adjustment factors within these groups. In principle, adjustment factors can be developed for any phenomena that may affect bicycle traffic volumes at a specific time or location. In practice, they are generally created to adjust for regularly observed annual and diurnal traffic volume patterns. Different sets of adjustment factors are estimated for each factor group, which can account for land-use and other spatial factors that affect traffic volumes if these were considered in the definition of the factor groups used. At its simplest, adjustment factors work by multiplying a ***daily*** average bicycle traffic volume estimate from a short-duration count by a factor that adjusts it to represent an ***annual daily*** average traffic volume or AADB. Other average periods and methods are also used, but they all function similarly in terms of transforming an estimate from a specific time period to a longer-term average value which allows data collected from different short-duration time periods and locations to be aggregated and compared to one another.

Annual factor groups can span from 4 seasonal factors to 365 day-of-the -year factors. Most research indicates that AADB estimation errors can be reduced by using adjustment factors that correspond to shorter time periods such as monthly, week-of-the-year and day-of-the-year factors (El Esawey, 2014, 2016; Hankey et al., 2014). Seasonal and day-type or day-of-the-week factors have been shown to produce higher errors. If less than 24-hr count data are collected, then hourly adjustment factors are first used to estimate a daily average traffic volume estimate which is then further adjusted to AABD using additional adjustment factors. These temporal adjustment factors are created from continuous count data from sites within each factor group. Therefore, as discussed previously, it is important to minimize error in the continuous count data used in each factor group by using at least 2 continuous counters per factor group and defining factor groups that capture significant temporal and spatial differences in bicycle traffic travel patterns.

2.5 Site Selection

Many bicycle count programs select a limited number of continuous count sites first, followed by a greater number of short-term count sites (Jackson et al., 2015). Criteria for selecting both continuous and short-term count sites vary by program, but generally they will cover a range bicycle facilities (mix-use trails, local streets, arterials with and without bicycle lanes), in a range of different settings and land-

uses (urban, suburban, rural), which generate different traffic patterns (commute, mixed, recreational) (Lindsey, 2017). Site requirements for each type of counter will also need to be considered.

Continuous count sites should be selected to be representative of traffic patterns in the factor group that they are part of (FHWA, 2016c). The highest volume sites within a region are often not the most representative and may not be ideal locations for continuous counters. The primary purpose of continuous count sites is generating data for estimating adjustment factors.

Short-duration count sites can be sited using various methods and criteria. An accurate regional estimate of bicycle traffic volume would be achieved with a large ***randomly selected*** set of count sites. In practice, however, such an approach would require a very large number of sites to avoid problems caused by the high likelihood of selecting a large number of low volume locations which would result in a high error in AADB estimates (FHWA, 2016c; TRB, 2014a). A random selection process may also select sites that are unsuitable for automated counting (TRB, 2014a). Stratified random sampling, where random selection occurs on subsets of all possible sites, could avoid many of these issues but would still require a relatively large number of sites (FHWA, 2016c; TRB, 2014a). For example, sites could be randomly chosen from groups of roadways with high, medium and low expected bicycle volumes.

An alternative to random selection is selecting ***representative sites***. In this approach, sites are selected to ensure that data is collected from each type of community or infrastructure type in a region (TRB, 2014a). For example, sites can be selected to gather data from different geographic areas, from facilities with different surrounding land use types, on roadways with different facilities (e.g., different bicycle facilities) and traffic characteristics (e.g., motor vehicle speed and volumes), and from communities with different socioeconomic characteristics. This approach can be implemented with fewer sites than random sampling. While the data collected through this approach will not produce a statistically valid regional bicycle traffic volume estimate, it does allow for tracking changes in bicycle volume trends across locations, types of facilities, different land uses, different socioeconomic groups and any number of additional criteria used to define groups for siting counters. As with siting continuous count stations, selection of sites based on convenience or an expectation of them having the highest bicycle traffic volumes should be avoided (FHWA, 2016c; TRB, 2014a). Lu et al. (2017) discuss the design and implementation of a regional bicycle traffic count program following this general approach in Blacksburg, VA, a small college town where Virginia Tech is located which serves as a potential example that CCRPC could follow in the greater Burlington area.

Sites may also be selected in a more targeted approach that is designed to achieve a specific objective. Sites may be selected to address specific concerns, such as bicycle crash hotspots or to support project evaluations (before/after studies) (FHWA, 2016c; TRB, 2014a). Sites may also be selected to capture regional traffic flows across pinch points, such as a series of bridges over a river or highway that separates major origin-destination pairs (TRB, 2014a). When sites are selected to evaluate bicycle infrastructure projects, it is critical to include control sites to capture regional changes in traffic volume over time and sites on potential parallel routes to capture trip diversion caused by the project (Goodman et al., 2013, 2014; Krizek et al., 2009; Rowangould & Tayarani, 2016; TRB, 2014a).

Site selection should also consider where along a particular roadway or facility to count. There are two general choices: at intersections and at screen lines (FHWA, 2016c). Screen lines, an observation of traffic through an imaginary line drawn perpendicular to a facility, are typically used for traffic volume estimation. They are relatively easy to implement using a variety of automated counters and the data they generate is easy to work with (it represents counts in either one or two directions). Intersection counts are more complicated to collect and work with because of the many possible movements that can occur. Reducing intersection counts to estimate bicycle traffic volumes on individual legs of an intersection can be complex and time consuming. The main use of intersection counts is for addressing

safety and intersection operation (e.g., delay) concerns. Additional site selection criteria include natural funneling points where bicyclists are more constrained to stay within the detection zone of the counters being used and avoid under counting bicyclists that by-pass detectors and locations that minimize conflicts with other roadway uses and users (FHWA, 2016c; TRB, 2014b). For example, pneumatic tubes can be a tripping hazard for pedestrians and parked cars can also obstruct or occlude various counting devices.

2.6 Counting Technologies

Two general methods are available for counting bicycle volumes: manual and automatic. Manual counts rely on humans to observe traffic in the field or video taken from the count site. Both approaches can be very accurate but are limited to relatively short durations due to their high costs. Automatic counters are relatively inexpensive and can be permanently installed or portable. The main advantage of automatic counters over manual counts is their ability to collect greater volumes of data at lower cost; however, many automatic counters are less accurate than manual counts performed by humans. In practice, a robust count program will require a combination of manual and automatic counts, where manual counts are used to calibrate and validate automatic counters that are relied on to collect the bulk of the data.

2.6.1 Manual Counting Techniques

Manual counts are generally tallied in-person by an observer using tally sheets, mechanical handheld counters, or electronic devices in the form of tablet or smartphone apps. The advantages of manual counts are that they can be collected at any site, are mobile, are relatively accurate, have no installation requirements, and can collect some types of user data (e.g., gender) in addition to count data. However, using a person to collect bicycle count data means that only short-term data can be collected given the high costs for training, management, and on-site labor (TRB, 2014a).

Manual counts can also be reduced from video footage, in which a human reviews videos from a permanently or temporarily installed camera and tallies counts using a computer. Like in-person manual counts, video manual counts have high accuracy, few installation requirements, and can collect some types of user data. Additionally, video manual counting has the advantages of not having to send data collectors into the field during inclement weather or nighttime hours, being able to review video footage at any time to accommodate schedules of data collectors and having the flexibility to slow down or speed up video based on bicycle volume levels. This method for collecting bicycle count data is believed to be the most accurate because of the ability to re-watch video as needed. Despite the advantages, video manual counts are constrained to short-term counts due to high costs for training, management, and labor. Additional constraints of video manual counts are that they require frequent field visits to maintain cameras, require a fixed or moveable pole to mount the camera, and cameras are susceptible to theft and tampering unless they are well-disguised and out of reach (TRB, 2014a).

2.6.2 Automated Counting Technologies

Automated bicycle counting technologies generally include the following components: sensors that detect the bicyclists, a counter or processor that records the detection, a data logger that stores the detection, a power supply to operate the technology, a communications method to transfer recorded counts to the operator's database, and some sort of physical shelter to protect it from weather and the environment (TRB, 2014a). Automatic counters come in permanent and portable solutions. Permanent counters are generally used for continuous count sites while portable counters are used for short-duration counts, although some portable counters can count for several or more months. Automatic counters can also be classified by their ability to differentiate bicycles from pedestrians and bicycles from motor vehicles. Those that can differentiate bicycles from other roadway users represent a small

subset of the currently available automatic counter technologies, however, they are also some of the most commonly used technologies for monitoring vehicle traffic and have a long history of use.

The bicycle count program guidance from FHWA and NCHRP discussed previously both provide extensive overviews and guidance on the use of automatic bicycle counters (FHWA, 2016c; TRB, 2014a). Additionally, a second NCHRP project specifically focused on evaluating the accuracy of automatic bicycle and pedestrian counters and provides in-depth information on the use, pros and cons of most currently available technology (TRB, 2014b, 2017). These comprehensive guides and studies along with several academic studies focused on pneumatic tube counters all tend to reach similar conclusions and offer similar guidance.

Most automatic counter equipment is relatively inexpensive, costing less than $10,000 and often less than $3,000 (Alta Planning + Design, 2009; TRB, 2014a). The largest costs are generally realized in training personnel, setting up and maintaining equipment, installing permanent counters, and data processing and evaluation. Some vendors also charge additional fees to process data or use optional software for managing, storing and evaluating data from their devices. The costs of most automatic counters and related implementation costs are much less than equivalent manual data collection costs.

Regardless of the technology selected, it is critical to regularly calibrate, validate and inspect the operation of automatic counters, including those that are permanently installed (FHWA, 2016c; TRB, 2014a, 2014b, 2017). All of the currently available technologies have been found to vary significantly in their performance when installed in different field conditions. Accuracy should be validated using ground truth counts (e.g., manual counts) and devices should be calibrated following manufacturer recommended procedures and schedules. It is particularly important to ensure that continuous count sites are calibrated and validated on a regular basis since errors in these data will propagate through to short-duration counts if they are factored (Jackson et al., 2017). Furthermore, devices should be regularly inspected to ensure they are operating correctly and have not been damaged or stolen.

Almost all automatic counters are more likely to undercount bicycles than overcount (Nordback et al., 2016; Ohlms et al., 2019; TRB, 2017). This occurs due to occlusion from other vehicles and adjacent bicycles and detector by-pass. For example, a car may pass over a pneumatic tube at the same time as a bicycle, occluding the signal for the bicycle, or a bicyclist may ride around an inductive loop installed in a bicycle lane and fail to be detected. Site selection can play an important role in limiting these types of errors.

There are four predominant types of automatic counters that can differentiate bicycles from pedestrians, and three that can differentiate bicycles from vehicle traffic, that are possible candidates for use in a bicycle count program.

2.6.2.1 Inductive Loops

Inductive loops use a coil of wire that detects changes in an electric current when a bicycle or car passes through a magnetic field generated by the loop. The loops are typically embedded in the pavement surface although temporary surface mountable loops are also available for medium-duration counts. This is the same technology widely used to detect cars and bicycles at signalized intersections. Inductive loops are generally used for continuous count sites given the permanence of their installation methods. Some vendors provide inductive loops that can differentiate cars from bicycles, allowing them to be used in mixed traffic (FHWA, 2016c; TRB, 2017). Otherwise, inductive loops need to be placed in locations that bicycles are likely to pass over such as a bicycle lane or path to avoid by-pass errors which can be significant (TRB, 2017). Inductive loops can last for years and are very accurate with average percent differences from actual counts being less than 5% when by-pass errors are avoided (TRB, 2017).

2.6.2.2 Pneumatic Tube Counters

Pneumatic tube counters use a rubber tube that is stretched across the roadway or path. When a vehicle or bicycle passes over the tube, the counter detects the change in air pressure. Different patterns and magnitudes of air pressure changes can be used to classify counts by vehicle type. Pneumatic tube counters are widely used for short-duration vehicle traffic and bicycle counts and come in versions designed to classify a wide range of vehicles including bicycles or versions that are designed specifically for counting bicycles. Unlike inductive loops, pneumatic tube counters are very portable and they are also low cost. Like inductive loops, they can be installed on bicycle facilities or in mixed traffic.

A number of studies have evaluated the performance of general-purpose pneumatic tubes and bicycle specific pneumatic tubes given their ease of use and low cost. These studies find that accuracy can vary widely across vendors and site-specific conditions. When installed and calibrated properly, they can be relatively accurate. The average difference between actual and detected bicycle counts from pneumatic tube counters has been found to range from 7% to 70% when used in mixed traffic, with most under counting by about 10% to 30% (Brosnan et al., 2015; Nordback et al., 2016; TRB, 2017). The main cause of these errors seems to be occlusion from vehicle traffic. When used in a controlled environment without vehicle traffic, error can be substantially reduced, for example, to as low as 1% with bicycle specific counters from Eco-Counters (Nordback et al., 2016). Tests also find that pneumatic tubes are more accurate when bicyclists strike the tubes closer to the detector, presumably creating a stronger pressure signal (Brosnan et al., 2015; Nordback et al., 2016). Considering these factors, pneumatic tubes should be located in locations where bicyclists are likely to ride close to the right side of the roadway and away from vehicle traffic. The sensitivity of these counters to site specific conditions also means that it is important to validate and calibrate them with ground truth data. Correction factors can be estimated to correct for systematic undercounting in specific conditions (TRB, 2014a).

2.6.2.3 Machine Vision

Machine vision systems use computer algorithms to identify and count bicycles, along with other roadway users, in video recordings. It is typically used in short-duration counts of a week or less because of data storage and processing costs (TRB, 2014a). A strength of this technology is that it is the only one that can count and differentiate bicycles, vehicles and pedestrians. It can also be used for screen line or intersection turning movement counts. The main limitation to more widespread use of machine vision appears to be costs and fewer studies evaluating their accuracy in counting bicycles (and pedestrians) which depends on the algorithms that process the video developed by the vendors of these systems. The capital costs of machine vision systems are similar to other automated count technologies; however, unlike all other bicycle count technologies the video data must be processed as part of a fee-for-service model from the hardware vendor.

2.6.2.4 Piezoelectric Strips

Piezoelectric strips are a relatively new technology for bicycle counting. An electrical signal is created in a piezoelectric strip when deformed by a bicycle tire rolling over it, similar in concept to the operation of pneumatic tubes. Unlike pneumatic tubes, piezoelectric strips are permanently installed in the roadway or path surface, similar to inductive loops. There is relatively less testing and evaluation of piezoelectric strips than other bicycle count technologies; however, the limited amount of testing data that has been published suggests that they could be highly accurate when used in appropriate locations (TRB, 2017). Currently, piezoelectric strips are not designed for mixed bicycle and vehicle traffic, but they can be used on shared use paths (TRB, 2014a).

3 OUTREACH TO STATE AND REGIONAL BICYCLE COUNT PROGRAMS

To gain a better understanding of current bicycle count program practice and to supplement our literature review, we spoke with staff from five organizations that currently operate regional bicycle count programs. We contacted organizations that varied in size and agency type and that were all known to have operational, regional, bicycle volume count programs. We used a semi-structured interview method to learn about how bicycle count programs are implemented and operated, how sites are selected and what types of counting technology are used. We also asked staff to identify potentially innovative or best practices. Many staff also identified challenges they face.

3.1 Outreach Process and Virtual Interviews

We identified several bicycle count programs in the United States through a scan of websites of agencies and organizations involved with bicycle count data collection. We then contacted six state and municipal organizations by email to inquire about their bicycle count data collection programs and invite them to participate in a short online interview. Five organization responded and agreed to be interviewed for this project:

- Western Maine Region: Androscoggin Transportation Resource Center (ATRC)
- Central New Mexico Region: Bernalillo County Department of Public Works
- Delaware Valley Region, Pennsylvania/New Jersey: Delaware Valley Regional Planning Commission (DVRPC)
- Minnesota: Minnesota Department of Transportation (MnDOT)
- Virginia: Virginia Department of Transportation (VDOT)

The structure of the 30-minute interviews with bicycle count program staff was informal, and staff from every program were asked the same two overarching questions:

1. What are the goals of this bicycle count program?
2. What would you say is innovative, unique, or representative of a best practice in your program?

In most instances, these questions led to free-flowing discussions that covered the key elements of a bicycle count program including count duration, site selection processes, counting equipment and technologies, data management, and applications for bicycle count data. If these topics were not covered after these two initial questions, the research team prompted staff to address these items.

3.2 Overview of Programs

Prior reviews have found that practices for collecting bicycle count data in the United States vary greatly in purpose, data collection methods and program design, with local, regional, or state agencies each administering their own programs (FHWA, 2016b; Ohlms et al., 2019; Schneider et al., 2005). We reached similar conclusions based on our interviews. One overarching theme from prior reviews of practice and from our interviews is that many organizations recognize that bicycle data could be, and likely should be, collected in a more systematic way; however, resource constraints in the form of funding and staff availability often prevent the implementation of more robust programs. A second common theme is that while many organizations are collecting more bicycle count data, how to process and use the data effectively remains a challenge.

Other takeaways included:

- The goal for many programs is to replicate vehicle traffic count programs and have data that is expansive enough to be useful for a variety of applications.
- Most programs have a combination of continuous and short-duration counting locations, although not always located following a strategic plan based on current guidance.

- Mixed review of equipment. Some organizations found tremendous value in machine vision systems while others found it too complex and difficult to use. Bicycle specific count equipment sold by Eco-Counter was generally praised for ease of use and accuracy.
- Site selection was typically driven by a combination of receiving input from the public, key stakeholders and partners, and trying to distribute counters on a variety of facilities, land-uses, population centers, etc.

Table 1 Summary of Bicycle Count Programs

Community (*Agency*)	Program Goals	Count Types	Site Selection Processes	Data Uses	Technologies
Western Maine Region *Androscoggin Transportation Resource Center (Council of Governments)*	• Evaluate changes in bicycle traffic volumes. • Infrastructure project before/after studies.	• Short Duration	• Bicycle counts are collected at all signalized intersections in the region as part of the vehicle turning movement count program. • Additional count sites are determined by partner requests.	• Intersection traffic signal management. • Local committees use data for Complete Streets planning, infrastructure gaps and improvements. • Pattern and volume changes • Specific municipal projects, such as intersection changes. • Realtors and developers use data for siting projects.	• Machine vision • Radar counters
Central New Mexico Region *Bernalillo County Department of Public Works*	• Mirror motor vehicle count program. • Evaluate temporal volume and mode share (ped vs. bike) trends. • Estimate annual average volumes from short duration counts.	• Continuous • Short Duration	• Known high bicycle volume locations, including trails. • Initial site selection involved input from advisory groups on geographic coverage/ensure all parts of the city had some form of counting. • Short duration counts at specific sites as requested.	• Determining mode share on trails. • Understanding types of users (commuter vs. recreation). • Understanding demand for active transportation modes • Targeting limited infrastructure investments to key locations. • Tracking impacts of specific projects with before and after count data.	• Machine vision + inductive loops • Inductive loops • Infrared detectors • Pneumatic tubes

Delaware Valley Region, PA/NJ *Delaware Valley Regional Planning Commission*	• Mirror motor vehicle count program. • Collect as much bicycle count data as possible.	• Continuous • Short Duration	• 18 permanent count locations, 16 on multi-use recreation trails and 2 on streets. • Initial site selection involved input from community members and partners and tried to have counters on various types of facilities.	• Planning active transportation corridor treatments. • Tracking project impact through before and after count data • Used by municipalities to understand bicyclists' use of specific roadways	• Pneumatic tubes • Infrared detectors • Manual counts from video with vendor processing
Minnesota *Minnesota Department of Transportation*	• Estimate facility bicycle traffic volumes. • Mirror motor vehicle count program.	• Continuous • Short Duration	• Initial site selection involved input from partners. • Aimed to spread counters throughout the state and put them on different facilities. • For future potential permanent count sites, MnDOT uses a GIS process that weights various factors including, bicycle investment routes, trunk highways, and trails, and cities. After analysis, MnDOT works with partners to select precise locations of counters.	• Track internal performance metrics including Towards Zero Deaths initiative, bicycle miles traveled, greenhouse gas emission reductions, active travel impacts on health, number of people visiting natural areas and how those areas are being used. • Calculating average annual daily bicycle (AADB) traffic.	• Pneumatic tubes • Infrared detectors • Inductive loops
Virginia *Virginia Department of Transportation*	• Get more bicycle count data statewide. • Increase use of collected data. • Collect as much bicycle count data as possible.	• Continuous • Short Duration	• Half of count sites are requests. • Other count sites are selected to represent a range of infrastructure types and geography. • Counters are left in the field, collecting data at various locations if not scheduled for other counts to collect as much data as possible.	• Corridor, planning and safety studies • Justification for infrastructure implementation and improvements, such as path widening • Used to determine shared-use path capacity and level of service (e.g., FHWA shared-use path LOS calculator: https://www.fhwa.dot.gov/publications/research/safety/pedbike/05138/)	• Pneumatic tubes • Infrared + inductive loop

Table 2 Summary of Best Practices and Lessons Learned

Community (*Agency*)	Unique/Best Practices	Lessons Learned/Challenges
Western Maine Region *Androscoggin Transportation Resource Center (Council of Governments)*	• Low cost bicycle count add-on to existing machine vision vehicle-focused TMC program. • Public data portal with simple map interface (https://www.avcog.org/1100/Bicycle-and-Pedestrian-Counts)	• Making data easily accessible to the public has led to many additional uses of the data.
Central New Mexico Region *Bernalillo County Department of Public Works*	• Network of continuous count stations using combination of machine visions and inductive loops.	• Simple technology now preferred over machine vision system combined with inductive loop. Collect more data at less cost and with less staff. • Ease of maintaining, accessing data and processing data should be considered when selecting technology.
Delaware Valley Region, PA/NJ *Delaware Valley Regional Planning Commission*	• Comprehensive bike count program with 18 continuous counters and 1-week short-duration counts. • Public data portal website with continuous count data maps and plots (https://www.dvrpc.org/webmaps/permbikeped/)	• Field crews are all trained in collecting vehicle and bicycle counts so that they can set up both types of sites during a day in the field.
Minnesota *Minnesota Department of Transportation*	• Portable counter borrowing program. • Collaborate with other state departments, such as Department of Health and Department Natural Resources to collect count data for cross department initiatives. • Standardized and centralized data reporting and warehousing structure to maintain data collected from across the state.	
Virginia *Virginia Department of Transportation*	• Program is extremely flexible so that counters are mobile and can be moved for different projects and uses as needed. • Internal counter loaning program – has been picked up and well used by a few VDOT districts and MPOs which has helped the overall program expand reach.	

4 EVALUATION OF EXISTING BICYCLE COUNT DATA IN CHITTENDEN COUNTY

Bicycle count data in Chittenden County are collected by multiple organizations using several different data collection methods. Most data in the region are collected by CCRPC while some data have also been collected by community partners such as Local Motion and the UVM Transportation Research Center. There is currently no central repository for bicycle count data[1] which made it difficult to identify all currently existing bicycle count data in the region. It is possible that individual municipalities and the Vermont Agency of Transportation have also collected bicycle count data in the region, either to support bicycle projects and bicycle planning or incidentally for other traffic and transportation planning studies.

Working with CCRPC and the project Advisory Committee, we identified four sources of bicycle count data in the region:

- CCRPC intersection turning movement counts (TMCs)
- CCRPC automatic traffic recorder counts (ATRs)
- Manually reduced bicycle traffic counts made by Local Motion from video recordings
- Bicycle traffic counts made by various entities using various methods from the VTrans Vermont Bike and Pedestrian Count Data Portal.

Additional bicycle and pedestrian count data are also collected continuously along several shared use paths in the region using infrared PYRO-Box counters made by Eco-Counter[2]. The infrared counters currently used in the region do not discriminate between pedestrian and bicyclists, offering only a combined pedestrian and bicycle count. Since most shared use paths in the region have large volumes of pedestrians, the combined bicycle and pedestrian counts from infrared counters are not suitable for evaluating bicycle traffic trends and are not evaluated in our study.

In total, we obtained bicycle count data from years 2011 through 2020 from 207 individual count sites. TMC and ATR data were provided by CCRPC in separate Microsoft Excel files for each count site and date. Local Motion provided data in a series of separate Google Document spreadsheets for each count site and date. Data from the Vermont Bike and Pedestrian Count Data Portal "VT Data Portal" was downloaded by the UVM research team directly from the portal website. The data from the VT Data Portal is provided in two separate spreadsheets, one providing information about the count site (location, identifying information, and site characteristics) and the other providing the bicycle count data. The site and count data can be joined using a unique site identification number.

4.1 Bicycle Count Data Attributes

In order to evaluate what the region's current bicycle data reveals about bicycling in Chittenden County and to identify information gaps, we began our analysis by combining data from all four data sources into one unified geospatial database. This was a very challenging task because the attributes of bicycle count data available from each source differed in several ways including:

- Count duration,
- Count averaging period,
- Intersection versus mid-block location,
- Inclusion of weather information,
- Inclusion of site identifying information such as location coordinates,

[1] A prior Vermont Agency of Transportation funded effort did result in a statewide bicycle and pedestrian count data repository website (http://www.uvm.edu/~transctr/research/VTransBPPortal/index.html); however, the site was only actively used for a short period of time. No new data has been added since 2016.

[2] PYRO-Box manufacturer product information page: https://www.eco-counter.com/produits/pyro-range/pyro-box/

- Site naming conventions, and
- Electronic file format.

As summarized in Table 1, some data are collected over the course of an entire day while other data are only collected during AM and PM peak travel periods or daylight hours. Furthermore, these data are reported using different averaging periods. ATR and Local Motion's data are aggregated by hour while TMC data are aggregated by 15min periods. The data in the VT Data Portal appear to be collected at either 15min or 1hr periods (a mix of ATR and TMC data), but are only reported as aggregate counts for the entire daily count period (which varies in length from site to site and day to day) and for the peak traffic period.

Table 3 Summary of Count Type Attributes

Attribute	ATR	TMC	Local Motion	VT Data Portal
Peak Period Counts	Yes	Yes	Yes	Yes
Off Peak Mid-Day Counts	Yes	No	Yes	No[a]
Off Peak Evening Counts	Yes	No	early evening[b]	No[a]
Count Averaging Period	1hr	15min	1hr	varies (15min, 1hr, 24hr)
Location	Mid-Block	Intersection	Mostly Intersections	Both
Weather Conditions	No	No	Yes	Yes
Site Description	Speed Limit	No	Varies	Description of bicycle facility if exists
Site Coordinates	No	No	Some	Yes

[a] Bicycle counts are aggregated over the entire daily count period and separately for the peak period. While data are reported to have been recorded at 15min, 1hr, or 24hr periods, these disaggregated data are not available through the portal.

[b] Data are collected by video camera. The video is then reviewed by a technician who records the number of bicycles they see in the video for each time period. Low light conditions during the evening hours can make it difficult or impossible to accurately count bicyclists. This method of data collection is therefore generally limited to daylight hours.

4.1.1 Summary of Data Attributes by Source

TMC Data:

- TMC data were provided as a series of Microsoft Excel and PDF files that contained 15 minute counts, generally peak period only (7-9am and 4-6pm), directional movements at intersection by all modes.
- Excel file has TMCs by mode: auto, bike, truck, peds.
- Counts are collected manually in person or by video reduction.
- Includes bicycles in crosswalks.

ATR data:

- ATR data were provided as a series of Microsoft Excel files that contained 1 hour counts over 24 hours for 7 consecutive days (1 week).
- Screen line counts at mid-block locations.

- Data contain directional auto counts but non-directional bicycle counts (there are directional bicycle counts in PDF but not in Excel files).
- 51 ATR data sets were excluded because they did not contain data that classified bicycles.

Local Motion Data:

- Data were provided in a series of Google Spreadsheet documents that contained 1 hour counts from 7am to 9pm, generally for four days, although some had only two or three days, within the same week, including Tuesday, Wednesday, Friday and Saturday.
- Made by manual reduction of video recordings
- Includes observations of bicycles on sidewalks and shoulders/bike lanes
- Generally, these data were observed at intersections and contained turning movement counts. A few were screen lines.
- Some of the data had geographic coordinates.
- Weather conditions were described for each count day.

VTrans Portal Data:

- Data were uploaded to the portal by various users.
- Unclear how data were collected.
- While data were collected at 15min and 1-hour intervals, they were aggregated to daily totals and peak period totals prior to uploading. The more disaggregated data are not available.
- Some data collected for 5 to 6 hours for multiple days per year for multiple years, while other data are from 24 hours for 1 to 3 days (not necessarily in a row, but sometimes)
- Geographic coordinates are provided.
- Weather conditions are reported.

4.1.2 Data Processing and Aggregation

We began by combining all of the bicycle count data from each source into source specific datasets. For each source we created a list of site IDs and any information that was provided describing their location. For sites with no geographical coordinates, we used descriptions of the street locations provided with the data files to locate them on a map and recorded their coordinates. The VTrans Portal data already contained coordinates for all data collection sites and some of the Local Motion data contained coordinates.

We created a second file for each source that contained all of the count data for each site. ATR and TMC data were provided in a series of Microsoft Excel spreadsheets, one for each short-duration count campaign at each site. We wrote a computer script in R to automatically search through and extract the bicycle count data from these files. This automated process was chosen to avoid errors that would occur from manually copying and pasting records from the large volume of spreadsheets. The computer script will also allow for quick updates to our analysis and the database we have created if additional data becomes available. The data provided by Local Motion was converted to Microsoft Excel spreadsheets but the irregular formatting of the data fields required us to manually copy and paste data from individual files to build up a unified dataset. Data from the VTrans Data Portal were downloaded as a single, combined dataset.

The next step was to standardize the data so that it could be more readily compared with one another. Since data in the VTrans Data Portal were only reported as daily aggregates, we excluded these from comparisons with the other data, but kept them in the unified database. We aggregated the 15 minute TMC data up to 1 hour intervals to match the temporal resolution of the Local Motion and ATR data. We also aggregated the turning movement counts from the TMC data and Local Motion into totals for each

intersection. There is no simple, automated, approach to assign turning movement counts to individual legs to approximate a screen line count given the unique configurations of each intersection.

The final step was merging each count data set with its corresponding location data, and then merging all of the data into one unified dataset. We retained as much of the original data as possible through the data aggregation and merging process, including site descriptions and weather observations. All data aggregation and processing were completed using computer scripts written in the R programming language to avoid errors with manual data manipulation and automate the process of adding additional data to the unified dataset.

The final step involved importing the unified data into ArcGIS Pro so that the data could be placed on a map and queried by attribute or by their location. We used ArcGIS Pro to produce several maps showing the distribution of data collection sites throughout the region. Most other analyses shown below were performed in R using the ggplot graphical analysis package.

4.2 Data Coverage

We began by mapping the location of each count site to understand where data have been collected. The maps in Figure 1 show that most of the region's current bicycle count data has been collected in Burlington, South Burlington, Winooski and Essex. This is not surprising given that these communities are among the most urbanized in the region and are more likely to have higher rates of bicycling. There is very little data available in other towns.

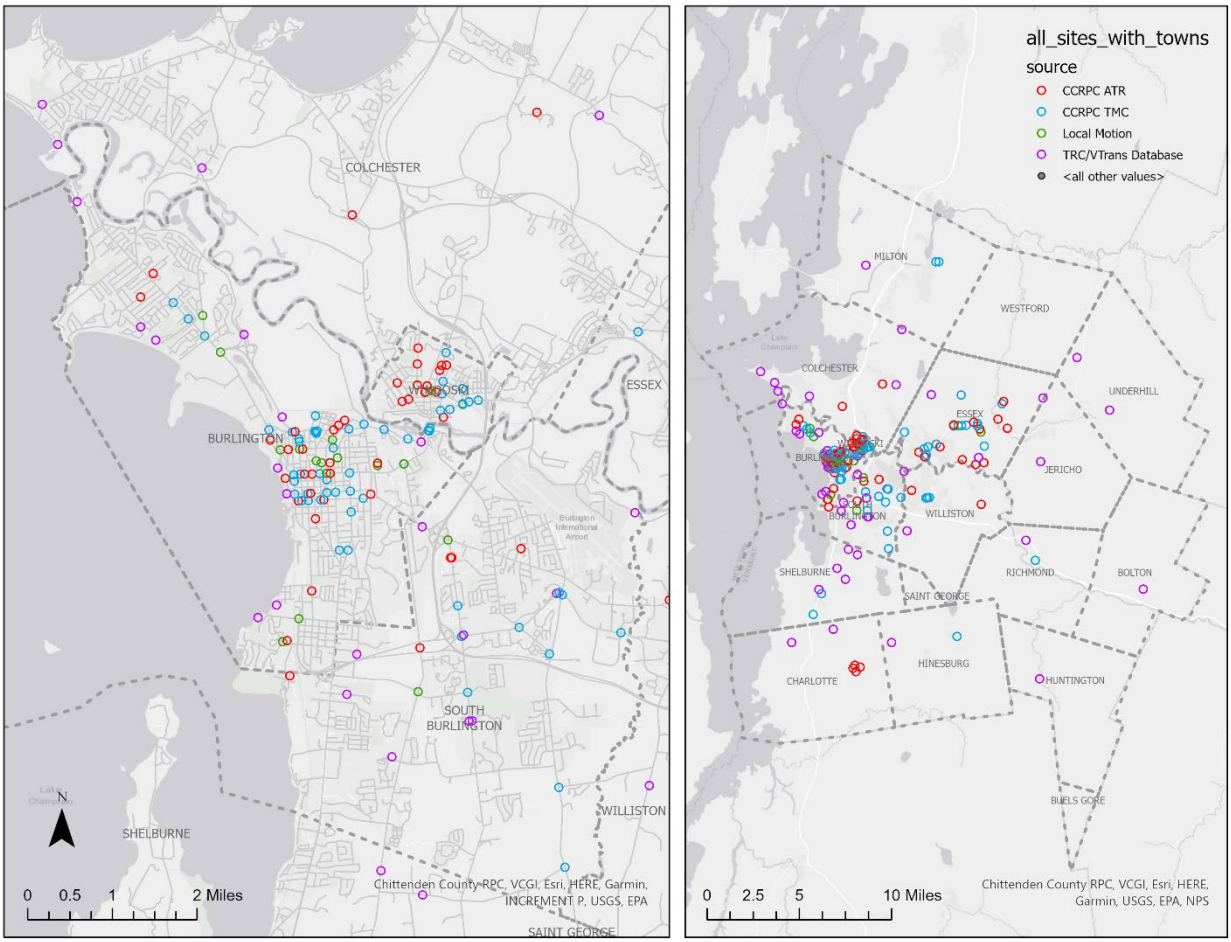

Figure 1 Map of Sites with Bicycle Counts

We also evaluated the availability of data for different time periods in each municipality and at each site, which is important for evaluating seasonal trends in bicycle use. As shown in Table 4, bicycle count data have not been collected consistently over time anywhere in the region. Burlington is the only municipality that has data available for most years, while data availability is more sporadic in all other municipalities. Furthermore, there is little consistency in the data collection methods over time in each municipality. For example, in Burlington where data are available in most years, the data in any particular year generally come from different combinations of the four data sources considered in this study which further limits the possibility of evaluating trends over time.

We also evaluated the availability of bicycle count data for different months and seasons. As shown in Figure 2 - 6, an overwhelming majority of the data have been collected during the summer months (June through August) with very little data collected during other times of the year. Most of the data collected during the fall through spring period has been collected in Burlington, South Burlington and Winooski. We also evaluated the availability of bicycle count data for weekdays and weekends. As shown in Figures 7 – 8, much more data has been collected during weekdays than weekends and that weekend data is largely confined to ATR and Local Motion data. There are very few sites in the VTrans Portal data and no sites in the TMC data that have weekend counts.

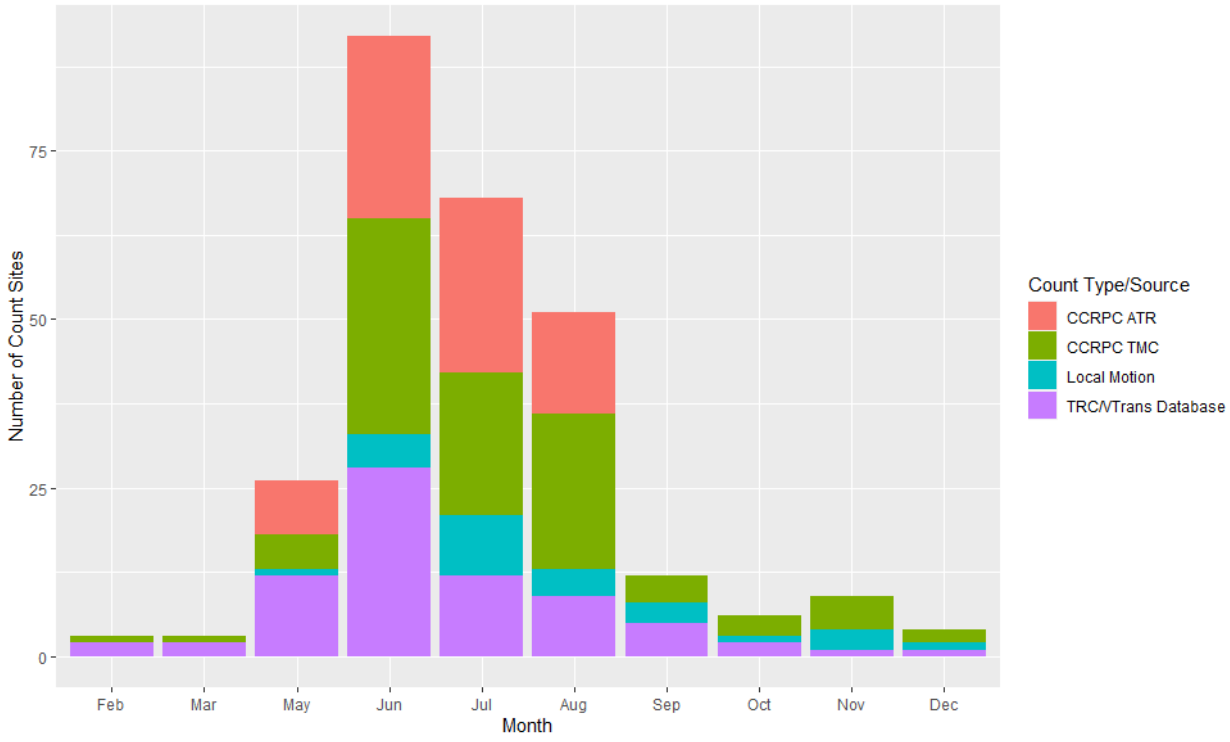

Figure 2 Bicycle Count Sites with Data by Month and Count Type

Table 4 Number of Bicycle Count Sites by Town, Count Type and Year

Town/City	Count Data Type/Source	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Bolton	TRC/VTrans Database	1	-	-	-	-	-	-	-	-	-
Burlington	CCRPC ATR	-	-	1	-	-	-	-	21	-	-
Burlington	CCRPC TMC	-	-	-	-	24	8	7	3	1	-
Burlington	Local Motion	-	-	-	-	-	-	-	-	12	2
Burlington	TRC/VTrans Database	-	8	9	5	3	-	-	-	-	-
	Total	***-***	***8***	***10***	***5***	***27***	***8***	***7***	***24***	***13***	***2***
Charlotte	CCRPC ATR	-	-	4	-	-	-	-	-	-	-
Charlotte	TRC/VTrans Database	1	1	-	-	-	-	-	-	-	-
	Total	***1***	***1***	***4***	***-***	***-***	***-***	***-***	***-***	***-***	***-***
Colchester	CCRPC ATR	-	-	-	-	-	-	-	2	-	-
Colchester	TRC/VTrans Database	2	4	3	-	3	-	-	-	-	-
	Total	***2***	***4***	***3***	***-***	***3***	***-***	***-***	***2***	***-***	***-***
Essex	CCRPC ATR	2	6	-	-	-	-	-	5	-	-
Essex	CCRPC TMC	-	-	-	-	1	5	11	-	2	-
Essex	Local Motion	-	-	-	-	-	-	-	-	2	-
Essex	TRC/VTrans Database	2	1	-	-	-	-	-	-	-	-
	Total	***4***	***7***	***-***	***-***	***1***	***5***	***11***	***5***	***4***	***-***
Hinesburg	CCRPC TMC	-	-	-	-	-	-	-	-	1	-
Hinesburg	TRC/VTrans Database	1	-	-	-	-	-	-	-	-	-
	Total	***1***	***-***	***-***	***-***	***-***	***-***	***-***	***-***	***1***	***-***
Huntington	TRC/VTrans Database	1	-	-	-	-	-	-	-	-	-
Jericho	TRC/VTrans Database	-	1	-	-	-	-	-	-	-	-
Milton	CCRPC TMC	-	-	-	-	2	-	-	-	-	-
Milton	TRC/VTrans Database	-	1	-	-	-	-	-	-	-	-
	Total	***-***	***1***	***-***	***-***	***2***	***-***	***-***	***-***	***-***	***-***
Richmond	CCRPC TMC	-	-	-	-	1	-	-	1	-	-
Richmond	TRC/VTrans Database	1	-	-	-	-	-	-	-	-	-
	Total	***1***	***-***	***-***	***-***	***1***	***-***	***-***	***1***	***-***	***-***
Shelburne	CCRPC TMC	-	-	-	-	-	1	-	-	1	-
Shelburne	TRC/VTrans Database	3	2	-	-	-	-	-	-	-	-
	Total	***3***	***2***	***-***	***-***	***-***	***1***	***-***	***-***	***1***	***-***
South Burlington	CCRPC ATR	-	-	-	-	-	-	-	5	-	-
South Burlington	CCRPC TMC	-	-	-	-	7	4	3	1	-	-
South Burlington	Local Motion	-	-	-	-	-	-	-	-	2	-
South Burlington	TRC/VTrans Database	2	2	7	5	6	-	-	-	-	-
	Total	***2***	***2***	***7***	***5***	***13***	***4***	***3***	***6***	***2***	***-***
Underhill	TRC/VTrans Database	2	-	-	-	-	-	-	-	-	-
Williston	CCRPC ATR	-	-	-	-	-	-	-	2	-	-
Williston	CCRPC TMC	-	-	-	-	-	2	-	-	1	-
Williston	TRC/VTrans Database	1	-	-	-	-	-	-	-	-	-
	Total	***1***	***-***	***-***	***-***	***-***	***2***	***-***	***2***	***1***	***-***
Winooski	CCRPC ATR	-	-	-	-	-	-	-	13	-	-
Winooski	CCRPC TMC	-	-	-	-	4	-	-	7	-	-
Winooski	Local Motion	-	-	-	-	-	-	-	-	2	1
	Total	***-***	***-***	***-***	***-***	***4***	***-***	***-***	***20***	***2***	***1***
Total		**19**	**26**	**24**	**10**	**51**	**20**	**21**	**60**	**24**	**3**

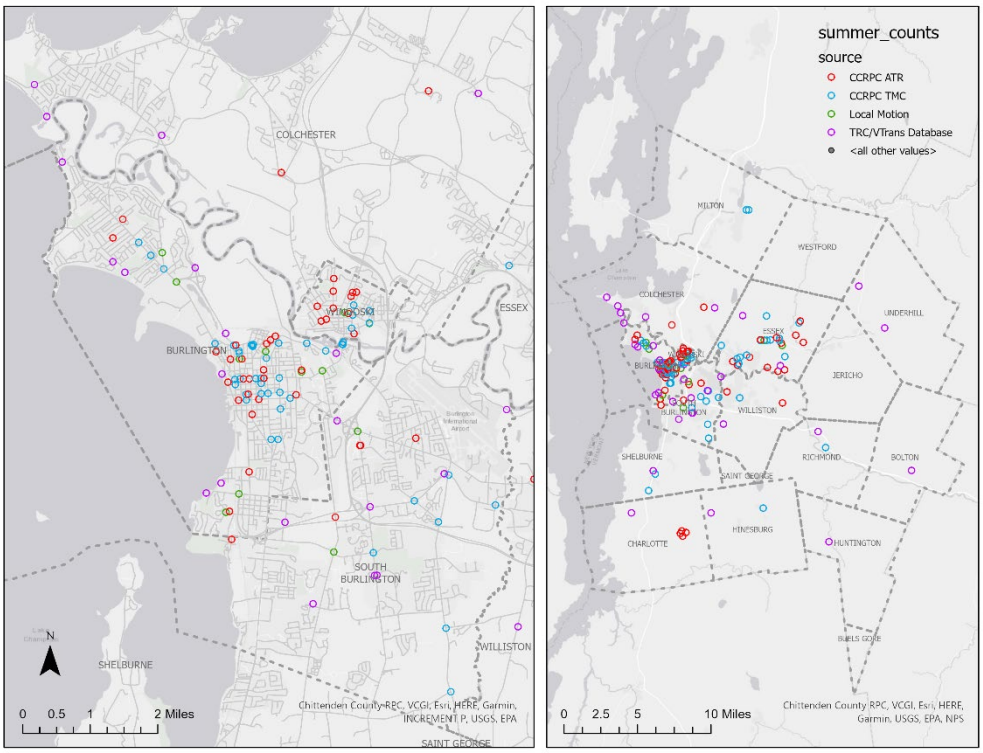

Figure 3 Location of Bicycle Count Sites with Data from Summer Months (June – August)

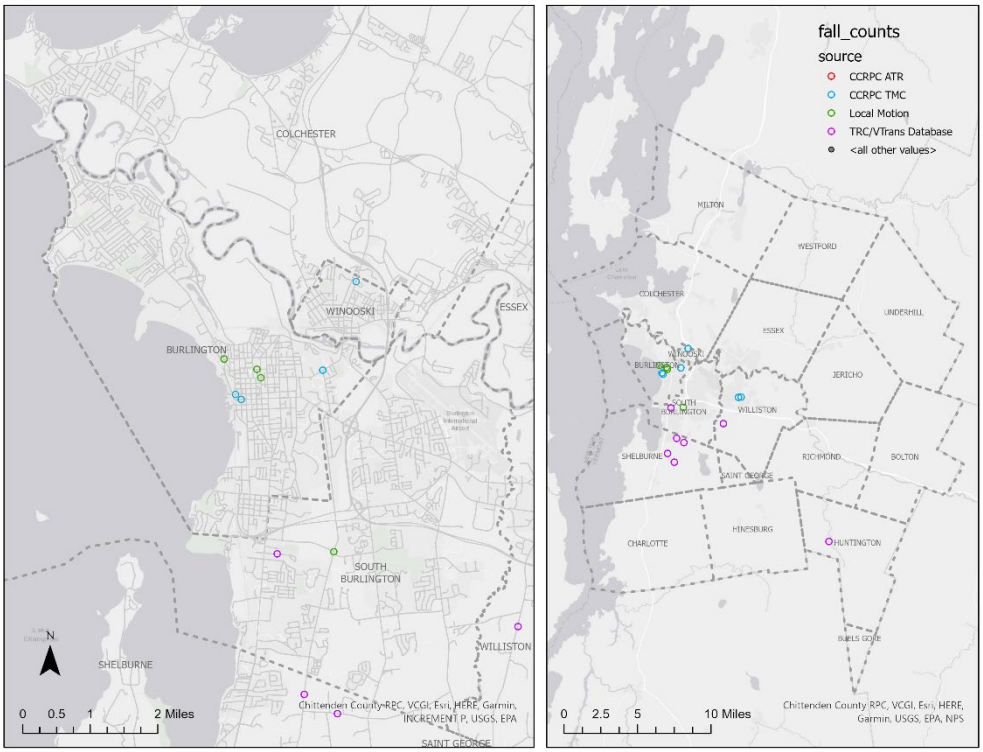

Figure 4 Location of Bicycle Count Sites with Data from Fall Months (September - October)

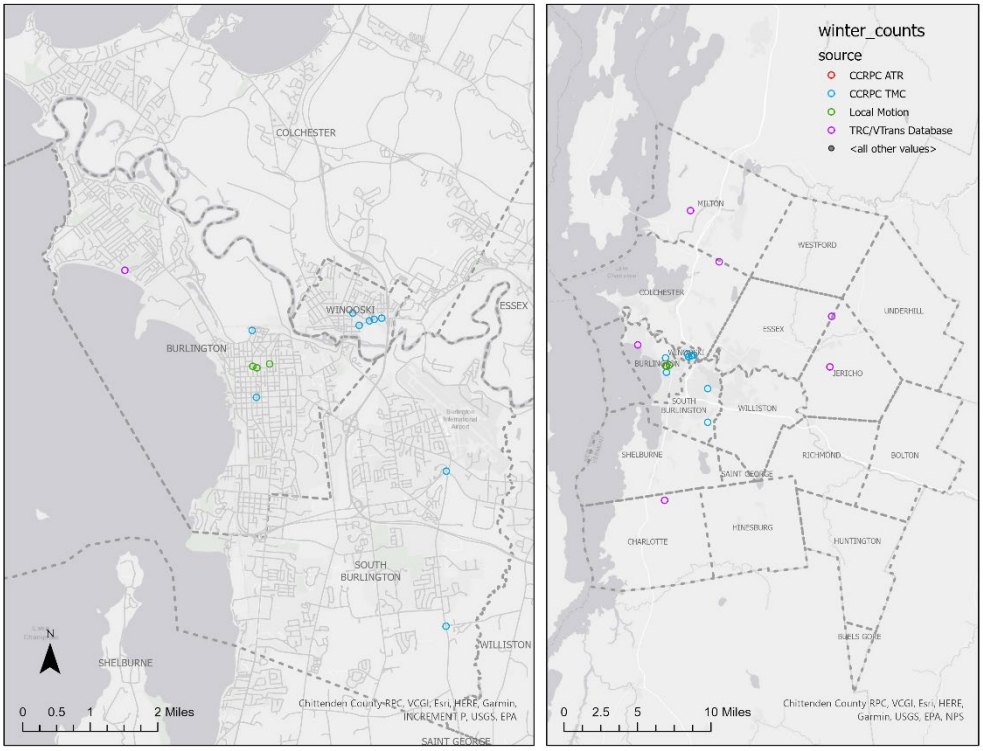

Figure 5 Location of Bicycle Count Sites with Data from Winter Months (November – March)

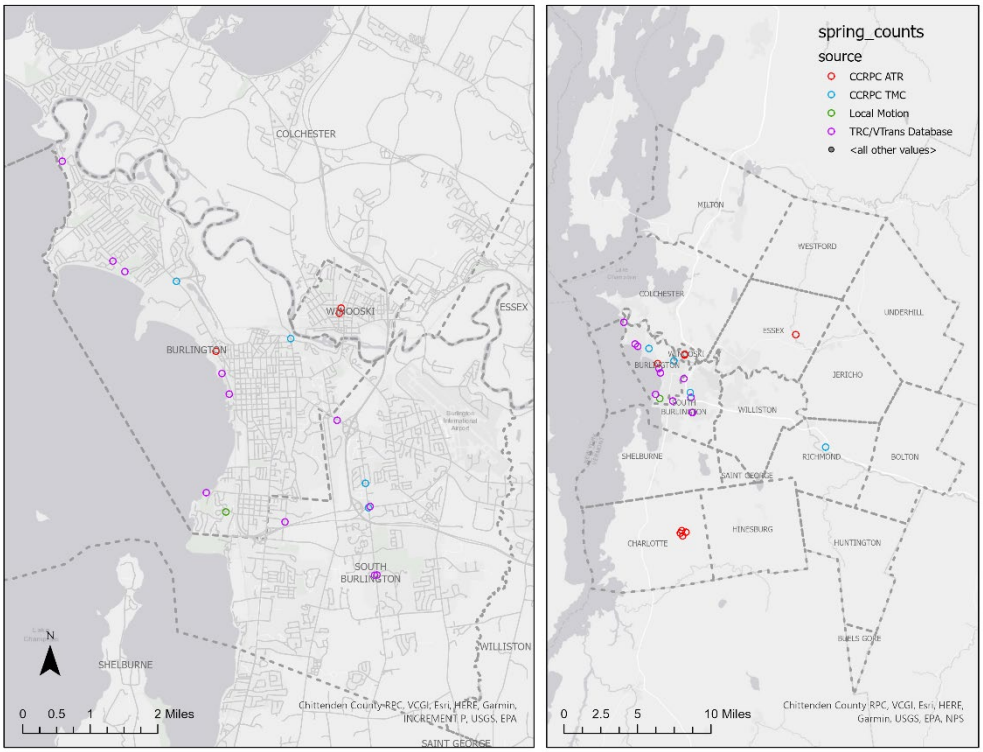

Figure 6 Location of Bicycle Count Sites with Data from Spring Months (April – May)

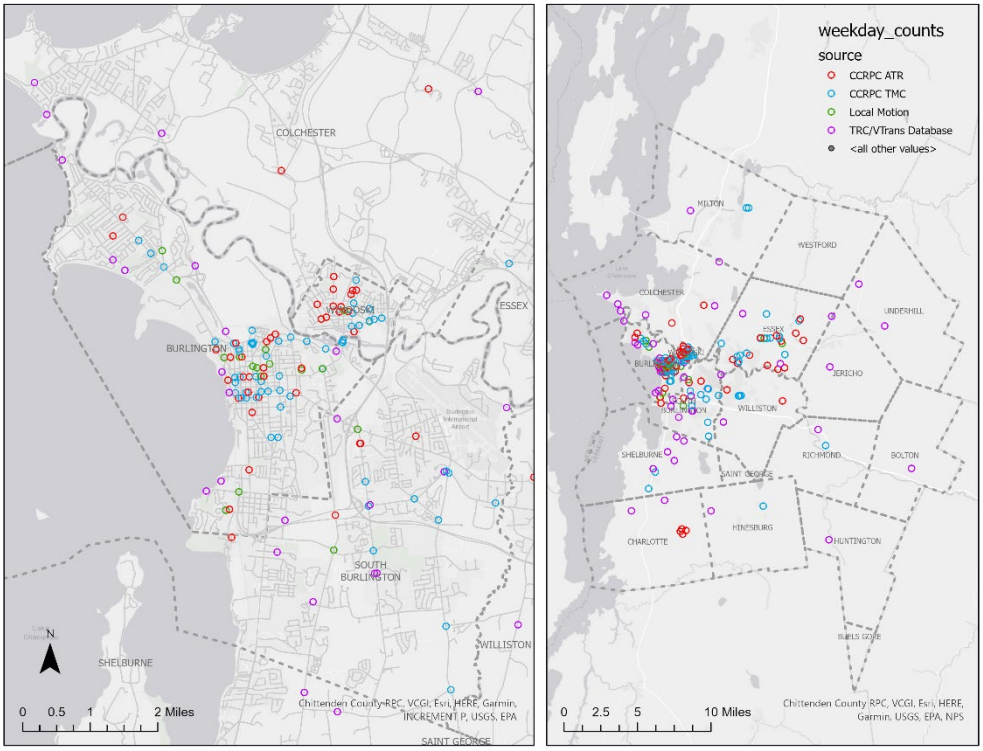

Figure 7 Location of Bicycle Count Sites with Data from Weekdays

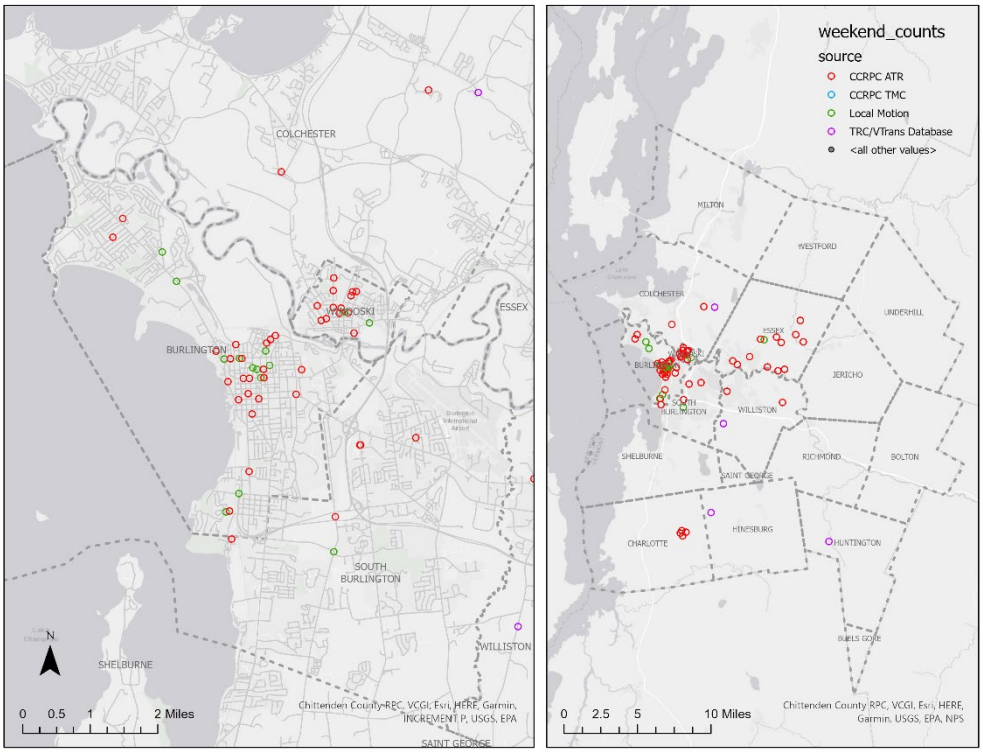

Figure 8 Location of Bicycle Count Sites with Data from Weekends

Next, we evaluated the data available at each count site. Figures 9 – 11 provide plots showing 1 hour counts of all data available at each ATR, TMC and Local Motion site. VTrans Portal data are not displayed and trends were not evaluated because no disaggregate data were available. The plots in Figures 9 – 11 show data from each year with different colors. In addition to showing each individual data point, smoothed trend lines are also included. Solid lines indicate trends from weekday data and dashed lines for weekend data. Separate trend lines are generated for each year so that changes between years can be compared if data from more than one year were collected at a site. Also note that the plots in each figure are drawn on the same scale, so the height of the data points and trend lines indicates the absolute difference in the volume of bicycle traffic between sites. Also note, that the y-axis scale spans twice the range in Figure 9 (Burlington) than Figures 10 and 11, reflecting the much higher bicycle traffic volumes observed in Burlington.

The hourly count plots reveal several important facts about bicycle count data in the region:

- Very few sites contain data from more than one year (more than one color of data points and trend lines) and no sites contain data from more than three years. There is no apparent trend in bicycle volumes over time from the limited data that are available.

- Several distinct traffic patterns are seen in the 12- and 24-hour data from Local Motion and the ATR data, respectively. Some of the sites clearly display morning and evening peaks, indicating sites capturing significant volumes of commute trips, including the example in Figure 9. Other sites show a single pronounced peak in the afternoon or evening, possibly indicating recreational or other utilitarian trips (Figure 10). Many of the sites have two peaks but the afternoon peak is much more pronounced, possibly indicating a mixture of commute and recreational/other utilitarian trips. Sites with relatively flat trends throughout the day are generally low volume sites and may represent mostly utilitarian or recreational trips.

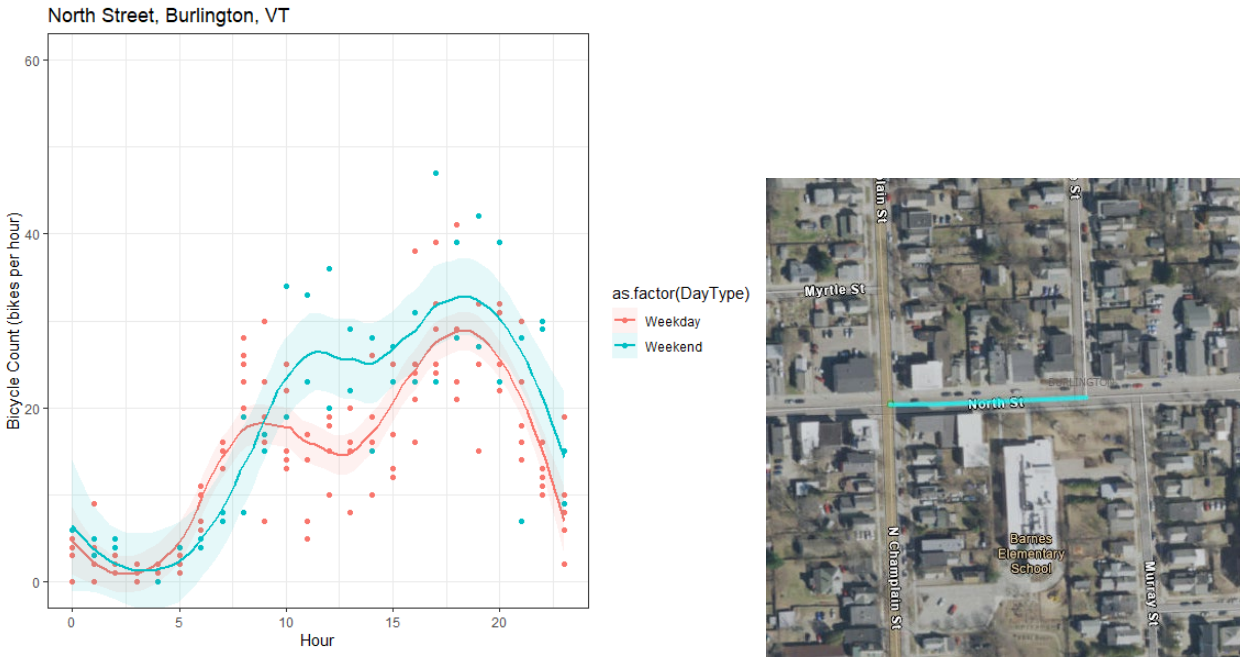

Figure 9 Example of Commute Site

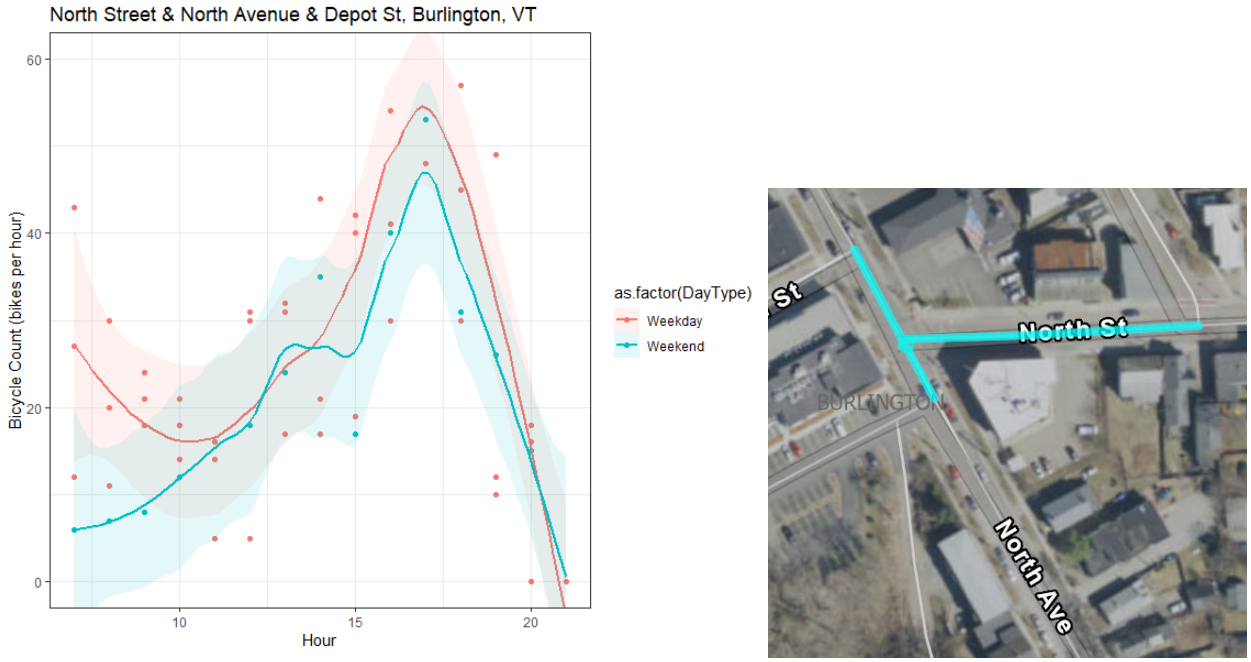

Figure 10 Example of Recreation/Utilitarian Site

- Weekend plots generally show a single mid-day or afternoon peak, indicating recreational or non-commuting utilitarian trips.

- The peak period TMC data show the same morning and evening peaks as seen in the ATR and Local Motion data. The afternoon peaks are usually higher. However, the lack of off-peak and mid-day data from the TMC sites does not allow for identification of possible trip types.

- There is a relatively large amount of day to day variability in the count data at individual sites. This can be seen in the scatter of data points of the same color around the smoothed trend lines, indicating that day to day variability reaching as high as a factor of 2 is not uncommon (one day's count being twice as large as a prior day's count). Some of this variability can be explained by data being collected at different times of the year, but at most sites data were collected for several consecutive days in the same year.

- Bicycle traffic volumes are much higher in Burlington than anywhere else in the region, although several sites in Burlington have very low volumes.

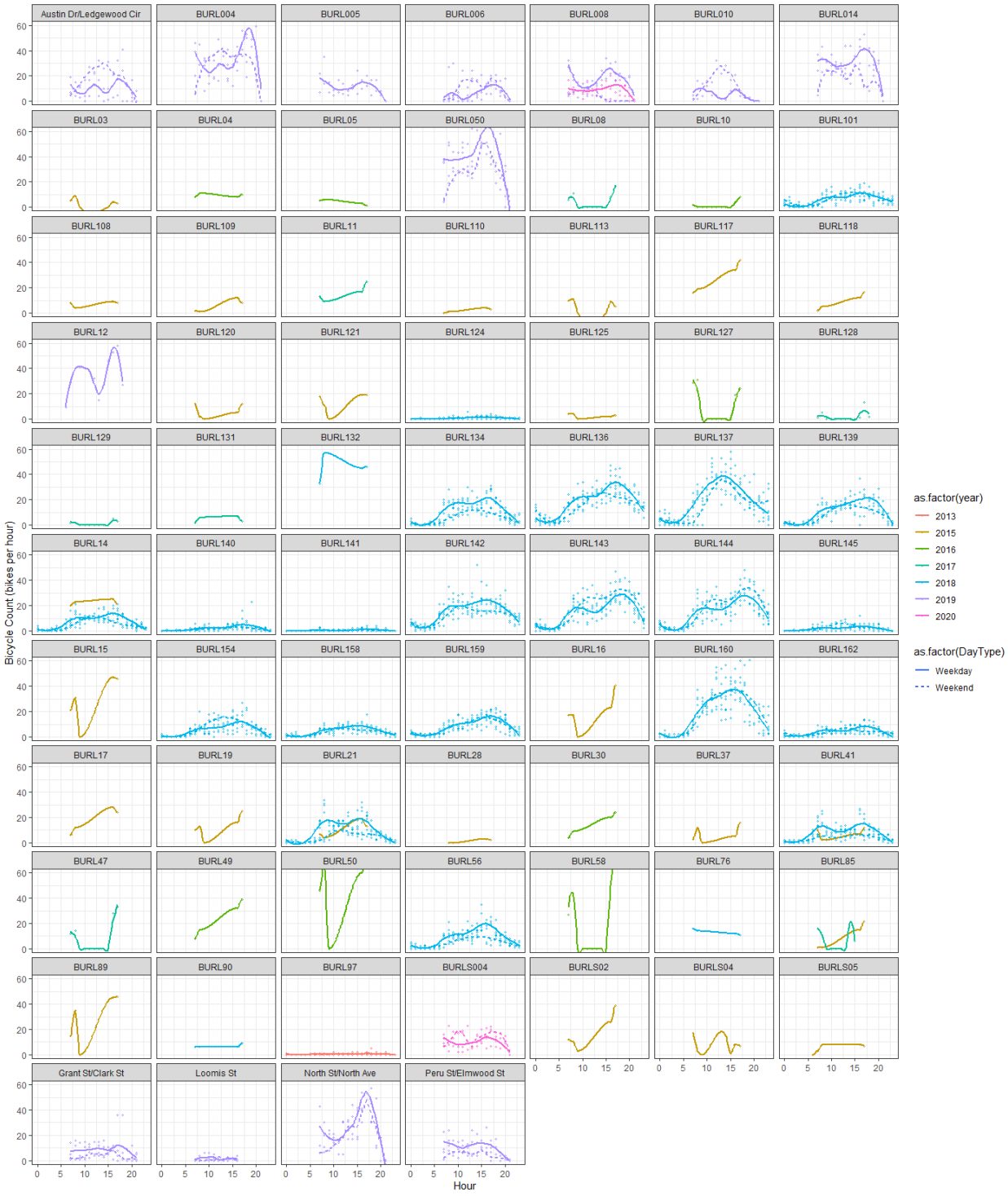

Figure 11 Burlington TMC and ATR Hourly Count Plots

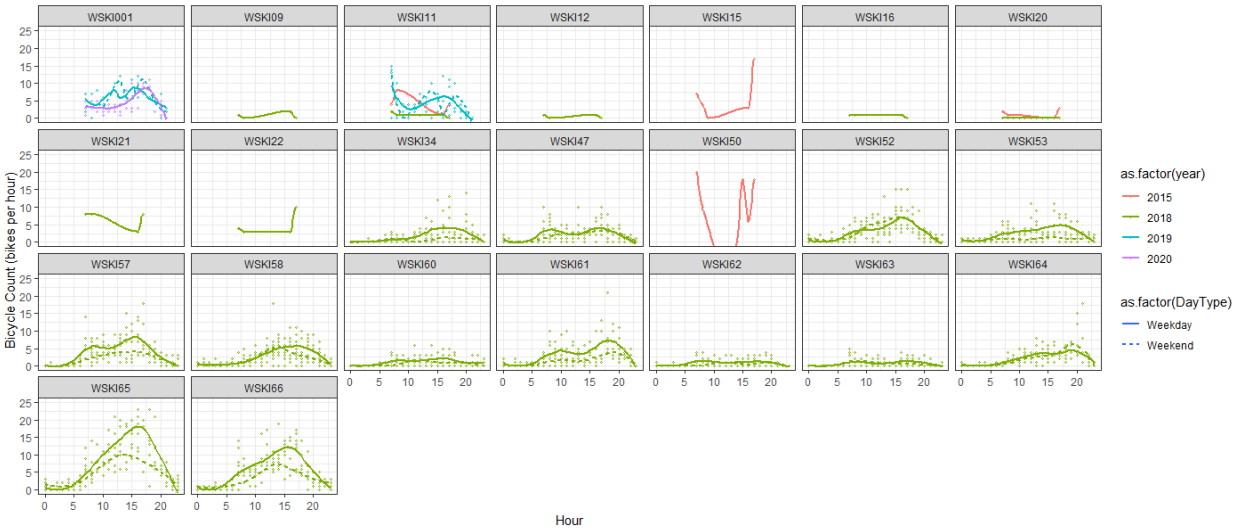

Figure 12 Winooski TMC and ATR Hourly Count Plots

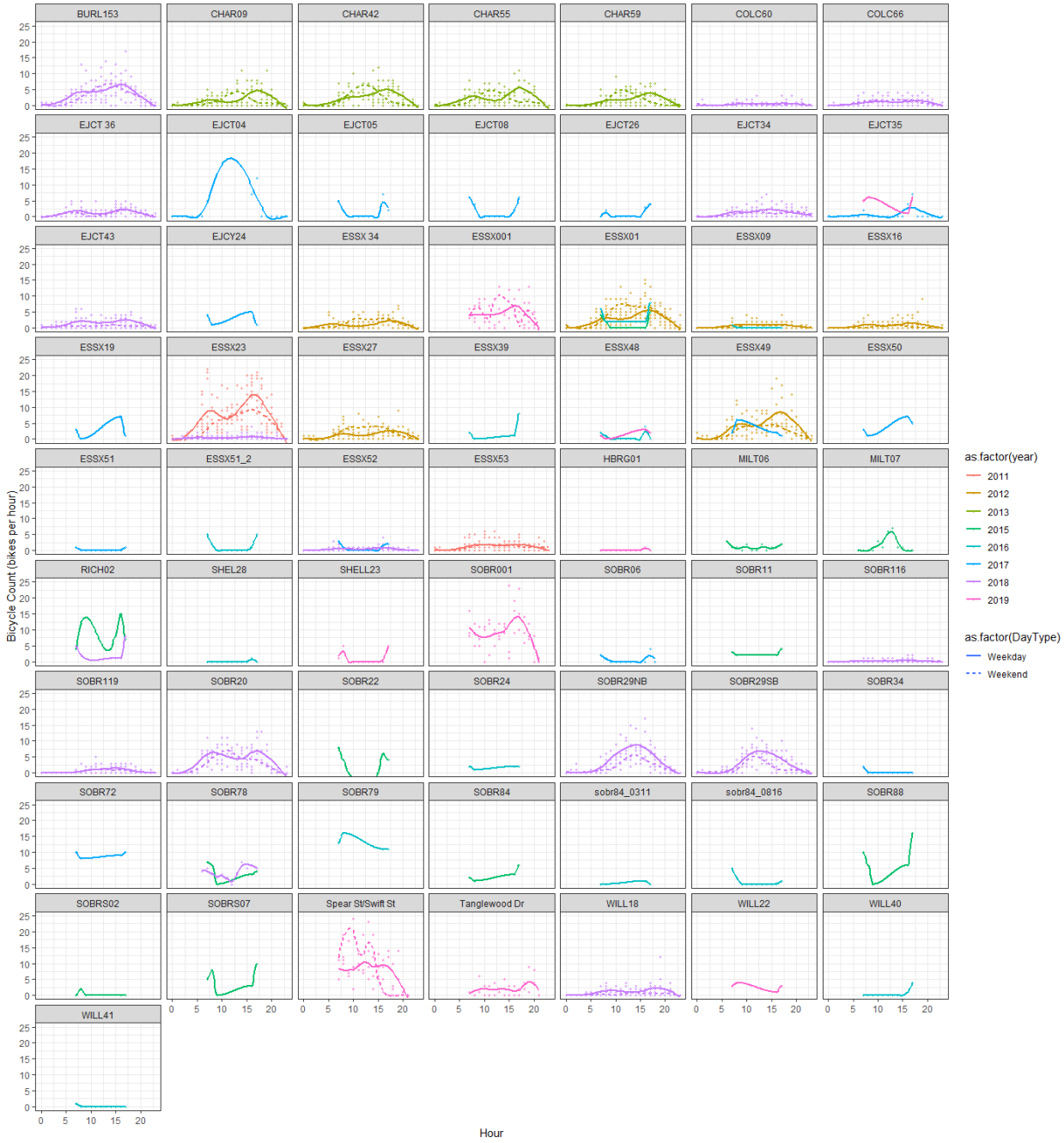

Figure 13 All Other TMC and ATR Hourly Count Plots

4.3 Data Limitations

Our review of currently available bicycle count data in Chittenden County reveals significant gaps and limitations that largely preclude an analysis of what the current level of bicycling is in the region, how bicycling has changed over time or differences between various routes, facilities and municipalities. The data are generally insufficient for evaluating if policies, plans, programs and infrastructure intended to increase the amount of bicycling have had an effect.

The most critical limitations include:

- A lack of continuous count data. While continuous count data are available for mixed pedestrian and bicycle counts along several shared-use paths, these are not useful for factoring short-duration bicycle counts. Even if the continuous counters along shared-use paths were upgraded to differentiate between bicycles and pedestrians, they would be unlikely to represent on street bicycle traffic patterns. Current guidance recommends at least two continuous counters per factor group. Continuous counters should also be located in representative locations rather than those with the highest traffic volume. Without continuous bicycle count data, there is presently no way to estimate AADB or otherwise adjust short-duration data collected at different locations and at different time periods to make them more comparable. More standardized data is required to evaluate trends across space and time.

- While a few sites have data for multiple, often consecutive, days, most sites do not have data from multiple years or for more than one week of the year. This significantly, and in most cases completely precludes, an analysis of how bicycle traffic volumes have changed over time for the region as a whole, for individual municipalities and for specific bicycle corridors and facilities. Local Motion has collected additional data from 2020 and 2021 for many of the sites they monitored in 2019 (see Figure 1 and Table 4). These data were not processed in time to be considered in this analysis but will help address this limitation.

- Little to no fall, winter and spring counts. Almost all data are collected during the late spring and summer. The availability of college student interns who assist CCRPC with field data collection may explain the focus on summer data collection and lack of data during other seasons. Figure 14 compares the daily traffic volume trend of all data collected during the summer and winter, indicating that there is some winter bicycling (bicycle traffic volumes at some winter sites exceed summer traffic volume at some other sites in the region) and that there is no defined winter peak, indicating that most trips may be recreational or non-commute utilitarian. Surprisingly, little data is collected during the fall (September and October) when the weather is generally very favorable to bicycling in Vermont and K-12 schools and the region's universities and colleges and back in session. Schools and universities are likely to be significant bicycle traffic generators, but almost no data is collected when classes are in session. As the plot in Figure 15 shows, bicycle traffic volumes increase significantly at a site near the University of Vermont campus when classes are in session during September (teal colored line) and are lower in July and June when students are on summer break.

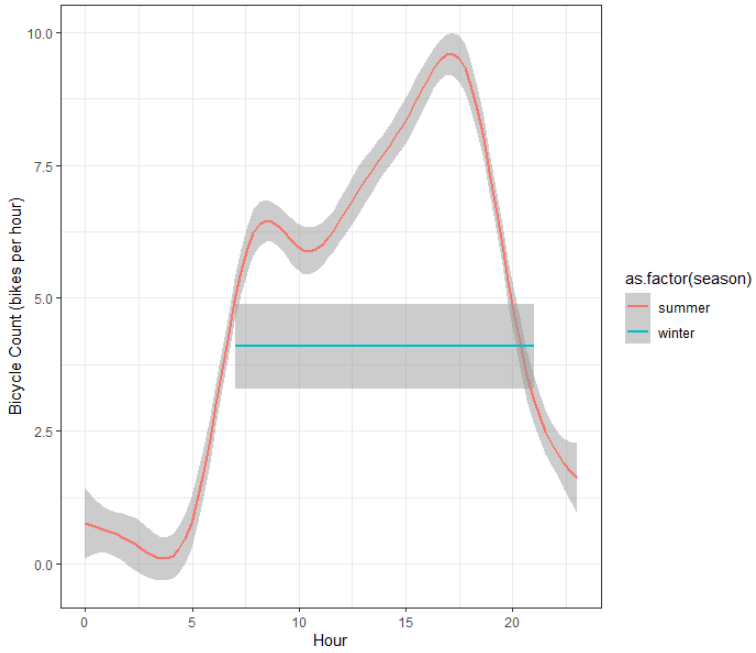

Figure 14 Plot of All Count data by Summer (May to September) and Winter (November to March)

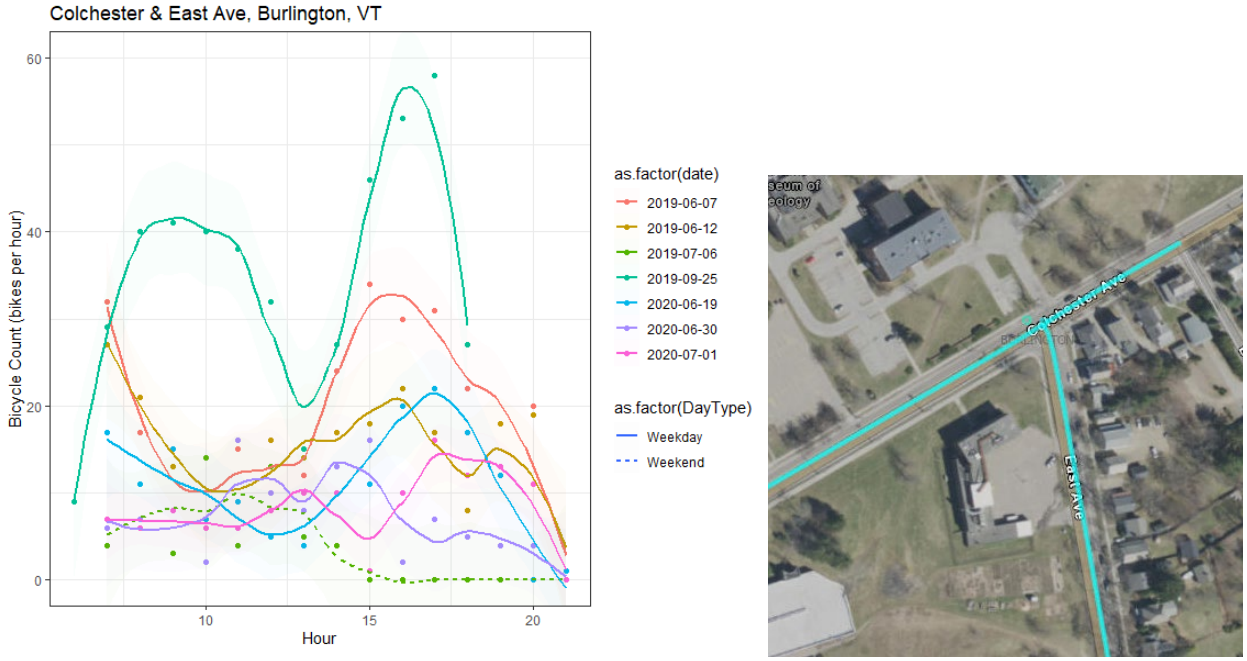

Figure 15 Example of College Site

- An insufficient number of observations. Bicycle traffic is a relatively small share of overall traffic volume in the region and heavily impacted by weather conditions. Sites where several consecutive days of data are available display a large amount of variability, including the site shown in Figure 15. This is generally expected when observing events that are relatively uncommon and impacted by the weather. A longer period of data collection is required to more

accurately estimate average bicycle traffic volumes and compare changes in them across locations and time. Only the ATR data meet the current 1 week minimum of data suggested by most guidance.

- A lack of standard data reporting and storage methods. A large effort was undertaken to organize the data evaluated in this study because data were not recorded and stored in a way that makes them readily available to evaluate using modern computational and geospatial methods. Many of the datasets did not contain coordinates defining where the data were collected which required the TRC research team to identify these based on site descriptions provided in each data set (typically the names of cross streets). Each data source also used different conventions for naming sites, which when combined with the lack of geographic coordinates, made it very difficult to identify all data collected at the same physical location through different methods. The storage of data in individual spreadsheets, often with differing column naming conventions and formats makes it incredibly difficult to compare data collected from different sites or from the same time over multiple time periods. We developed custom computer scripts written in R programming language to search for and extract the relevant bicycle count data from the files provided by CCRPC. The format of the data provided by Local Motion prevented a similar automatic data extraction, and therefore had to be manually processed which is not only time consuming but also more error prone. The VTrans Portal contains a more standard framework for reporting data, including the inclusion of coordinates for each site; however, the aggregation of the portal data to daily totals is extremely limiting.

- Site selection. Most data collection appear to be incidental or part of an effort mainly aimed at counting vehicle traffic, except for the data collected by Local Motion. Sites need to be selected following a strategy designed to meet specific count program goals which can range from conducting a before/after study for a specific bicycle infrastructure project or monitoring trends in bicycling across a municipality or region. Monitoring municipal and regional trends requires careful selection of long and short duration count sites that capture a range of bicycle trip types in a range of street and urban environments. A well designed and coordinated program allows data from many count locations to be leveraged to paint a broader picture of regional bicycling trends and traffic patterns. The current data generally lack a diversity of facility and community types.

- Weather is a very important factor that affects bicycle traffic volumes. Weather observations were provided in the VTrans Data Portal and with the Local Motion data but not the ATR or TMC data. None of the weather data was reported in a standard or otherwise directly useable format for adjusting counts.

- No standard site naming convention. We identified co-located sites with different site IDs and sites located in different places with similar site IDs. A standardized site naming convention should be used. FHWA provides guidance on count site naming conventions (FHWA, 2016a).

- Most data are collected from Burlington, South Burlington, Winooski, and Essex. Within these municipalities, the data are largely collected from places where bicycling is expected to be relatively common. While this strategy is not unreasonable, it does result in little to no information about the level of bicycling in other municipalities. Some of these municipalities such as Williston and Colchester have installed a large amount of bicycle infrastructure and therefore would likely benefit from data that could evaluate the use of these investments.

5 BICYCLE COUNT PROGRAM RECOMMENDATIONS FOR CCRPC

Based on our understanding of CCRPC's bicycle planning objectives as expressed in the ATP, our review of the region's current bicycle count data collection efforts, and our review of best practices, guidance and current research, we recommend that CCRPC consider a hybrid regional bicycle traffic volume count program that implements:

- A comprehensive regional bicycle count program following national guidance in the greater Burlington area where bicycle mode share is currently highest or has the potential to become significantly higher. This area includes Burlington, Winooski, South Burlington, Colchester, Essex and Williston. This is an area where current or planned land use, development patterns and infrastructure provide the necessary conditions for growth in bicycling. Bicycle counts should include a network of permanent continuous count sites that will be used to factor a larger number of short-duration counts made across a representative set of facilities.

- Beyond the greater Burlington area, we recommend a targeted bicycle count program focused on evaluating bicycle-focused infrastructure projects (before/after studies), bicycle crash hotspots and monitoring bicycle traffic on facilities where bicycle traffic volumes are known to be relatively high for the area. Bicycle counts are limited to short-duration counts in these locations. Communities within the targeted bicycle count program could be added to the comprehensive program over time based on changes in bicycle volume trends and changes in supportive land use and development patterns or bicycle infrastructure.

The hybrid approach is designed to maximize the impact of limited resources by focusing the comprehensive program on places where bicycling volumes are higher and where the information provided by the program is likely more useful. The duration of data collection required to achieve a specific level of accuracy in estimating average bicycle traffic volumes increases with decreasing volumes. In places with low bicycle volumes, bicycle trips are more sporadic and difficult to monitor at a discrete number of locations along the street and shared-use path network. The costs of collecting accurate and regionally representative data in communities where few people make bicycle trips would be very expensive while also being less valuable in supporting planning and policy decisions. Communities where bicycling is uncommon, however, could benefit from a comprehensive bicycle count program that provides evidence of what works elsewhere. Which combinations of land use, development pattern, and infrastructure change are associated with increasing bicycle traffic volumes? Collecting accurate bicycle traffic volume count data that is representative of a wider range of land use, development patterns and infrastructure requires fewer count sites with shorter durations where more people bike because regular patterns are more likely to emerge and they can be used in count data factoring and extrapolation. A targeted count program in communities with lower levels of bicycling provides data to understand special bicycle-focused projects and maintains a baseline level of data to track changes over time.

5.1 Comprehensive Regional Traffic Volume Count Program

We recommend implementing a comprehensive regional traffic volume count program designed to estimate AADB on a representative set of network links in the greater Burlington area following the most current national-level guidance provided by FHWA (FHWA, 2016c) and NCHRP Report 797 (TRB, 2014a). The following sections provide additional recommendations; however, FHWA guidance and NCHRP Report 787 should be consulted for additional information.

5.1.1 Factor Groups

A key first step is determining a set of factor groups that represent the main spatial and temporal bicycle traffic volume patterns observed within the area. Factor groups are a set of bicycle count sites that

share common hour-of-day and day-of-year traffic volume patterns. They are often defined by bicycle trip purpose including, commute to work and/or school trips, recreation and/or other utilitarian (non-commute) trips, or a mixture of these purposes. Additional factor groups may be required to account for differences in the patterns of these trips in different geographic contexts.

Our analysis of historical count data from the region identifies two potential factor groups. One factor group has defined morning and afternoon peak periods that likely correspond to commute to work trips (school trips would not be picked up since most data is collected during the summer). A second factor group shows a single late afternoon or evening peak that likely corresponds to recreational and a mixture of non-commute utilitarian trips. A third factor group may also be identified as those with relatively consistent volumes throughout the day, which may correspond to a mixture of trip purposes. Data collected on over a longer time period and a more diverse set of locations may reveal different factor groups.

Additionally, bicycle traffic volumes appear to be much higher in Burlington than surrounding communities, which suggests that a separate set of factor groups may be necessary for Burlington and adjacent portions of surrounding communities. A second set of factor groups may be able to represent the remainder of the greater Burlington area that has a more dispersed and suburban development pattern and much lower population density. The definition of factor groups should also consider unique facilities that support tourism such as the Colchester Causeway and Burlington Greenway and major bicycle trip generators such as UVM and other area colleges and K-12 schools in some communities. More data is required to further define factor groups.

A well defined set of factor groups is important for determining how many permanent, continuous, count stations are required and where they should be located. Factor groups are also used in determining where short-duration counts take place. Therefore, we recommend that CCRPC start developing a more comprehensive count program by first collecting additional short-duration counts at a range of representative sites as discussed in more detail below. These counts should be conducted at each site several times over a full year (e.g., spring, summer and fall) and then evaluated to identify different time-of-day and day-of-year patterns which may vary by municipality, facility-type or proximity to major bicycle trip generators such as colleges, schools and active travel tourism destinations. An alternative or supplementary approach is to purchase passively collected bicycle mobility data from a commercial vendor (e.g. Strava or StreetLight) to identify how traffic volume patterns differ across the region and define factor groups. While passively collected bicycle mobility data is likely to be non-representative, it may provide a better starting point than using only the data that are currently available. Patterns observed in the passively collected mobility data can be validated with short-duration counts before final decisions are made about factor groups.

5.1.2 Continuous Count Sites

Once factor groups have been determined, several permanent count sites are required to collect continuous bicycle traffic volume data from representative sites within each factor group. The latest available guidance and research suggest a minimum of 4 continuous count sites per factor group, with some guidance suggesting up to 7 sites. A minimum of two sites is required to produce an average value while additional sites are required to account for scheduled or unscheduled downtime at each count site. These sites must differentiate between bicycles and pedestrians, which precludes the use of any of the region's existing permanent count sites. Furthermore, site selection should be primarily focused on representing trends in the factor group rather than on locations with the highest volumes or other special interests.

Inductive loops, permanently placed in the paved surface of streets and shared-use paths are known to be highly accurate and reliable for counting bicycles in a wide range of conditions. Various vendors

provide inductive loops specifically designed for counting bicycles, including in mixed traffic. We see few reasons at this time to use other technologies given the long performance history, low cost, and versatility of inductive loops. It is one of only two technologies that can differentiate bicycles from both pedestrians and motor vehicles.

Machine vision systems are even more versatile than inductive loops, being able to classify all roadway users and perform turning movement counts while inductive loops are confined to screen lines. However, at this time machine vision systems are limited to short-duration (typically one week) counts and data costs scale with the hours of video that needs to be processed by the vendor, making this an unsuitable and expensive option for a continuous count site. Other technologies can be used where bicycles are confined to well-defined paths (for example, a physically protected bicycle lane) and there is no interference from other users or vehicles, but few sites present these conditions.

5.1.3 Short-Duration Count Sites

The primary purpose of continuous count data collected at permanent count sites is to create adjustment factors that are applied to short-duration counts to estimate AADB. AADB estimates (or other period averages) make it possible to compare counts from different sites and time periods to evaluate trends in space and time. The count program should aim to collect a large number of short-duration counts across a representative sample of network links. While a random or random-stratified sampling method could produce data for estimating a regional annual average traffic volume estimate (e.g., bicycle miles traveled) and bicycle volumes on most network links similar to HPMS traffic volume data for vehicle traffic[3], this would require a very large number of short-duration counts. This is currently very uncommon and largely limited to ongoing academic research.

A more tractable approach is to collect short-duration counts at sites that represent a range of different land uses, development patterns, infrastructure types, traffic conditions (e.g., car, truck and transit vehicle volumes and speeds), and communities (including those in different geographic locations and those with different socioeconomic characteristics). There is little guidance on how many short-duration counts to collect, but the guidance pertaining to permanent count locations should provide a reasonable benchmark: 2 to 7 short duration sites per representative site within each factor group. Data collection can be spread out over 2 or 3 years if necessary. Data in a representative set of sites still allows for evaluating changes in bicycle traffic volume trends across time and space, although space is now binned into representative categories rather than a continuum that may be possible with random sampling. Current research and guidance strongly support one week of 24 hour counts for short-duration counts. Longer durations have sharply decreasing benefits under most conditions. Shorter durations are significantly less accurate.

Short-duration counts should be collected throughout the year, focusing on periods when the weather is generally favorable to bicycling (generally April through November in Vermont). Some attempt should also be made to collect counts during the winter when conditions permit along facilities that are known to have at least some year-round bicycle traffic such as in Burlington, particularly near the UVM and Champlain College campuses and the Burlington Greenway (i.e., Burlington Bike Path) which is plowed in the winter. The current CCRPC practice of focusing most data collection between June and August is strongly advised against. The summer period is strongly influenced by tourism in certain communities within the region while at the same time college and K-12 students who commute to school are largely absent since most public schools and colleges are not in session during this period. Our review of currently available data shows that bicycle traffic count volumes are larger in the fall than in the summer

[3] Highway Performance Monitoring System: https://www.fhwa.dot.gov/policyinformation/hpms.cfm

along streets near the UVM campus in Burlington. There is very little data available to evaluate trends near the region's K-12 schools when they are in and out of session.

Short-duration sites can be located at intersections where turning movement counts are collected or mid-block screen lines. Generally, screen line counts are easier and less expensive to collect. Intersection counts can be processed to create data equivalent to a screen line on each intersection leg but this requires more complex data processing and more expensive counter technology. Currently, only machine vision technology which requires a data processing fee is feasible for conducting the recommended week long, 24 hour, short-duration counts at intersections.

We recommend using pneumatic tubes from a vendor that can show reliable performance when counting bicycles in mixed traffic. Many studies have shown both general purpose tubes when used with equipment designed to classify bicycles along with other vehicles and bicycle specific tubes to be relatively accurate, depending on the vendor and traffic conditions. They are known to undercount due to occlusion, but correction factors can be estimated to account for this. Generally, pneumatic tubes perform better where there is less vehicle traffic and bicycles hit the tubes closer to the detector (e.g., right side of the roadway). Therefore, placement is a balance of focusing the tubes on places where bicycles are most likely to ride and vehicle traffic is less likely such as a bicycle lane or shoulder but also avoiding excessive "by-pass" errors from bicyclists riding around the tubes. The selection of short-duration count sites should be hierarchical, first identifying roadway segments that meet the representative sampling criteria and then identifying suitable locations along the segment to conduct a screen line count. Count sites should not be chosen primarily out of the convenience of installing counters.

5.1.4 Implementation Approach

Implementing a regional count program following the recommendations provided previously will require more resources than CCRPC's current bicycle count program and community stakeholder input. The program outlined above can be phased in over time, by adding additional count locations as funding and staffing levels allow. Community stakeholder input will be important for determining the most appropriate starting point. Regardless of the pace of implementation, we recommend the following implementation priorities:

1. Using a combination of institutional knowledge and community input, define the criteria to be considered when determining the location of short-duration counts. For example, should sites be located on streets with each type of possible bicycle infrastructure (including no bicycle specific infrastructure)? Should sites also be located so that there is data collected from communities representing a spectrum of socioeconomic characteristics?
2. The next step should aim to begin collecting short-duration counts at various locations that fulfill the criteria defined in step 1. The main purpose at this point is collecting data to define factor groups and identify possible locations for continuous count stations. It will be important to collect enough short-duration data to evaluate how traffic patterns differ across representative sites and therefore this phase could take more than one year.
3. The next step is evaluating the short-duration data to determine factor groups. We anticipate at least two sets of factor groups: one focused on Burlington and adjacent parts of surrounding communities where bicycle traffic volumes are much higher than elsewhere and where there are special traffic generators including the Burlington Greenway, UVM and Champlain College. The second set of factor groups is focused on the remaining greater Burlington area that has a more suburban or dispersed development pattern and lower rates of bicycling.
4. With factor groups determined, the next step is identifying sites for continuous counters. The continuous count sites can be implemented over time; however, it is important to realize that

more than one count site is necessary per factor group in order to get reasonably accurate data for factoring short-duration counts. Priority should be given to completing the count sites necessary for one factor group at a time.

5. With continuous count sites up and running for at least one factor group, short-duration counts can be collected and then factored to estimate AADB. Initially, short-duration counts could focus more heavily on locations in a factor group with a functioning pair of continuous count stations. This will allow the full potential of the data collected from short-duration and continuous count sites to be realized. As the count program expands overtime, additional continuous count stations and associated short-duration counts can be implemented. Data collected from the initial implementation phase may be useful for demonstrating the value of the information gained through this approach and gaining support for the resources necessary to build out the entire program.

5.2 Targeted Count Program

The comprehensive count program is more resource intensive than CCRPC's current bicycle count program, which currently focuses on the greater Burlington area (refer back to Figure 1). We recommend a targeted program for municipalities not included in the comprehensive program. A targeted program could be implemented as a program that provides short-duration counts upon request for the evaluation of a new infrastructure project (e.g., before/after study), a specific bicycle safety concern (high crash locations), or to monitor specific high-volume facilities. One week of 24 hour counts using automated count equipment is generally recommended. This is recommended even when most activity occurs during discrete time periods (e.g., weekends and daylight hours) in order to track changes that may occur overtime and avoid undercounting. The targeted count program could also include a short-term count equipment loan program which has been successful in other regions.

Alternatively, or supplementing, the above, CCRPC could identify several strategic short-duration count locations in the targeted program area to monitor and track bicycle traffic volume trends in these more rural and small-town settings. Unlike the recommended guidance for a comprehensive count program in a more urban setting, sites should be selected that are likely to have higher than average bicycle traffic volumes. Very low bicycle traffic volumes will result in highly inaccurate average traffic estimates that are necessary for evaluating trends overtime. CCRPC could also consider conducting strategic counts along facilities identified as part of the region's active travel network (CCRPC, 2017). Since there are no continuous count sites in the targeted program area, repeated short-duration counts should be made during the same time of year and should consist of at least one week of 24 hours counts.

5.3 Before/After Studies

Evaluating the effectiveness of a new bicycle infrastructure project (or policy or program) requires important considerations to ensure the validity of study findings. Clearly, data should be collected before and after a project is implemented and naturally these data should be collected in the area where the project is constructed. However, it is critical to also collect data at two additional sets of locations:

1. Traffic volume data must also be collected from a representative ***control location(s)***. Control locations are necessary to account for how bicycle traffic volumes change over time between the before and after counts for reasons other than implementation of the project of interest. For example, bicycle traffic volumes will generally grow over time with population growth, a new program such as a regional bicycle share, or other factors that influence regional bicycling rates. Ideal control locations capture regional trends but are not influenced by the project being studied. When relying on a small number of control locations, it is also important to ensure that are not impacted by nearby projects or events that could significantly affect bicycle traffic

volumes (e.g., additional bicycle infrastructure projects, new retail or housing development, or roadway construction.) The comprehensive count program discussed above will capture regional changes in bicycle traffic volumes and provide the necessary control location data. Within the targeted program area, before/after studies require the identification of control locations where additional short-duration counts will be collected.

2. Traffic volume data must also be collected from sites to account for ***trip diversion***. After a project is constructed, a comparison of post construction traffic volumes with those collected before may show an increase in bicycle traffic, after correcting for any regional changes in bicycling from control locations. In this example, one may assume that the project caused an increase in bicycling when in fact there are no new trips. The observed trips may have been diverted from alterative routes, making use of the improved facility. If understanding how a project affects the number of bicycle trips (rather than traffic volume in a particular location), collecting bicycle traffic volume on routes where trip diversion may occur is also necessary. Generally, short-duration sites that monitor for trip diversion will be required for before/after studies conducted in the comprehensive count program area and the targeted count program area given that the location and number of count locations to detect trip diversion will be specific to individual projects.

5.4 Additional Considerations

The recommended strategy aligns with best practice, national level guidance, and current research that we believe is cost effective and feasible if implemented in stages over time. The strategy will require more investment than the current program but is also expected to provide much more valuable information that can support a broad range of bicycle planning objectives. The recommendations provided in this report are designed to provide CCRPC with a roadmap for developing a more robust regional traffic volume count program. More detailed guidance on implementing specific recommendations are available from the sources identified and discussed in the literature review (section 2).

Collecting new and more robust bicycle count data is a significant challenge; however, a plan for managing, processing and sharing the data will also be required to maximize the value of the count program. The management, processing and sharing of bicycle count program data is a significant limitation in current practice and an area with much less guidance. Few of the agencies we interviewed or that have been studied in prior research have developed a robust program for managing and applying the data they collect from their bicycle count programs. Most of the effort to date has apparently been focused on trying to collect data rather than using it.

A significant challenge in our review of currently available bicycle count data in Chittenden County was the inconsistent and incomplete information recorded about each count site and the data collected from them. A large scale data collection program like the one we recommend will require a more organized and systematic approach to recording and storing count data. FHWA provides guidance on systematically recording and coding information about traffic count sites (FHWA, 2016a). Individual count data should be stored using a consistent format that requires few, if any, manual processes (e.g., copying and pasting, changing file names, etc.) that could introduce errors. The goal is to store data so that they can easily be read by a wide range of data analysis platforms. Most modern automated count technology provides software for managing the data they record.

Our review of best practices, guidance and current research also identified the calibration and validation of automated counters are a critical part of any count program. All automated count equipment requires periodic calibration following manufacturer recommendations and validation with ground truth

data. Automated counts are typically validated with manual observations. A quick validation is usually performed each time a portable counter is set up in the field, and more robust validation steps are typically required to understand how the specific count equipment operates in different traffic conditions. Almost all automated bicycle count technologies under count. The validation process can be used to estimate correction factors to adjust systematic under counting in specific use cases (TRB, 2014a).

Finally, our recommendations have focused on the development of a regional bicycle traffic volume count program using a mixture of continuous and short-duration automated counters. CCRPC should also reserve budget, equipment and staff time for additional special purpose bicycle counts that can be expected to occur periodically, such as evaluating the use of a new bicycle facility or conducting a study to support the design of a new project. In most cases, these counts should follow the same guidance as for other short-duration counts: one week of 24 hour counts using automated counters. However, if the aim is to understand bicyclist behavior at intersections or more complex environments or where bicyclists may be riding on sidewalks, manual counts may be necessary which will generally require shorter count durations. Before/after counts are intended to understand how a new project, program and policy impacts the level of bicycling in an area (e.g., the number of bicycle trips), and requires careful planning to identify control locations and monitor for trip diversion.

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