Colorado DOT

Non-Motorized Monitoring Program Evaluation and Implementation Plan

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ACKNOWLEDGMENTS

COLORADO DEPARTMENT OF TRANSPORTATION

Erik Sabina, Information Management Branch

Jeff Sudmeier, Multimodal Planning Branch

Mehdi Baziar, Mobility Analysis Section

Steve Abeyta, Traffic Analysis Unit

Miguel Aguilar, Traffic Analysis Unit

Betsy Jacobsen, Bicycle/Pedestrian/Scenic Byways Section

Ken Brubaker, Bicycle/Pedestrian/Scenic Byways Section

TOOLE DESIGN GROUP TEAM

Toole Design Group, LLC

Tom Huber

Jessica Juriga Fields

Joe Fish

Geneva Hooten

Spencer Gardner

Cambridge Systematics, Inc.

Evan Enarson-Hering

Tony Hull, Non-Motorized Transportation Consultant

Dr. Robert Schneider, University of Wisconsin at Milwaukee

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Cover Photo by Kevin Zolkiewicz

CONTENTS

FIGURES

TABLES

Chapter 1
Introduction

The 2012 *Colorado Statewide Bicycle and Pedestrian Plan* called for an expansion of Colorado Department of Transportation's (CDOT) Non-motorized Monitoring Program to better account for bicycle and pedestrian activity throughout the state. In recent years, CDOT has been at the forefront among other state departments of transportation in collecting bicycle and pedestrian volume data. However, while CDOT's monitoring efforts have generated useful data, the time has come to evaluate and reassess the program to ensure data collection efforts in the future are efficient and continue to produce information that is useful for future state and local planning and design efforts.

The purpose of this study is to make recommendations for a strategic non-motorized data monitoring program for CDOT with clearly articulated goals and objectives. This framework will ensure collected data contributes to a comprehensive understanding of pedestrian and bicycle activity in Colorado. To develop the strategic framework and implementation plan, a careful review was undertaken of the number and distribution of CDOT count locations, processes for organizing and analyzing collected data, internal and external uses of the data, and opportunities to leverage emerging technologies.

Study Objectives

This study satisfies several key objectives identified by CDOT early in the study process:

Identify appropriate uses and needs for non-motorized data.

Tracking overall levels of bicycling and walking on a statewide basis was identified as a key purpose for non-motorized data collection. Additional uses include: improved understanding of user demand based on facility types and land use contexts, evaluation of program and infrastructure investments as determined by before and after studies, and development of crash rates based on exposure.

Develop program goals.

The establishment of goals for non-motorized data collection was a central objective for this study. The goals steer the implementation plan, thereby ensuring data is collected and evaluated according to its intended use.

Create an implementation plan.

The development of a five-year implementation plan based on the identified needs and established program goals was a key objective of the study. The implementation plan establishes the specific activities that need to be conducted to fulfill the program goals.

Study Process

To meet the project objectives listed above, the following steps were taken, and are presented in this report:

1. Review existing non-motorized traffic monitoring program
2. Identify non-motorized data needs
3. Develop non-motorized monitoring program goals
4. Evaluate current program effectiveness
5. Create a program implementation plan

To ensure CDOT's non-motorized data collection plan considered a range of perspectives, significant input was sought from various divisions within CDOT, as well as other state and local agencies, universities, and other stakeholders. An internet survey, focus group interviews, and stakeholder meetings were held to understand data collection practices and the current and desired uses of non-motorized volume data.This report is the culmination of the background research and stakeholder outreach.

SOURCE: Toole Design Group.

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Chapter 2
State of the Practice

Compared to data collection for other modes of travel, non-motorized data collection is still in the early stages of development. A widespread systematic approach to collecting volume data for non-motorized modes comparable to that for motor vehicles has yet to be developed and institutionalized throughout the United States.

Challenges

On the surface, it would seem simple to bridge the data collection gap for non-motorized modes by adding pedestrian and bicycle volumes to existing motor vehicle traffic monitoring programs. However, while these programs are a useful starting point, there are unique challenges associated with the collection of non-motorized volume data that require careful consideration and, in some cases, entirely new approaches. These challenges are described in more detail below.

Facility Characteristics

Motor vehicle travel is fairly constrained, as vehicles must operate within defined lanes. This characteristic makes the task of monitoring a relatively straight-forward matter of detection and classification. By comparison, bicycle and pedestrian travel is far less constrained. Bicyclists and pedestrians may enter or exit a facility at any point along a segment. Furthermore, they travel along a facility in a less predictable manner (e.g., a bicycle may travel within the roadway, or may instead travel on the sidewalk or an adjacent path) that is difficult to account for. The complexity and diversity of facility types and path of travel makes identification of appropriate detection zones a challenge.

Physical and Behavioral Differences

Motor vehicles are designed to specific sizes and dimensions defined by the Uniform Vehicle Code (UVC). The size, weight, and speed of motor vehicles is predictable and fairly consistent. Bicycles and pedestrians are not prescribed design controls — pedestrians and bicyclists come in all shapes, sizes, and abilities. The slower variable speeds and unpredictable paths of travel create challenges for effective detection and classification.

Local/seasonal Variability

Compared to motor vehicle traffic, bicycle and pedestrian travel tends to have high variability. Seasonal patterns can vary greatly and short duration weather events greatly influence the choice to ride a bicycle or walk on any given day. Additionally, there are significant local and regional differences in behavior that are not well understood — the volume and distribution of bicycle and pedestrian travel can vary significantly in different parts of the state or community, depending on the land use context and local norms. As a result, the transferability of pedestrian and bicycle usage patterns from one facility to another on the basis of facility characteristics or other easily-identified features is questionable without additional validation. Similarly, it is not currently practical to use motor vehicle travel patterns as a predictor of bicycle and pedestrian travel volumes.

Lack of Historical Data

Unlike motor vehicle travel which draws on decades of collected data, very little historical data is available for bicycle and pedestrian volumes. Aggregate survey data from the U.S. Census or National Household Travel Survey provide some useful information, but do not identify volumes on the network. This lack of historical data makes it difficult to answer simple questions, such as what is a "typical" level of pedestrian or bicycle travel on a particular facility, or whether a specific design treatment will result in an increase in the amount of bicycling or pedestrian activity. As a result, it is difficult to establish rational performance metrics for pedestrian and bicycle travel, which is a challenge because the allocation of funding is increasingly tied to such metrics.

Unique Challenges for Pedestrian Monitoring and Data Usage

In addition to the challenges associated with monitoring bicycle traffic, pedestrian volume monitoring has its own unique challenges and considerations. Pedestrians are even less constrained than bicyclists in terms of their ability to travel outside the confines of a particular facility — they often cut through parking lots, cross the street at midblock locations, or otherwise walk in locations without a designated facility. Furthermore, every trip begins and ends with some amount of pedestrian travel. Pedestrian trips are relatively short and volume can vary greatly over short distances. As a result, estimating the total amount of pedestrian activity at a statewide or regional level using pedestrian counts would be extremely challenging and may be less accurate than using other methods, such as travel surveys. This report recommends useful approaches to pedestrian monitoring, however the majority of the discussion and recommendations are geared toward bicycle monitoring.

Primer on Non-Motorized Monitoring and Estimation

There are two basic types of bicycle and pedestrian counts: continuous and short-duration counts (SDCs). At continuous count locations, data is collected 24 hours per day, and the counters are intended to remain in place indefinitely. SDCs occur over a limited period of time ranging from a few days to several weeks. Although some agencies conduct shorter counts (e.g., two-hour counts), CDOT does not use that approach.

For both continuous counts and SDCs, agencies increasingly rely on automated counters, rather than manual counts. Automated counters typically use infrared, piezoelectric technology, or pneumatic tubes to detect bicyclists and pedestrians. Video is also used in some applications, but is more labor-intensive to process than other methods. All of CDOT's counts are automated, rather than manual counts.

Continuous counts and SDCs are both necessary to develop a complete picture of non-motorized activity. Continuous counts provide an in-depth understanding of travel patterns at a single site, whereas SDCs contribute to a breadth of coverage across the geographic area of interest. Data from SDCs can be extrapolated to develop annual estimates based on patterns from continuous count sites. However, reliable extrapolation of SDC data from a particular site can only occur if the site can be matched to a "factor group," which establishes the basis for extrapolation (see "Appendix A: Factor Group Development" for a more in-depth discussion of factor groups).

Collection and analysis of pedestrian and bicycle volume data are conducted for different purposes, as these modes exhibit different travel behaviors and patterns. Due to the challenges of estimating pedestrian activity at a large scale, most of the effort in developing non-motorized monitoring programs at a statewide or regional level has been geared toward estimation of bicycle activity. This is particularly the case for the development or validation of bicycle or pedestrian miles traveled estimates.

While there are several important uses of pedestrian volume data such as before/after studies and safety studies, the development of a statewide pedestrian miles traveled estimate is not currently seen as a feasible or worthwhile goal for many transportation agencies, including CDOT. As a result, the methodologies contained in this report are focused on development of count data to support statewide bicycle activity estimates. However, targeted applications of pedestrian volume data collection and analysis are also included.

Recent Developments

In recent years, significant work has been undertaken to rectify the omission of bicycles and pedestrians in traditional traffic monitoring schemes. Two important contributions to the practice are discussed below.

National Bicycle and Pedestrian Documentation Project

The *National Bicycle and Pedestrian Documentation Project* (NBPDP), started in 2002, was the first coordinated effort to establish protocols for short duration manual bicycle and pedestrian counts. This effort developed the first understanding of the value of these data and the challenges and limitations of developing a systematic program. The initial intention was to develop a national database of counts that could be used to extrapolate factors that would allow agencies to estimate daily, monthly, and annual pedestrian and bicycle traffic volumes. However, the early program findings identified several key issues and challenges to achieving the initial program goals. The extreme variability of walking and bicycling activity makes it difficult to capture in short duration observations. Additionally, regional and seasonal variations prohibit the development of a singular set of extrapolation factors based on these counts.

NCHRP Report 797 and FHWA Update of the Travel Monitoring Guide

Lessons from the NBPDP helped inform future research efforts, including the more recent National Cooperative Highway Research Project (NCHRP) 07-19 Study, *Methods and Technologies for Collecting Pedestrian and Bicycle Volume Data* that led to the NCHRP Report 797, *A Guidebook for Collecting Pedestrian and Bicycle Volume Data*, which is the first national standard for developing a non-motorized data collection program. The NCHRP 797 Report does not prescribe specific methods and technologies; rather, it provides a thorough evaluation of the performance characteristics of various technologies and their applicability to data collection needs.

The report also identifies a number of key steps for planning, implementing, and maintaining a data collection program with the goal of developing consistent and reliable data compatible with the concurrent update to the Federal Highway Administration's Traffic Monitoring Guide (TMG). The TMG was updated in 2013 to include a new chapter (chapter 4) for reporting pedestrian and bicycle volume data. These efforts have mapped out a more strategic approach to bridging the data collection gap, but achieving full institutional capacity will still take years of work as agencies and researchers gain experience in this area.

Stages of Non-Motorized Volume Data Collection Programs

Despite the progress in refining best practices, most agencies remain in the early stages of program development. To assess where CDOT's program is (and more importantly where the program should be headed), it is important to understand the stages in the development of volume data collection programs.

This section provides some information based on the experiences of other agencies that have implemented these types of programs.

For non-motorized monitoring program development, there are four distinct program stages that range from experimentation to full institutionalization of data collection.

STAGE 1 Experimentation

The earliest stage in pedestrian and bicycle volume data collection is the "experimentation" stage. Data collection is typically initiated by an agency because they have an immediate need to know pedestrian and bicycle volumes in a location, or series of locations. Whether it is organizing manual counts following the NBPD Protocol or purchasing portable counters, this stage is usually characterized by trial and error. Much is learned about the challenges and limitations of various methods for data collection. The experimentation stage may be shorter if the agency has access to more resources and professional knowledge of pedestrian and bicycle data collection from the outset. That said, the lessons learned by the early adopters have guided the development of practices and standards for future program development.

STAGE 2 The Basic Program

This stage reflects lessons from experiments where basic protocols are established and consistent routines for data collection are followed. Data is collected and managed to allow for basic and simple reporting of raw data from discrete locations, or perhaps some benchmarking and basic analysis. The level of resource commitment for a Stage 2 program is moderate with perhaps a single person overseeing the program or a few staff members splitting time and program responsibilities. Without a formal work strategy and dedicated resources, a Stage 2 program has low sustainability, as the capacity for the system may reside in one or two individuals who take ownership in the effort. CDOT, along with several other leading state DOTs like North Carolina and Minnesota are currently at the Stage 2 level.

STAGE 3 Systematic Program

A Stage 3 program reflects a more formalized approach where data is not only collected and managed with high quality standards but is also used for analytics or creating a narrative about what is being learned from the counts. A Stage 3 program has a clear strategy for program maintenance and expansion with key roles and resources clearly identified. Stage 3 programs have strong sustainability as there are documented procedures for ongoing program management and the quantity and quality of data become useful at an agency-wide level. Stage 3 programs allow for a coherent narrative about bicycling and walking supported by routine reporting, benchmarking and analytical capabilities. Very few agencies have achieved a Stage 3 program and most of these are local or regional agencies (examples include Boulder, CO; Seattle, WA; Delaware Valley Regional Planning Commission, and Arlington County, VA). The recommendations of this report map out a strategy for CDOT to advance from a Stage 2 to a Stage 3 program.

STAGE 4 Fully Institutionalized Program

The fourth and final stage of program development is the fully developed pedestrian and bicycle monitoring program that is characterized by routine widespread data collection of the highest quality and reliability for extrapolating bicycle and pedestrian miles of travel along the transportation network. At this stage the ability to perform advanced analytics integrated with motor vehicle planning efforts is achieved. This stage is currently an aspirational stage, with no clear U.S. examples to model. There is not an avenue to skip from Stage 2 to Stage 4, as the lessons of Stage 3 identify needs and characteristics of what the Stage 4 program should be.

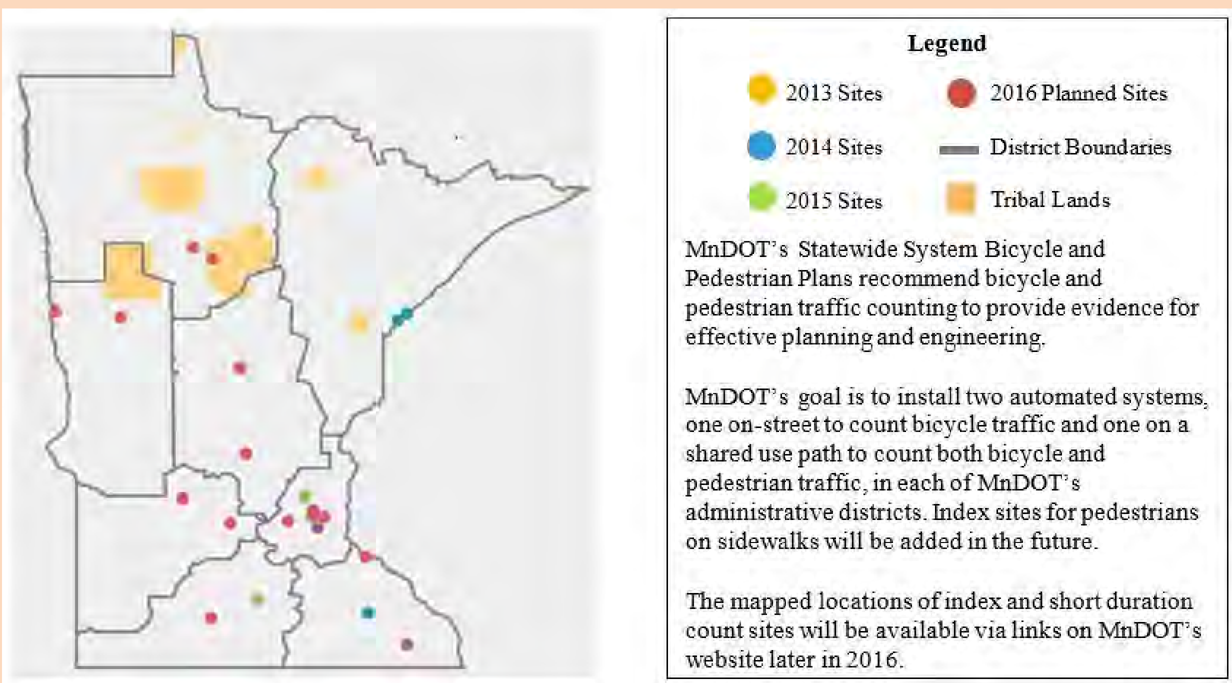
Case Studies

Only a handful of State DOTs have non-motorized monitoring programs at a level comparable to CDOT's program (Stage 2). However, several DOTs are engaged in endeavors to improve their respective programs. In addition, some regional planning agencies have developed sophisticated non-motorized monitoring programs. In particular, several Metropolitan Planning Organizations (MPOs) have implemented websites to share data with other agencies and, in some cases, with the public. The following case studies describe several noteworthy programs that can inform the strategic direction for CDOT and provide ideas for future initiatives.

Minnesota Department of Transportation

The Minnesota Department of Transportation (MnDOT) began monitoring bicycle and pedestrian traffic in 2013 using technologies and procedures similar to those used to monitor vehicular traffic. From 2013 through 2015, MnDOT procured and installed 13 continuous, automated counters at nine index sites throughout the state (Figure 1). MnDOT uses the term "index sites" to characterize sites used to analyze trends in non-motorized traffic volumes over time. These sites will be used for extrapolation factors as the program matures. MnDOT plans to install counters at several additional index sites in 2016.

Figure 1. MnDOT Permanent Non-motorized Traffic Monitoring Index Sites



SOURCE: MnDOT.

Southern California Association of Governments

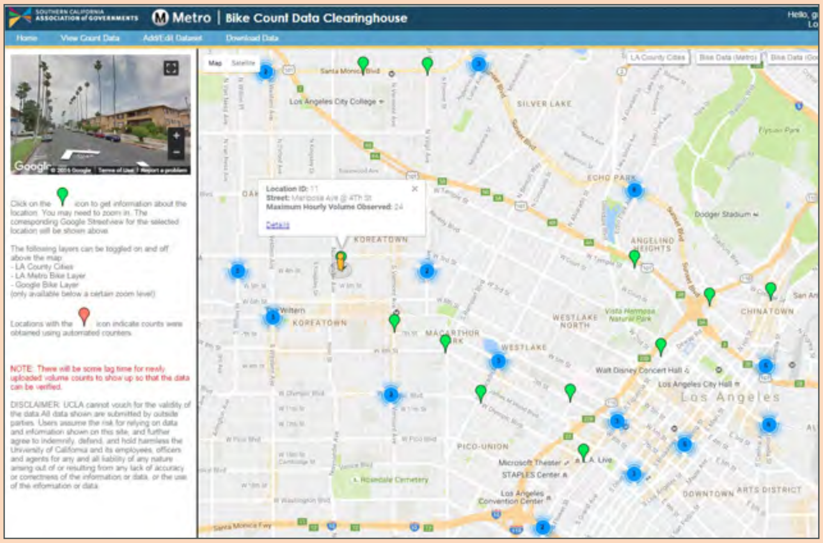
One of the best examples of a large scale, online active transportation database is the *Bike Count Data Clearinghouse* operated by the Southern California Association of Governments (SCAG), the Los Angeles region MPO representing six counties (Figure 2). This site, currently hosted by University of California, Los Angeles, allows registered users (primarily city and county agencies, as well as some stakeholders and advocacy groups) to upload count datasets and allows the general public to view data on the map and download raw datasets as text files. Data can be downloaded for individual locations, groups of locations, or for the entire database. Counts at almost 1,000 locations have been uploaded, predominately within Los Angeles County by LA Metro and its affiliates.

The system's ease of use is also its greatest weakness: because any data format can be uploaded, every count has a different schema of fields, and these cannot be easily standardized or aggregated for summary or comparison. Furthermore, most of the data are from manual counts conducted by volunteers, with inconsistent count protocols.

A project is currently underway to upgrade the database to address these weaknesses. The future database will be hosted on SCAG's website and will similarly allow for two-way data sharing. A standard schema for all uploaded counts will be enforced and the site will provide flexibility to include both manual and automated counts as well as inclusion of data from smartphone apps that SCAG may commission and make available. Methods for incorporating third party datasets (such as from Strava) are also being researched and explored.

While the existing database of almost 1,000 count locations is impressive, outreach to counties beyond Los Angeles is seen as a priority for the updated version. In order to incentivize counties and jurisdictions to upload data they do collect, interviews and surveys have been conducted with these diverse stakeholders (counties, cities, Caltrans districts). A consensus has emerged that joining other datasets (U.S. Census demographic information, crash data, vehicle traffic, public health, roadway characteristics, etc.), as well as providing summary statistics and data visualizations for corridors or selected areas are key value-added features to include. As a result, the future database will help jurisdictions prepare for grant applications, among other things.

Figure 2. SCAG Bike Count Data Clearinghouse



SOURCE: SCAG. Bike Count Data Clearinghouse. http://www.bikecounts.luskin.ucla.edu/.

Delaware Department of Transportation

In 2013, the Delaware Department of Transportation (DelDOT) initiated a statewide pedestrian and bicycle data collection program. Prior to this effort there was no formal count program in place for the State of Delaware, aside from three counters that had been installed by the Department of Parks and Recreation along the Chesapeake and Delaware Canal.

The DOT program began with a pilot implementation of short duration counts (pneumatic tubes and passive infrared detectors) at 10 locations across the state for two weeks each. The lessons from the first and second year of implementation informed the count program strategy which includes plans for at least 10 to 15 permanent count installations and short-duration monitoring of 30 locations. Permanent count locations are identified from a review of data from the short duration counts. If the data indicates the site fills a need within the program, it may be established as a permanent count site.

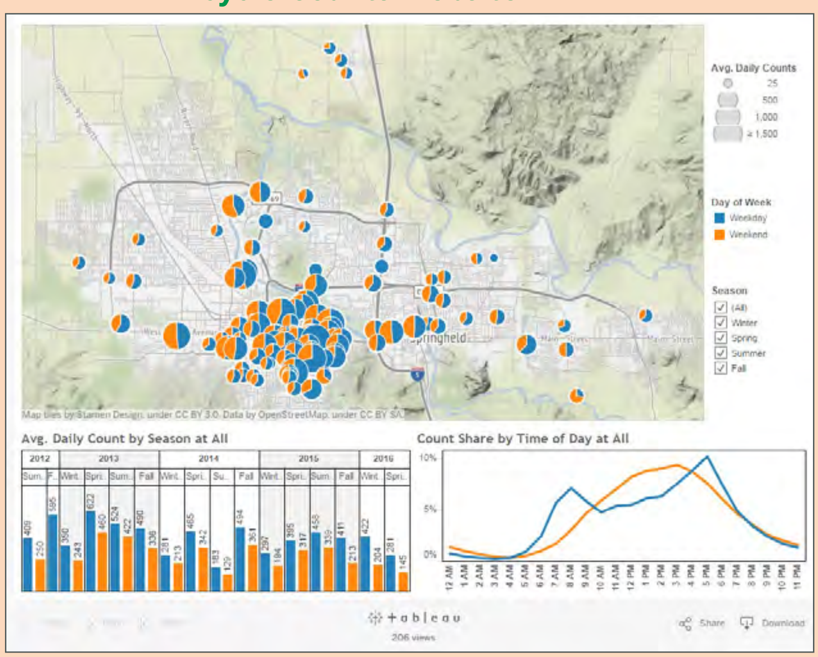
Limited staffing presented a challenge for the operation of Delaware's short-duration count efforts. Starting in 2016, the agency contracted with private vendors to conduct the counts based on the DelDOT specifications and program protocols.

Lane Council of Governments

The Lane Council of Governments (LCOG), the MPO for Eugene, OR, shares bicycle count data with the public on their website using the Tableau Public tool (Figure 3). Twenty-four hour weekday and weekend counts are conducted twice a year around the same time of year at over 100 locations. These counts are uploaded to the website as new count data is collected. Data visualization and sharing are made easier through the use of a standard count data format.

The website allows for automated display of summary charts for individual count locations, a selected area, or the entire dataset. These summary charts show count results by season of year and time of day. The distribution of weekday versus weekend travel is also shown. Count data can be downloaded in various formats, including Tableau workbook, PDF, crosstab spreadsheet, raw CSV file, or an image file of the charts and maps.

Figure 3. Central Lane Council of Governments Bicycle Counts Website



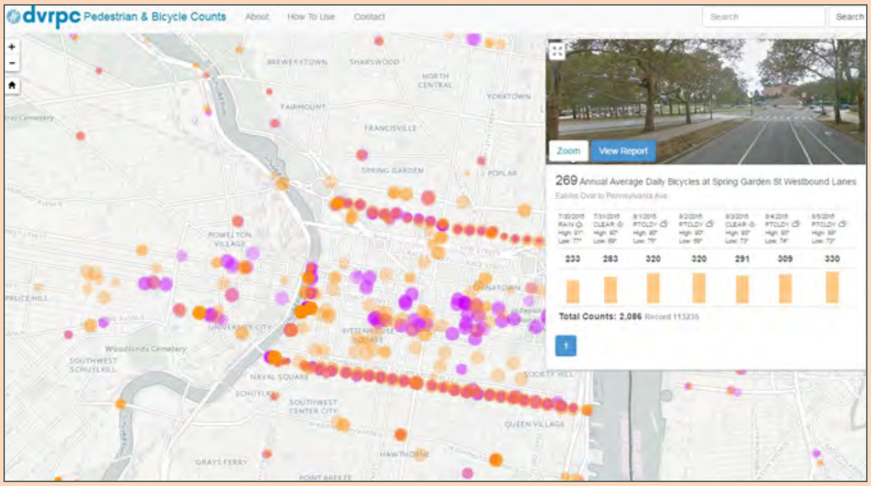
SOURCE: LCOG. Bicycle Counts. http://www.thempo.org/356/Bicycle-Counts.

Delaware Valley Regional Planning Commission

The MPO for the Philadelphia, PA region, Delaware Valley Regional Planning Commission (DVRPC), maintains a webmap of short-duration pedestrian and bicycle counts with a user interface for online viewing (Figure 4). Count locations are plotted on the map, color-coded for each mode and by size for the number of travelers counted. Clicking on a point reveals the count results, time and weather information, street name and direction of travel, and a picture of the location.

The site does not provide an option for uploading or downloading data, but allows users to generate a pdf report for a location of interest. This automated report provides hourly count totals and average annual daily pedestrian or bicyclist (AADP/AADB) estimates. It also notes any seasonal or equipment scaling factors used to develop the estimate.

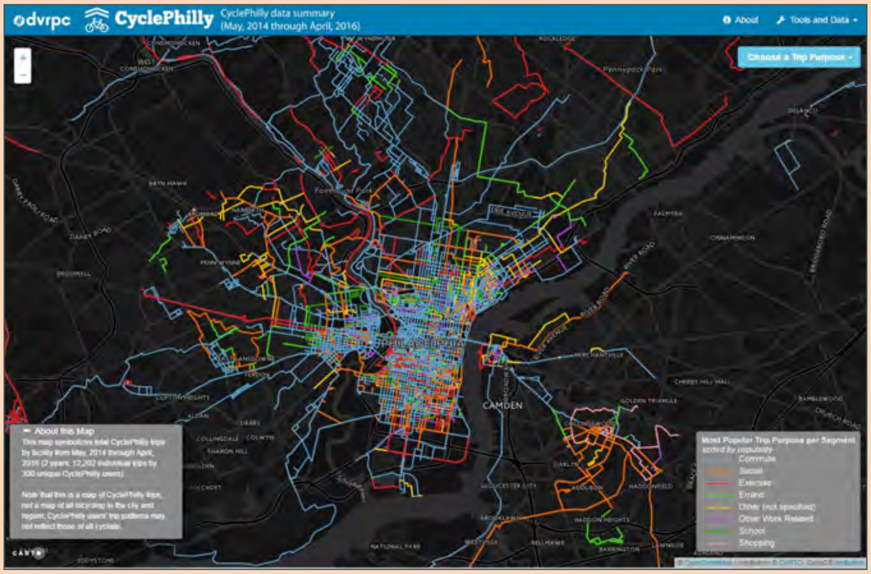
Figure 4. DVRPC Pedestrian and Bicycle Counts Website



SOURCE: Delaware Valley Regional Planning Commission. Pedestrian and Bicycle Counts. http://www.dvrpc.org/webmaps/pedbikecounts/.

While DVRPC does not maintain a public database where agencies can share data, it did gather bicycle trip data from the public from May 2014 through April 2016 via the DVRPC CyclePhilly smartphone app. The app tracks GPS traces and allows users to report trip purposes. The collected data was then snapped to the nearest road or trail segment and published on the CyclePhilly webmap (Figure 5).

Figure 5. CyclePhilly Data Summary Map



SOURCE: DVRPC. CyclePhilly. http://www.dvrpc.org/webmaps/CyclePhilly/

The map reports the distribution of trip purposes for each road segment, with color-coding to indicate the most popular trip purpose. Though the user base of CyclePhilly was limited to 300 people and may not represent the patterns of all bicyclists, the map provides a rough visualization of bicycle trip purposes across the city, based on the roughly 12,000 trips captured over the two year data collection period.

Photo by Kevin Zolkiewicz

Chapter 3

CDOT Non-Motorized Program Goals and Objectives

A central motivation for undertaking this study was to develop a strategic framework for CDOT's Non-motorized Monitoring Program. Establishment of this strategic framework, including clearly-articulated goals and objectives, will help CDOT focus its efforts on activities that advance the program to meet the Department's objectives.

Program goals were developed with input from CDOT staff, external agencies, researchers, and other stakeholders. More detailed strategies and actions required to achieve program goals are provided in Chapter 6.

GOAL 1 Create a strategic and consistent approach to data collection.

Establish a program that counts pedestrians and bicyclists across a range of facility types and geographic land use contexts.

Objectives:

1. Develop criteria for selection of count locations, durations, and facility types.
2. Consistently monitor bicycle travel to support trend analysis and safety performance measures.
3. Focus pedestrian volume data collection on specific projects, locations, or short corridors. A system-wide estimate of pedestrian miles walked is not the most productive use of resources at this time.
4. Collect data that supports development of a bicycle miles traveled (BMT) metric and informs the understanding of statewide levels of bicycling.
5. Create, document, and implement a realistic QA/QC process that results in high quality data.

RATIONALE: A more structured approach to data collection, particularly site selection and count duration, will give CDOT greater confidence in the data that is collected, and allow it to be used for a variety of purposes across the agency.

GOAL 2 Create a focused approach to data analysis that supports CDOT policies, programs, and projects.

Ensure collected data is analyzed to provide insight into pedestrian and bicycle travel and support a broad range of agency decision-making processes.

Objectives:

1. Establish processes for routine data analysis and prioritize such analyses. Data analysis topics may include: trend analysis, crash rates or safety evaluations, and comparative before/after statistics for varying facility types or infrastructure improvements.
2. Develop improved correction and seasonal adjustment factors for short-duration and continuous monitoring count sites.
3. Institutionalize data analysis through the development of templates or other automated processes.
4. Support departmental needs for performance metrics such as pedestrian and bicycle crash or injury rates.
5. Continue to monitor advancements in data collection technology and analysis that improve the quality, reliability, and ease of collecting data.

RATIONALE: Making better use of non-motorized count data is a high priority for CDOT. Trend analysis and performance monitoring have been identified as immediate needs, along with focused pedestrian data collection to support project-level decision-making. Over the long-term, the ability to reliably estimate BMT would support additional CDOT and local agency processes and policies.

GOAL 3 Proactively share data that CDOT collects.

The value of data is measured by its availability and utilization for routine practice in the planning, operations, and maintenance of the bicycle and pedestrian system.

Objectives:

1. Share existing data in an accessible location online.
2. Allow for user-friendly publishing of data (raw exports in easy to transfer electronic file types).
3. Develop automation and/or templates for routine analysis, including hourly, daily and annual trends, to share with internal and external stakeholders.
4. Integrate non-motorized count data with the CDOT Traffic Monitoring Program through the reporting standards developed in Chapter four of the Traffic Monitoring Guide.
5. Create reports to summarize trends and provide case studies for local jurisdictions.
6. Combine CDOT-collected data with data from other sources into a single database.

RATIONALE: The desire for improved access to count data was a common theme heard from stakeholders. In the short-term, providing existing data in a convenient location and format would help solve this problem; however, automated approaches to analysis and data sharing would be more efficient in the long-term. In particular, reports and summaries for local jurisdictions would provide access to data without the need for time-intensive and costly efforts at the local level.

GOAL 4 Consider other sources of data to measure non-motorized activity.

External data sources such as local jurisdiction counts, user-generated or self-reported data and "big data" can enhance understanding of bicycle and pedestrian travel beyond the count program.

Objectives:

1. Explore opportunities to supplement program data with external sources where feasible, with the intention of the Non-motorized Monitoring Program being a primary data source for the state.

RATIONALE: Unless resources are greatly expanded, CDOT's count program alone will not be able to provide a comprehensive assessment of the level of bicycling and walking in Colorado. Leveraging the efforts of local jurisdictions, other data sources, and emerging data sets such as Strava and other examples of "big data" is essential to developing a complete understanding of bicycling and walking trends and patterns in the most efficient manner possible.

GOAL 5 Institutionalize the Non-Motorized Monitoring Program.

In order to ensure the long-term success of the Non-Motorized Monitoring Program, it is critical to establish roles, responsibilities, and resources for sustaining the count effort, as described in the Implementation Plan.

Objectives:

1. Formalize and document roles and responsibilities and identify resource needs for ongoing program maintenance and expansion.
2. Incorporate the program into standard operating procedures and other CDOT plans such as the Strategic Highway Safety Plan and the Statewide Bicycle and Pedestrian Plan.
3. Build relationships with local jurisdictions so they can contribute to and benefit from CDOT's Non-Motorized Monitoring Program.

RATIONALE: Formalized responsibilities and processes would help to institutionalize the program and may be necessary to achieve the long-term goals and objectives outlined in this report, such as automation of analysis routines and improved data sharing. Over the long-term, local jurisdictions should play an important role by conducting counts on local facilities that meet CDOT's criteria for inclusion in the statewide monitoring database.

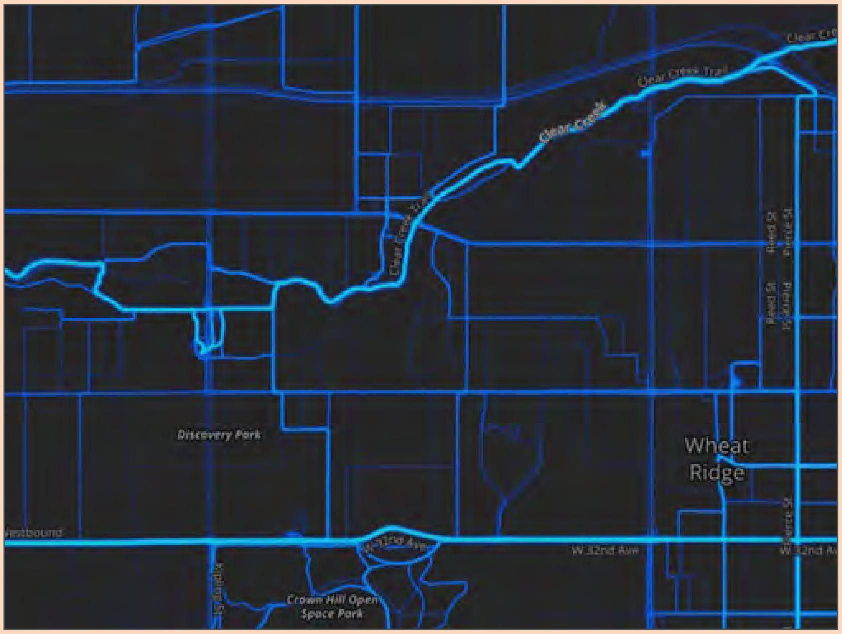
"BIG DATA"

Researchers and practitioners have begun to recognize and explore the potential of emerging data sources collectively referred to as "Big Data." According to the International Transport Forum, Big Data refers to "extremely large data sets now able to be acquired, stored, and interpreted by modern technology." The implications of Big Data for transportation agencies are significant, ranging from improved understanding of travel patterns to better facility management and investment decisions.

As more people are using devices equipped with GPS (such as smart phones) to track their bicycling, jogging, and walking trips, the obvious appeal of using these large data sets is to allow greater understanding of bicycling and walking activity, while reducing the reliance on conventional and relatively expensive means of data collection. Some companies such as Strava currently share this reported trip information in aggregate form with the public and make data sets available for purchase (Figure 6).

While Big Data holds the potential to revolutionize non-motorized data collection, there are also concerns and challenges associated with the use of Big Data. Among these, inherent data collection biases related to smart phone users (and their facility choices) are perhaps most significant. Additional concerns related to data ownership and privacy are also important. Finally, technical capacity required to process and interpret Big Data represents another hurdle for some public agencies.

Figure 6. Strava Heat Map for Wheat Ridge, CO



SOURCE: Strava. http://labs.strava.com/

It is important to recognize that Big Data should complement rather than replace CDOT's current and expanded monitoring program. Big Data can only be considered reliable when validated against a robust sample of counts conducted over a wide geographic distribution and a variety of facility types and contexts. This validation will ensure the data can be used for planning purposes and help CDOT understand when it is less reliable.

As the field of Big Data and its application to transportation is rapidly evolving, an exploratory approach is recommended for the short-term. However, the opportunity is available for CDOT to exercise leadership and serve as a model for other state DOTs by aggressively pursuing Big Data. Development of a pilot study in partnership with an MPO, university, or other partner would be a useful avenue to explore potential uses and limitations of Big Data, and to better understand the level of effort required for development of a broader strategy around Big Data as it relates to non-motorized monitoring.


GRAND VIEW

Chapter 4
Non-Motorized Monitoring in Colorado

CDOT began counting non-motorized traffic in 2010 with the installation of their first continuous counters. These counters were purchased with $50,000 in grant money provided by the healthcare group Kaiser Permanente. State Planning and Research funds have since been used to sustain the program, which has grown to include a combination of continuous and short duration counts (SDCs) that are dispersed throughout the state. As the program has evolved, CDOT staff have developed processes to choose counter technologies, select count locations, deploy counters, and collect and process data.

In addition to CDOT's program, many local and regional agencies across Colorado engage in some level of bicycle and pedestrian counting. CDOT's current monitoring program is described below, followed by a brief description of local efforts to count bicyclists and pedestrians.

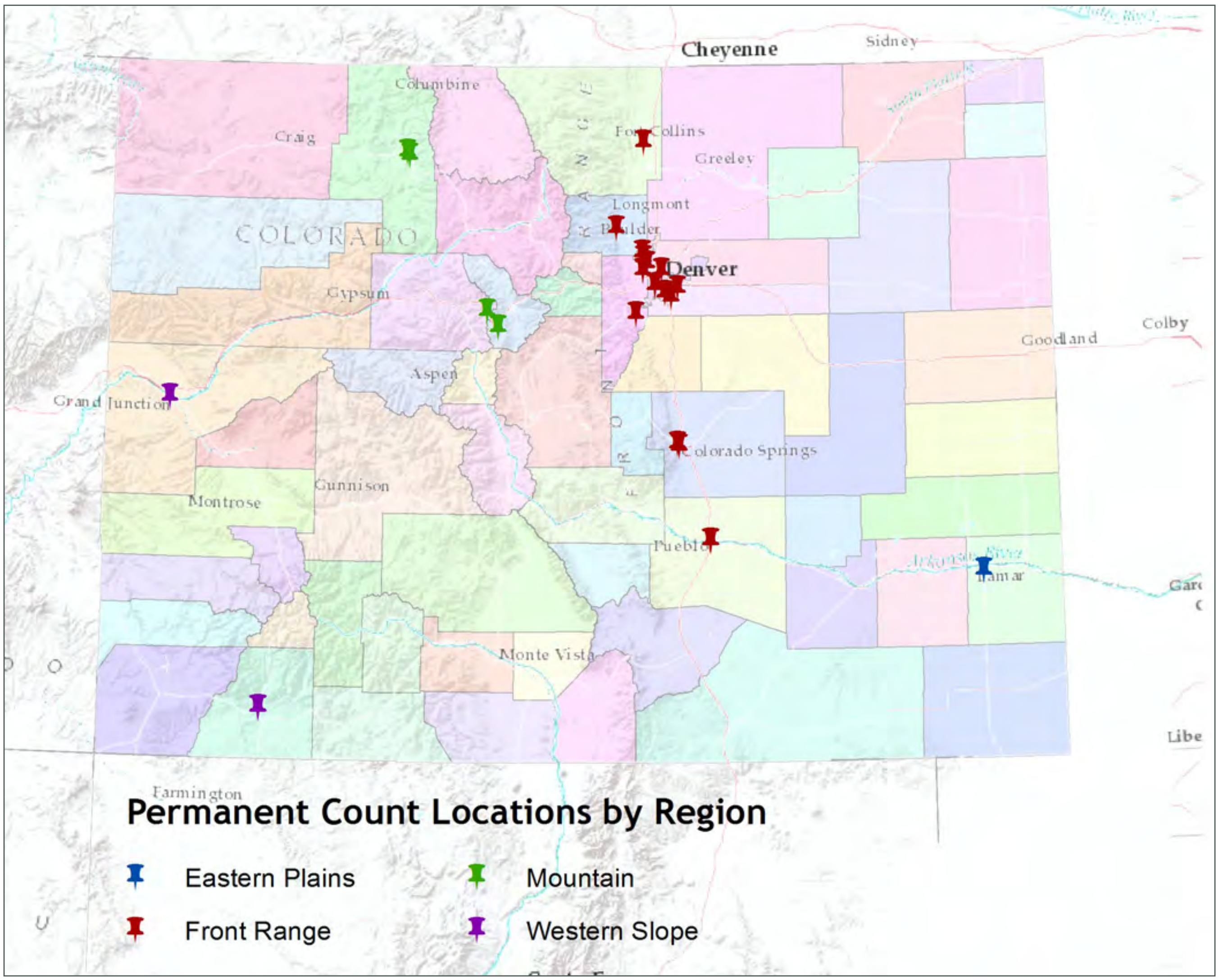
CDOT's Current Non-Motorized Monitoring Program

CDOT currently performs continuous counts and SDCs to understand bicycle and pedestrian activity throughout the state. Both types of counts are necessary to develop a comprehensive understanding of travel patterns and volumes, but continuous monitoring sites form the foundation of the program because they establish the seasonal and daily factors on which extrapolation of SDCs depends.

Permanent Continuous Monitoring Sites

At permanent continuous monitoring sites (PCMS), non-motorized count data is collected throughout the year. In 2015, reliable data were produced from 24 sites (Figure 7, Table 1). Of these, 17 are located in the Front Range, 4 are in mountain communities, and the other 3 are in the Western Slope and Eastern Plains. The counters are evenly distributed between urban and suburban areas, with 11 and 10 in each. The remaining three are located in rural areas (Table 2).

Figure 7. Permanent Continuous Locations, 2015



SOURCE: CDOT, ESRI.

Table 1. Permanent Continuous Monitoring Sites, 2015

SITE ID	LOCATION NAME	REGION	COUNTY	CITY/PLACE	CONTEXT
B90012	Memorial Dr	Eastern Plains	Prowers	Lamar	Suburban
B90013	Platte River Trail	Front Range	Adams	North Washington	Suburban
B90009	High Line Canal Trail	Front Range	Arapahoe	(Unincorporated)	Suburban
B90007	Vaughn Street	Front Range	Arapahoe	Aurora	Suburban
B90004	US 36	Front Range	Boulder	(Unincorporated)	Rural
B90008	Neighborhood Trail	Front Range	Broomfield	Broomfield	Suburban
B90024	US 36	Front Range	Broomfield	Broomfield	Suburban
B00007	Cherry Creek Trail, W of Holly St	Front Range	Denver	Denver	Urban
B00053	Cherry Creek Trail, Champa St (Bike)	Front Range	Denver	Denver	Urban
B00054	Cherry Creek Trail, Champa St (Ped)	Front Range	Denver	Denver	Urban
B90021	Midland Trail	Front Range	El Paso	Colorado Springs	Urban
B90022	Tejon St NB/SB	Front Range	El Paso	Colorado Springs	Urban
B90005-6	W 72nd Ave WB/EB	Front Range	Jefferson	Arvada	Suburban
B00008	C-470 Trail, S of Ken Caryl Avenue	Front Range	Jefferson	Ken Caryl	Suburban
B90023	US 36	Front Range	Jefferson	Westminster	Suburban
B90020	Mason Trail	Front Range	Larimer	Fort Collins	Urban
B90010	E 8th St WB	Front Range	Pueblo	Pueblo	Urban
B90011	E 8th St EB	Front Range	Pueblo	Pueblo	Urban
B90016	Tenmile Canyon Trail	Mountain	Eagle	(Unincorporated)	Rural
B90003	Elk River Road	Mountain	Routt	Steamboat Springs	Urban
B90019	Yampa Street	Mountain	Routt	Steamboat Springs	Rural
B90015	Tenmile Canyon Trail	Mountain	Summit	Copper Mountain	Rural
B90001-2	Hwy 550 SB/NB	Western Slope	La Plata	Durango	Urban
B90018	Broadway Ave Path	Western Slope	Mesa	Grand Junction	Urban

Table 2. Permanent Continuous Monitoring Sites by Region and Context, 2015

REGION/AREA TYPE	URBAN	SUBURBAN	RURAL	TOTAL
Eastern Plains	0	1	0	**1**
Front Range	8	8	1	**17**
Mountainous	1	0	3	**4**
Western Slope	2	0	0	**2**
Total	**11**	**9**	**4**	**24**

CDOT has employed a few different counter technologies at its PCMS (Table 3). Inductive loops are the most common, having been installed at 20 of the 24 PCMS. While this technology is limited to counting bicyclists, loop counters have been installed in conjunction with passive infrared counters in some locations to allow CDOT to separately track pedestrian and bicycle activity. Four passive infrared counters have been installed along trails in the Front Range. These counters do not distinguish between pedestrians and bicyclists as either mode triggers the infrared sensor.

Among the 24 counters in operation in 2015, 14 count bicyclists and pedestrians, nine count bicyclists only, and one counts pedestrians only. CDOT's continuous counters have been most commonly deployed on multiuse trails, which account for 14 out of 24 locations.

In general, the technologies deployed by CDOT are appropriate for the locations where they have been installed. However, technology options should be periodically re-assessed as the monitoring program expands, ensuring that the count devices give CDOT the greatest return on its investment.

Table 3. Permanent Continuous Monitoring Site Characteristics, 2015

SITE ID	LOCATION NAME	FACILITY TYPE	COUNTER TECHNOLOGY	MODES COUNTED	INSTALLATION YEAR
B90012	Memorial Dr	Street	Inductive Loop (4 Loop System w/ direction)	Bicycle	2013
B90004	US 36	Trail	Inductive Loop (4 Loop System w/ direction)	Bicycle	2014
B90009	High Line Canal Trail	Trail	Inductive Loop and Passive Infrared (2 Loop System)	Bicycle & Pedestrian	2012
B90005-6	W 72nd Ave WB/EB	Street	Inductive Loop (1 Loop System)	Bicycle	2010
B90007	Vaughn Street	Street	Inductive Loop (4 Loop System w/ direction)	Bicycle	2010
B90008	Neighborhood Trail	Trail	Inductive Loop and Passive Infrared (2 Loop System)	Bicycle & Pedestrian	2014
B90024	US 36	Trail	Inductive Loop and Passive Infrared (2 Loop System)	Bicycle & Pedestrian	2015
B90021	Midland Trail	Trail	Inductive Loop and Passive Infrared (2 Loop System)	Bicycle & Pedestrian	2015
B90022	Tejon St NB/SB	Street	Inductive Loop (2 Loop System w/ direction)	Bicycle	2015
B00007	Cherry Creek Trail, W of Holly St	Trail	Passive Infrared Pyro Box	Bicycle & Pedestrian	2009
B00053	Cherry Creek Trail, Champa St (Bike)	Trail	Passive Infrared Pyro Box	Bicycle & Pedestrian	2013
B00054	Cherry Creek Trail, Champa St (Ped)	Trail	Passive Infrared Pyro Box	Bicycle & Pedestrian	2013
B90020	Mason Trail	Trail	Inductive Loop and Passive Infrared (2 Loop System)	Bicycle & Pedestrian	2015
B00008	C-470 Trail, S of Ken Caryl Avenue	Trail	Passive Infrared Pyro Box	Bicycle & Pedestrian	2014
B90013	Platte River Trail	Trail	Inductive Loop and Passive Infrared (2 Loop System)	Bicycle & Pedestrian	2013
B90010	E 8th St WB	Street	Inductive Loop and Passive Infrared (2 Loop System)	Bicycle & Pedestrian	2013
B90011	E 8th St EB	Street	Inductive Loop and Passive Infrared (2 Loop System)	Bicycle & Pedestrian	2013
B90023	US 36	Trail	Inductive Loop and Passive Infrared (2 Loop System)	Bicycle & Pedestrian	2015
B90016	Tenmile Canyon Trail	Trail	Inductive Loop and Passive Infrared (2 Loop System)	Bicycle & Pedestrian	2013
B90015	Tenmile Canyon Trail	Trail	Inductive Loop and Passive Infrared (2 Loop System)	Bicycle & Pedestrian	2013
B90003	Elk River Road	Street	Inductive Loop (2 Loop System w/ direction)	Bicycle	2014
B90019	Yampa Street	Street	Inductive Loop (4 Loop System w/ direction)	Bicycle	2014
B90001-2	Hwy 550 SB/NB	Highway	Inductive Loop (1 Loop System)	Bicycle	2010
B90018	Broadway Ave Path	Trail	Inductive Loop and Passive Infrared (2 Loop System)	Bicycle & Pedestrian	2013

Short Duration Count Program

In addition to data collection at PCMS, CDOT and local agencies conduct SDCs at a variety of locations throughout the year. SDCs are focused on expanding the breadth or geographic coverage of the program; however, there is not a standard definition for what constitutes a SDC at CDOT or nationally, and in practice SDCs have been used to collect data at sites for as little as 24 hours or as long as several months.

Reliable guidance as to what constitutes an adequate number of short duration counts for a statewide or regional count program also does not exist. As with motor vehicle traffic monitoring, a greater number of count stations results in better geographic coverage, allows for additional analysis opportunities, and increases the overall confidence level of the program. Nonetheless, resource constraints are likely to be the limiting factor for expanding the number of SDCs conducted annually. Consideration should be given to examining methods of supplementing the SDC program, such as incorporating Big Data sources.

CDOT's approach to SDCs has been driven by a range of factors, but in general has not always been based on strategic goals. The motivation for conducting SDCs is often project-related (e.g., before/after study, corridor study, local agency request, grant application, etc.). Although these are valid and useful count purposes, they do not contribute to a broader understanding of statewide non-motorized travel patterns. In some cases, data collected from an ad hoc count may support further investigation to include the location as a future short duration or even permanent count station.

Local governments, counties, and MPOs can request SDCs by filling out an online form, which is linked from CDOT's Bicycle and Pedestrian Counts webpage. Requests are completed when staff time is available and historically, priority has been given to counts requested by CDOT staff or those related to CDOT projects. In some cases, counters may be provided to local agency staff to conduct the count.

There are two types of counter technology used by CDOT to conduct SDCs: pneumatic tubes and infrared sensors or PYRO-Boxes (Figure 8). Pneumatic tubes are used to count bicycles on trails or in roadways, and can be installed by CDOT staff. However, between 2012 and 2014, a vendor completed all pneumatic tube bicycle counts for the agency. When conducting tube counts, CDOT (or its vendor) typically installs tubes at three or four locations within a corridor to facilitate error detection, such as over- or under-counting.

The second type of SDC technology used by CDOT, PYRO-Boxes, are most commonly deployed on trails and sidewalks. A PYRO-Box uses a passive-infrared sensor that detects people walking or bicycling via their body temperature. The sensors produce combined bicycle and pedestrian counts, but can be installed in combination with tubes to disaggregate pedestrian and bicyclist counts. Four PYRO-Boxes are rotated throughout the state, with each typically installed for approximately one month at any given location.

A key challenge facing CDOT's overall monitoring program is the lack of strategic direction in the implementation of SDCs and the interpretation of the resulting data. Much of the data collected to date

Figure 8. Pneumatic Tube Counters in Fountain, CO (left) and PYRO-Box Counters at the Poudre River Trailhead in Greeley, CO (right)

SOURCE: CDOT.

has not been validated or used by the agency. The implementation plan contained in Chapter 6 of this report will help CDOT make better use of SDC data.

Data Management and Analysis

Non-motorized count data management practices at CDOT have evolved as the size of the program has increased. Quality control processes have been established for PCMS data and a reproducible analysis process has been developed.

Quality Control

CDOT has established protocols and a documented process for cleaning the data obtained from PCMS. On a weekly basis, CDOT checks for equipment malfunctions through the Eco-Visio website, which provides real-time counter status updates. These weekly checks give CDOT timely information to prevent significant loss of data.

A more thorough data quality control process is conducted on a semi-annual basis and includes the following checks:

- **Data gaps**: The data gap check identifies hourly periods where data is missing from the raw data file. The corresponding 24-hour period is removed from the data set.
- **Directional split**: This check compares the volume of the primary direction at a site to the secondary direction of the site. Any count site exhibiting a directional split greater than 70/30 is flagged for further analysis or count verification. Those with a directional split greater than 75/25 are removed from the data set, unless the validation determines such a split to be accurate.
- **Number of consecutive zeros**: For warm weather months (May 1 to September 30) any count site exhibiting more than two continuous days of hourly zero values is flagged. These 24-hour periods are removed from the data set. During cold weather months (October 1 – April 30) this check is not applied to mountain locations. For non-mountain locations, recent weather events are taken into consideration before removing data from the data set. If adverse weather conditions have been experienced, data are not removed from the data set.
- **Maximum daily total (Interquartile Range Formula - IQR):** This check uses a formula based on the interquartile range (IQR) to identify daily values that are significantly higher than expected. If daily counts exceed the IQR then they will be removed from the data set. The formula for the IQR is as follows:

$$IQR = 2.5(Q_3 - Q_1) + Q_3$$

Where: Q_3 = Third quartile of data set

Q_1 = First quartile of data set

The quality control process outlined above ensures that several important types of reporting errors are not included in permanent count records, which would bias any subsequent analysis based on that data. However, there are no existing CDOT guidelines for correcting biases in the data generated by the automated counters.

A similar data cleaning and validation process for SDCs has not been developed to date. As a result, CDOT typically does not use this data for analysis purposes and does not promote the use of this data among stakeholders.

Data Storage

Non-motorized count data are currently stored and managed in differing ways depending on the type of count (PCMS or SDC). PCMS data are transmitted over the cellular network to a centralized website, Eco-Visio. These are raw, unchecked data that do not meet CDOT's requirements for data quality. While Eco-Visio does offer limited data validation services, the data cannot be cleaned to CDOT's standards within the Eco-Visio website.

In addition to Eco-Visio, count data are stored by CDOT staff in spreadsheets, with one file for each location and year. Continuous count data are also uploaded to CDOT's traffic monitoring website built on the MS2 platform. An advantage of MS2 is that it is also used for motorized traffic volume monitoring and can serve as a centralized repository for all of CDOT's count data. However, the site was not specifically intended to support non-motorized traffic counts and has limited functionality beyond data storage and display.

Data Analysis

CDOT has developed and documented a process to analyze raw data from PCMS to generate statistics and graphics for each count location. This analysis template serves as a foundation for understanding non-motorized travel patterns at each location in terms of hourly, day of week, and month of year patterns. It could also be used to develop broader statewide trends, but additional work would be needed to integrate data from multiple sites, as they are currently stored in separate files.

Despite the wide geographic coverage of the counts, system-wide evaluation of usage levels or historic trends does not occur on a routine basis. Furthermore, CDOT has yet to establish an official channel for publishing count data for public use, preventing analysis by external parties. A key finding from outreach conducted for the current project is that there is a desire for more robust analysis of past and future data collected through the program, along with greater access to data from external parties.

Program Operation

CDOT's Non-Motorized Monitoring Program exists as a collaborative effort between two groups within CDOT's Division of Transportation Development (DTD): the Bicycle and Pedestrian Program (BPP) and the Traffic Analysis Unit (TAU). This arrangement is logical in that it couples the domain knowledge of the BPP with the technical and implementation expertise of the TAU. Additionally, as the bicycle and pedestrian modes are increasingly integrated into all of CDOT's functions, shared responsibility for non-motorized traffic monitoring creates broader ownership than if the program were managed solely by one unit or the other.

A challenge of the shared management approach is that roles and responsibilities are not formalized. Non-motorized counting tends to be a low priority as the traditional functions of the BPP and TAU take precedence. Similarly, dedicated funding for the Non-motorized Monitoring Program is not guaranteed and staffing resources are allocated on an "as available basis." Counter maintenance is a special area of concern, as failure to address maintenance issues in a timely manner can result in significant loss of data. In addition, there are no dedicated maintenance resources for the Non-motorized Monitoring Program. BPP and TAU staff absorb maintenance activities and lack dedicated vehicles and equipment to perform routine maintenance functions.

More broadly, the role of non-motorized monitoring within CDOT is not widely recognized or institutionalized, even as promotion of bicycling and walking are high priorities for the agency and the State as a whole. A variety of processes across the agency including bicycle and pedestrian facility investment, safety project selection, corridor studies, performance management, and asset management could utilize non-motorized volume data to make more informed decisions.

Local Non-Motorized Volume Data Collection

Complementary to CDOT's monitoring program, cities, counties, MPOs, university researchers, other agencies, and advocacy organizations have recognized the need for non-motorized volume data and are collecting their own data. Practices vary, but there are some common themes across the state, as identified by survey respondents from a variety of agencies and organizations engaged in bicycle and pedestrian counting:

- The majority of counting is performed on an as-needed basis to evaluate projects, such as before and after installation of new bike facilities.
- Both automated and manual count methods are used, though more agencies use automated methods (67 percent) than manual counts (50 percent).
- Of the agencies that conduct manual counts, the majority count on both trails and streets. Automated counts are more common on trails (67 percent).
- Tube counts are the most common automated count technology in use (41 percent), followed by passive infrared (35 percent), then active infrared (29 percent).

Local agencies and stakeholders collect non-motorized count data to support evaluation of progress toward broader agency and community goals, including goals related to changes in mode split/reduced automobile travel, walking or biking to school, improved health outcomes, and increased recreational activity. For example, the City of Boulder collects non-motorized count data to assess progress toward achieving their *Transportation Master Plan* goal of increasing bicycling, walking, and transit. Additionally, count data allows the City to justify its programs and show changes in mode split over time. Similarly, the City of Steamboat Springs has used count data to support area plans, sidewalk plans, the *Community Plan*, and the City's *Circulation Plan*.

At the MPO level, the Denver Regional Council of Governments (DRCOG), which encompasses over 50 jurisdictions, conducts weekday two-hour manual counts of their funded projects as a means to gauge usage. This data is reported internally to committees, but is not used beyond that.

Colorado State University (CSU) is an innovator in the collection of non-motorized volume data in a university setting. CSU has purchased and installed six counters to go along with one CDOT-owned counter, and it has plans to add one more in 2016 and another in 2017. CSU's count data is shared with CDOT and the North Front Range MPO. Additionally, students conduct 90-minute counts at 45 locations across the University's three campuses. Counting is done to track the University's progress toward implementation of its Climate Action Plan. CSU is also using bike counts to justify infrastructure changes, such as a new signal at an intersection with high bike ridership.

Advocacy groups are also involved in the effort to count pedestrians and bicyclists. For example, the Wheat Ridge Active Transportation Advisory Team completes community-based manual counts, following the standards established in the NBPDP. Their baseline year was 2015 and count locations were chosen based on proposed facility locations, facilities under construction, or newly-constructed facilities. The counts are used to track ridership changes over time, and have fostered greater interest in counting in the City of Wheat Ridge.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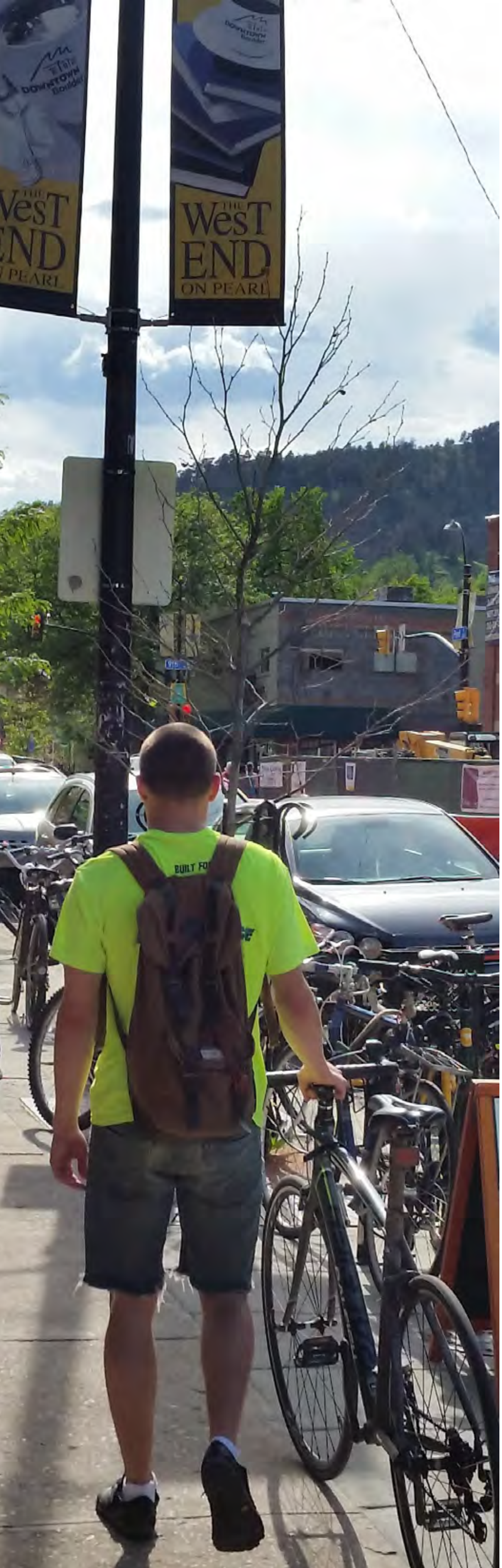

Chapter 5
Gap Analysis

To achieve the goals and objectives developed for the Non-Motorized Monitoring Program, CDOT must understand and address the gaps in its current Non-Motorized Monitoring Program. The program review conducted for the project and documented in Chapter 4 lays the groundwork for a detailed inventory of program gaps which follows. These gaps inform the development of strategies for the Implementation Plan (Chapter 6).

Organizational Gaps

CDOT's Non-Motorized Monitoring Program has developed over time without formal recognition of the activities and resources required to maintain and expand the program. As a result, the ability to achieve program goals under the current organizational structure is unclear, but is likely challenging due to competing demands for staff time and other agency resources. Clearly defined roles and responsibilities, along with increased resources, would help CDOT achieve the goals of the program.

Another concern is that the data produced and the program itself are not well integrated into a broad range of CDOT functions. For example, non-motorized volume data could be used to improve the understanding of pedestrian and bicycle crash rates and trends, but these data are not systematically used for that purpose.

Data Collection Gaps (Number and Selection of Permanent Count Monitoring Sites)

Selecting the number and locations for the placement of PCMS is a complex task that should be based on several considerations. Whereas CDOT's location selection process has been fairly informal to date, the location selection process should deliberately account for the following factors:

- **Context**: Counters should be located in urban, suburban, and rural areas in rough proportion to the bicycling and walking activity in the state that occurs in each context.
- **Geography**: Counters should be dispersed throughout the state. For this study, informal designations of "Front Range," "Eastern Plains," "Mountain," and "Western Slope" have been used to assess the geographic distribution of counters throughout the state (Figure 7, Tables 1-2).
- **Facility type**: Counters should be located on a variety of facility types to account for each type's unique travel characteristics. Facility categories used for this study include: trails, streets, and highways.
- **Travel pattern**: Counters should be located on facilities to obtain non-motorized volume data for a variety of travel patterns. Categories include commute, non-commute, and mixed. SDCs can be conducted at proposed sites to determine whether the location meets CDOT criteria for installation of a PCMS. Categorization of travel patterns (i.e., factor grouping) is discussed in greater detail in "Appendix A: Factor Group Development."

Although a reasonable number of PCMS have been deployed through the CDOT program, based on the above considerations, the overall number and distribution of monitoring locations is low for the state's size and geographic diversity. A greater number of PCMS would increase confidence in the factor groupings, which is needed to develop a comprehensive understanding of bicycle and pedestrian activity in Colorado.

Table 4 shows the number of active PCMS in terms of these categories. Although it would not be reasonable or desirable to have an even distribution of locations across all factor combinations, some factor combinations are clearly over- or under-represented. For instance, there are 10 locations in the Front Range with a "mixed" travel pattern compared to only one location with a "commute" pattern. The following gaps are apparent in the current set of PCMS:

- **Few monitoring sites in Eastern Plains and Western Slope**. More information is needed to determine whether this is truly a gap or the number of PCMS is proportional to the amount of non-motorized travel in these areas.
- **Few sites along highways and streets relative to trails**. Although it is typically easier to establish monitoring sites on trails than along highways or streets, the lack of data from these facilities may result in biased data.
- **Under-representation of commute travel pattern**. Many of the current PCMS show elements of commute traffic, but only two out of twenty four sites indicate a strong commute pattern.

As CDOT expands the number of PCMS, it should seek locations that fill multiple gaps in the current set of locations simultaneously wherever possible.

Table 4. Characteristics of Permanent Count Monitoring Sites

		REGION				CONTEXT			FACILITY TYPE			TRAVEL PATTERN		
		Eastern Plains	Front Range	Mountain	Western Slope	Rural	Suburban	Urban	Highway	Street	Trail	Commute	Non-Commute	Mixed
REGION	Eastern Plains	1				0	1	0	0	1	0	0	0	1
	Front Range		17			1	8	8	1	5	11	1	6	10
	Mountain			4		3	0	1	0	2	2	1	2	1
	Western Slope				2	0	0	2	1	0	1	0	0	2
CONTEXT	Rural	0	1	3	0	4			1	1	2	0	3	1
	Suburban	1	8	0	0		9		0	3	6	1	4	4
	Urban	0	8	1	2			11	1	4	6	1	1	9
FACILITY TYPE	Highway	0	1	0	1	1	0	1	2			0	0	1
	Street	1	5	2	0	1	3	4		8		2	1	5
	Trail	0	11	2	1	2	6	6			14	0	6	8
TRAVEL PATTERN	Commute	0	1	1	0	0	1	1	0	2	0	2		
	Non-Commute	0	6	2	0	3	4	1	1	1	6		8	
	Mixed	1	10	1	2	1	4	9	1	5	8			14

Note: Cell values represent the number of PCMS with the combination of row and column characteristics. For example, there are five Front Range PCMS installed on streets and eleven at trail locations.

Data Collection Gaps (Quality Control)

Quality control is an important aspect of data collection. Data of poor or uncertain quality are not useful and could lead to incorrect interpretations. The quality control process outlined in the previous chapter ensures that several important types of reporting errors are not included in permanent count records, which would bias any subsequent analysis based on that data. However, the removal of records creates another bias that complicates trend reporting.

Another significant concern with respect to CDOT's quality control process is that a data cleaning and validation process for SDCs has not been developed to date. As a result, CDOT typically does not use this data for analysis purposes and does not promote the use of this data among stakeholders. The development of factor groupings and application to SDCs will provide a framework for implementing quality controls for SDCs.

Data Management Gaps

Data management is an easily overlooked element of non-motorized monitoring. However, bicycle and pedestrian counters produce a considerable amount of data over time and inefficient data management practices can quickly lead to unwieldy datasets that are burdensome, particularly with limited staff resources.

While CDOT has given a lot of thought to its data management approach, some challenges and inefficiencies remain. Data is currently stored in multiple systems and in various stages of the quality control process. For instance, PCMS data on the Eco-Visio site is unvalidated/uncleaned, while PCMS data on the MS2 website has gone through the quality control process. On the other hand, data from SDCs that are posted on MS2 have not been validated or undergone quality control checks. In addition to these two data storage platforms, CDOT maintains quality controlled data in spreadsheets. For end users, this multifaceted approach to data storage is confusing and potentially error prone.

The data structure for the non-motorized data collection sites and the resulting data is another potential source of confusion. In general, count data are tied to sites with unique identifiers; however, in some cases, separate identifiers are used for different directions or modes, and these distinctions have not been consistent over time and in the various data storage systems.

A final concern related to data management is that comprehensive documentation for the data collected by the program has not been developed. CDOT has documented aspects of data management including the quality control process, site identifier codes, and basic information about active and historic count locations. A more systematic and comprehensive effort to document the data generated by the program would be useful to internal and external data users, and would minimize risks associated with staff turnover.

Data Analysis Gaps

Improved and expanded analysis of non-motorized data was one of the key reasons for CDOT to undertake this study. It is important to have a clear understanding of the types of policy and programmatic questions facing CDOT that would be informed by analysis of non-motorized volume data. The establishment of program goals in Chapter 3 provides direction for CDOT's analysis efforts to ensure the data is being analyzed strategically.

The need for routine, established analysis processes that help CDOT monitor progress toward program goals cannot be overstated. CDOT currently has an established process for analyzing continuous count data sites, but the process falls short of translating the findings from individual sites into a broader narrative. Additionally, data collected from SDCs are only used on an ad hoc basis and does not contribute to an overall assessment of walking and bicycling in Colorado.

Many of the gaps and challenges noted elsewhere in this report make analysis of CDOT's current data challenging or problematic. For instance, missing data in validated data sets makes it difficult to document volume trends or reliably compare locations.

Another challenge is that the analysis process relies heavily on manual manipulation of data. So while there is a need for improved analysis in the short-term, longer-term changes are also needed to support and facilitate the analysis process, including greater reliability and accuracy, and moving towards automated, institutionalized data management processes. The Implementation Plan includes specific recommendations for an improved analysis process based on the established goals and best practices from other agencies.

Data Sharing Gaps

Sharing non-motorized volume data with external stakeholders was identified as a priority in feedback received throughout the project. Other state and local agencies, researchers, and advocacy groups are interested in using this data for many of the same reasons as CDOT, and they may provide a different interpretation of the data, depending on their perspective.

The specific material to be shared can take various forms including raw data files, cleaned data files, or analysis reports. In general, the greatest need is for reports, which can be readily used by a broad range of stakeholders. Whereas interpreting data files from individual count locations requires a significant amount of work from end users, reports provide useful information without any effort on the part of stakeholders. This does not imply that sharing raw data is a bad idea, but that developing a mechanism for sharing raw data is a lower priority for the near-term, particularly as CDOT currently shares on an as-needed basis with local agencies or researchers.

A key challenge is that CDOT is currently reluctant to share unvalidated count data or data with significant gaps, as this data is subject to misinterpretation. While steps can be taken to reduce these risks, it may also be wise for CDOT to consider developing language surrounding the use and interpretation of non-motorized monitoring data.

Chapter 6
Implementation Plan

The Implementation Plan is perhaps the most important aspect of this study. It gives CDOT the direction needed to make better use of existing data and expand the program to ensure it continues to meet the needs of the Department.

The goals and objectives in Chapter 3 as well as the program review and gap analysis contained in Chapters 4 and 5 inform the Implementation Plan. Seven overarching strategies are recommended, and each strategy includes several discrete actions.

Actions are designated as short-term (one to two years) or long-term (three to five years) to give a sense of the urgency and feasibility for implementation in the near future. Additionally, notes are included for certain actions to clarify the rationale for the action or to identify any dependencies in such cases where implementation is not possible until other actions have been taken or more information is obtained.

Table 5. Non-motorized Monitoring Plan Strategies

STRATEGY	DESCRIPTION
1	Refine quality control processes to comprehensively address data quality concerns.
2	Integrate non-motorized monitoring data into CDOT systems and processes.
3	Develop and implement a strategic approach to short-duration counts.
4	Implement continuous counters at new locations to achieve 10 representative sites for each factor group (commute, non-commute, mixed).
5	Implement routine analysis to make better use of existing and future data.
6	Continue to explore evolving technologies and methods for monitoring non-motorized travel.
7	Build CDOT Non-Motorized Monitoring Program capacity.

Strategy 1: Refine quality control processes to comprehensively address data quality concerns.

	ACTION	TIMEFRAME	NOTES
1-1	Develop quality control process for short-duration counts.	Short-term	It is difficult to ensure SDCs are accurate with limited data. Manual review of data may be required in the absence of a formalized process.
1-2	Establish a maintenance protocol to reduce data gaps.	Short-term	Timely response to counter failures will result in fewer data gaps, which undermine the reliability of the count data. Minimizing these gaps is an essential aspect of the quality control process.

Strategy 2: Integrate non-motorized monitoring data into CDOT systems and processes.

	ACTION	TIMEFRAME	NOTES
2-1	Identify and document key roles and responsibilities for Bicycle and Pedestrian Program, Traffic Analysis Unit, and other divisions with respect to implementing the Non-Motorized Monitoring Program Plan.	Short-term	
2-2	Integrate non-motorized monitoring data into CDOT's Online Transportation Information System (OTIS).	Short-term	This action is currently in progress and will allow internal and external users to access CDOT's pedestrian and bicycle count data.
2-3	Identify CDOT uses of non-motorized data.	Long-term; ongoing	

Strategy 3: Develop and implement a strategic approach to short-duration counts.

	ACTION	TIMEFRAME	NOTES
3-1	Implement short-duration counts at pedestrian and bicycle high-crash locations on State Highway System on annual basis.	Short-term; ongoing	Locations could be staggered to cover the top 25 locations over a 3-year period.
3-2	Determine appropriate factor groups for historic short-duration count locations and whether they meet minimum data collection standards.	Short-term	SDCs must have been at least one week in duration to identify the appropriate factor group.
3-3	Develop annual estimates of past SDCs using identified factor groups.	Short-term	Based on factor groups established in Action 3-2 and associated adjustment factors.
3-4	Develop schedule for collecting short-duration counts based on geographic distribution, facility type, and factor group representation.	Short-term	
3-5	Conduct identified SDCs	Long-term; ongoing	Based on schedule developed per Action 3-4.
3-6	Allocate counters to support unscheduled counts.	Long-term; ongoing	It is important to have additional counters available to avoid competing with scheduled counts; this may require purchase of additional counters or setting aside existing counters.

Strategy 4: Implement continuous counters at new locations to achieve 10 representative sites for each factor group (commute, non-commute, mixed).

	ACTION	TIMEFRAME	NOTES
4-1	Identify 10 new suitable index sites for the Commute factor group from previous or new SDCs.	Short-term	Preference should be given to on-street facilities; consider working with local jurisdictions to identify appropriate locations.
4-2	Identify five new suitable index sites for the Non-commute factor group from previous or new SDCs.	Short-term	Preference should be given to on-street facilities; consider working with local jurisdictions to identify appropriate locations.
4-3	Identify five new suitable index sites for the Mixed factor group from previous or new SDCs.	Short-term	Preference should be given to on-street facilities; consider working with local jurisdictions to identify appropriate locations.
4-4	Expand the number of PCMS to achieve 50 total statewide locations.	Long-term	50 total locations would serve as a substantial statewide sample for benchmarking.

Strategy 5: Implement routine analysis to make better use of existing and future data.

	ACTION	TIMEFRAME	NOTES
5-1	Estimate Average Daily Bicycle Traffic (ADBT) and Average Daily Pedestrian Traffic (ADPT) annually for each site with appropriate data.	Short-term; ongoing	Calculate for continuous locations and use factor group estimation to apply to short-duration counts.
5-2	Conduct trend analyses based on ADBT and ADPT with a set of benchmarked locations.	Short-term; ongoing	Starts with basic reporting of the count data in ADBT and ADPT for CDOT counters and grows with benchmarking comparison of common count locations for trend analysis.
5-3	Calculate pedestrian and bicycle crash rates for top 25 crash locations on CDOT-maintained system	Long-term; ongoing	This data could be used by CDOT's safety program staff to identify the highest priority locations pedestrian and bicycle safety improvements.
5-4	Evaluate bicycle and pedestrian facility usage before and after implementation of projects; support local evaluation as appropriate.	Ongoing	Before and after counts for various facility types would be useful in helping CDOT evaluate the facilities that have the greatest impact on bicycling and walking.
5-5	Develop a program report on annual basis.	Long-term; ongoing	This could be an internal update conducted annually or every two years describing how the monitoring program is progressing – how many new counters were installed, the number of valid data collection days, staff resources, etc. It could also include analysis results. It would be important to identify the appropriate audience and distribution list prior to developing the report.
5-6	Develop spreadsheet templates or other automated methods to make efficient use of staff time.	Long-term	

Strategy 6: Continue to explore evolving technologies and methods for monitoring non-motorized travel.

	ACTION	TIMEFRAME	NOTES
6-1	Develop a strategy to supplement count data with crowdsourced or other emerging datasets.	Short-term	Possible sources include: aggregated data sources (Strava, INRIX, Foursquare), intelligent infrastructure (traffic signals, pedestrian push buttons), and cell phone applications.
6-2	Monitor state of practice and research related to the effectiveness and applicability of emerging technologies to CDOT's Non-Motorized Monitoring Program.	Ongoing	

Strategy 7: Build CDOT Non-Motorized Monitoring Program capacity.

	ACTION	TIMEFRAME	NOTES
7-1	Develop a fact sheet/flyer to share with CDOT staff and local agencies regarding the use of short-duration counts in PEL and NEPA studies, safety studies, before/after studies, and other CDOT-funded projects.	Short-term	One- to two-page flyer covering key resources.
7-2	Identify a sustainable funding source for implementation of the Non-motorized Monitoring Program.	Short-term	
7-3	Conduct periodic training and information sharing within CDOT and with local agencies (coordinate with existing conferences and trainings).	Ongoing	Having multiple employees trained in both the technology and data collection protocols for the counters. Seek opportunities to gain more knowledge of the state of practice through webinars and research conferences.
7-4	Establish guidelines for sharing data with external agencies.	Long-term	

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Chapter 7
Resources Required for Implementation

Availability of resources is likely to be the primary limiting factor for expanding the Non-motorized Monitoring Program and achieving program goals and objectives. In this section of the report, the costs of implementing this plan are discussed, along with opportunities to leverage complementary resources.

The costs of implementing the Plan are largely associated with increased staffing and capital. Additional resources are needed to address current program deficiencies and sustain the improved and expanded program. Broadly, these resources require investments in two main activity areas:

1. Program Operation
2. Counter Acquisition and Deployment

Program Operation

Several of the Implementation Plan strategies are focused on improving the current operation of the Non-motorized Monitoring Program. These topics address crucial aspects of the program such as:

- Quality control,
- Maintenance,
- Documentation of roles and responsibilities,
- Data sharing,
- More strategic implementation of short duration counts (SDCs),
- Increased analysis,
- Integration of count data with emerging datasets (e.g., Big Data), and
- Improved program capacity.

These activities can occur without additional capital investment. However, additional staff resources are required to make significant progress in these areas. Current staff within the BPP and TAU have other responsibilities that often take precedence over the daily operation of the monitoring program, and as a result, significant enhancements to the program are not likely to occur under current staffing levels.

Staffing Recommendation

Based on the strategies outlined in the Implementation Plan, it is recommended that CDOT dedicate one full-time staff person to the ongoing operation of the Non-motorized Monitoring Program. A dedicated staff person would be able to address current program deficiencies and support the long-term expansion recommended in the plan. Key responsibilities of the proposed staff include:

- Serving as the main contact person for the program,
- Responding to data requests and other inquiries,
- Developing and implementing quality control processes outlined in the plan,
- Responding to counter failures and other maintenance issues,
- Conducting analysis and sharing results with stakeholders,
- Deploying new counters, and
- Developing trainings, fact sheets, and other materials related to the program.

Current BPP and TAU staff with responsibilities related to the program would continue to provide oversight and direction, but would not be responsible for day-to-day operations. Over time, their involvement may be reduced as the program manager would grow more confident and independent.

Counter Acquisition and Deployment

The Implementation Plan recommends that CDOT increase the number of permanent count monitoring stations (PCMS) in operation throughout the State to 50 locations within five years to develop a robust set of locations for benchmarking and for use as index sites. It also includes recommendations for implementing SDCs at high-crash locations, developing and implementing a schedule for collecting SDCs, and setting aside counters for unscheduled counts.

Within the 50 total PCMS, it is recommended that 10 index sites are established for each factor group (see “Appendix A: Factor Group Development” for factor group and index site criteria). While there is not a requirement or accepted standard for a specific number of sites for a factor group, establishing 10 sites for each factor group would provide a very substantial basis for annualizing SDCs. The additional 20 recommended sites could be used to develop future factor groups, such as for mountain locations or pedestrian count sites. Additionally, a greater number of overall PCMS would support more robust statewide trend analysis.

Based on the existing counter composition, the five-year implementation of PCMS installations should target identification and deployment of counters to meet the following factor index gaps:

- Ten new commute factor group index sites including at least five high volume locations (average daily volume greater than 250),
- Five new non-commute factor group index sites (all high volume locations), and
- Five new mixed factor group index sites including at least one high volume location.

Some of these gaps may be filled by relocating counters that currently do not contribute substantially to the overall program, such as certain low-volume sites. Nonetheless, acquisition of new counters will be needed to meet the recommended PCMS implementation target. Additional counters are likely to be needed to implement the SDC schedule.

Costs for permanently installed equipment that counts both bicycles and pedestrians ranges from approximately $6,000 to $15,000 per site. The number of counters required at any given location is a function of the facility characteristics (e.g., trail or street) and whether separate counts for pedestrians and bicyclists are desired. As CDOT expands the count program to include a more diverse set of PCMS, it is likely that some sites will require the installation of more than one counter to adequately account for bicyle and pedestrian activity (see "Appendix B: Pedestrian and Bicycle Volume Data Collection Toolkit" for more information).

There are a number of costs associated with both the procurement and ongoing management of automated counters, including:

- **Procurement:** Sensor equipment, software or licensing, additional tools or installation hardware not included with purchase, and installation (e.g., pavement cuts for installing loop counters).
- **Ongoing costs**: installation/deployment staffing, data collection support (cellular transmission or manual download), data management and analysis, replacement parts (i.e. tubes, fasteners, etc.) due to normal wear and tear, and potential equipment replacement due to damage or theft.

Counter deployment also requires staff to spend time on activities such as:

- Seeking permissions from local authorities or municipal governments (except where deployed on state facilities or where agreements already exist), determining the exact counter location and count detection zone based on installation considerations, creating a site plan of the location showing how the counter will be installed, addressing any possible disruptions to traffic, and ensuring that all materials for the deployment or retrieval are accounted for.
- Travel time to and from the count locations.
- Setting up and confirming the proper functioning of each counter during counter deployment, downloading data, and removing the counters during counter retrieval.
- Regular monitoring of the counters during data collection periods to ensure proper functioning. For the existing program equipment this can be conducted remotely via internet with daily data transmissions from each counter.

Leveraging Resources

As described in the previous section, the plan recommends a substantial expansion of the Non-motorized Monitoring Program over the next five years that will require additional funding. Separate funding sources for staffing and capital expenses (e.g., new counters, software, or installation costs) are likely to be needed. Some possible funding sources for implementation of the plan include:

- State Planning and Research (SPR),
- Congestion Management and Air Quality (CMAQ),
- Transportation Alternatives Program (TAP),
- Highway Safety Improvement Program (HSIP), and
- Foundations or other non-profit organizations.

Local Involvement

Over the long-term, engaging local agencies in non-motorized volume data collection would not only contribute to increased data collection in Colorado, but would also ensure the data represents a wider variety of facility types and context. As CDOT's program becomes increasingly formalized and documented, opportunities for local agencies and regional planning organizations to participate should increase. For example, with the establishment of criteria for inclusion of SDC data in CDOT's database, local agencies will have guidance on how to conduct these counts and may begin to implement routine data collection that meets CDOT's data quality standards. Local agencies are also likely to have insights into the identification of new SDC and PCMS candidate locations to help CDOT fill gaps in its current set of PCMS.

Local involvement in monitoring activities could reduce the long-term costs of implementing the program. CDOT's role may, over time, transition from being the primary data collection entity to a coordinating and oversight role. Conversely, local agencies would benefit from greater involvement in monitoring activities, provided they have access to the resulting data and any subsequent analysis generated by CDOT. Under the right scenario, local agencies could take ownership of routine counter maintenance activities. This would be particularly likely if small incentives were provided to subsidize the use of local staff time.

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Colorado DOT

Non-Motorized Monitoring Program Evaluation and Implementation Plan

CO CDOT

APPENDICES

FARGO
TURNING VEHICLES
TO
City of Boulder
Cyclists Today
90
500 000
450 000
400 000
350 000
300 000
250 000
200 000
150 000
100 000
50 000
0
Cyclists this Year
BOULDER
STOP

APPENDIX A: FACTOR GROUP DEVELOPMENT

Introduction to Factor Groups

According to the Traffic Monitoring Guide (TMG), factor groups are "groups of continuous counters that have similar traffic patterns."[1] These similarities may be based on observed hour-of-day or day-of-week traffic patterns, or other site characteristics. Once factor groups have been established, adjustment factors can be used to estimate annual traffic from short duration counts (SDCs) conducted at sites with similar patterns. Adjustment factors are "statistics or ratios derived from continuous monitoring results to extrapolate short-term monitoring results into estimates of longer-term monitoring results."[2]

Factor groups can be characterized by the amount of non-motorized traffic that occurs during typical peak commute periods (morning and evening commute times and weekdays) compared to the amount that occurs outside of typical peak commute times (middle of the day and weekends). The ratio of travel occurring during commute versus non-commute times allows the locations to be described as having work/school commute functions versus locations likely to serve discretionary or recreational trips. Some locations show characteristics of both, or demonstrate no significant variation in the two periods and are identified as 'mixed'.

In addition to hour-of-day and day-of-week patterns, consideration should be given to weather and seasonal variation to ensure that adjustment factors are appropriately applied. For instance, a mountain site and Front Range site, both exhibiting commute patterns, have significant differences in the monthly or seasonal distribution of traffic. As a result, these groups should be considered separately for the purpose of factoring SDCs. For sites with similar weather (e.g., two Front Range locations), it is reasonable to expect that a one- or two-week count sample from one location would reflect roughly the same ratio of annual traffic as other locations in the same factor group over that time period.

Based on the data collected from continuous monitoring locations, index sites, or "representative" count locations can be identified for each factor group. Index sites should be representative of the factor group based on the hour-of-day and day-of-week travel patterns and should have relatively high volume (100/day or more) to improve the predictive capacity of the estimation. Sites with higher volume are less impacted by external influences or random variation.

The TMG recommends three to five permanent, continuous count stations (index sites) for each factor group. A detailed analysis of factor grouping was conducted for a 2013 CDOT report, *Development of Estimation Methodology for Bicycle and Pedestrian Volumes Based on Existing Counts*, which supports this upper range of count stations. In that report, several findings were made that help inform the factor group analysis and discussion for this study. It is important to note that the 2013 study's objective was to establish factor groups using the existing continuous count stations and did not make recommendations regarding the potential expansion of factor group types.

The main findings were:

- For day-of-week and monthly factors, bicyclist and pedestrian factors can be grouped with bicyclist only factors.
- Commute and non-commute factor groups should be established, but the commute factor group could be geographically derived from just the Front-Range stations.

The recommendations contained in this report build from these findings.

1 FHWA. Traffic Monitoring Guide. 2013. https://www.fhwa.dot.gov/policyinformation/tmguide/tmg_fhwa_pl_13_015.pdf

2 Minge et al. MnDOT Bicycle and Pedestrian Data Collection Manual (Draft). 2015. https://www.dot.state.mn.us/research/TS/2015/201533.pdf

Continuous Count Data Analysis

CDOT count data was analyzed to identify appropriate factor groups for each of the existing permanent continuous monitoring sites (PCMS). The ratio of average hourly volume for the peak commute periods (M-F, 7-9am and 4-6pm), to the midday average hourly volume (M-F, 11am-1 pm) was first identified to determine the weekday hourly pattern, or AM/PM Peak-to-Midday Ratio (1).

(1) AM/PM Peak-to-Midday Ratio: $$\frac{\sum_{M-F}(Vol_{7a-9a} + Vol_{4p-6p}) / 4}{\sum_{M-F}(Vol_{11a-1p}) / 2}$$

Day-of-week patterns were also identified by comparing the average daily weekday volume (M-F) to the average daily weekend volume (Sa-Su) (2).

(2) Weekday-to-Weekend Ratio: $$\frac{Average\ Weekday\ Daily\ Traffic}{Average\ Weekend\ Daily\ Traffic}$$

These two measures taken together provide a good overall indication of whether the site is more closely associated with commute or non-commute travel patterns, or demonstrates characteristics of both. Ratio values above 1.1 indicate a commute pattern, while values below 0.9 indicate a non-commute pattern (including recreation and other non-commute trips). Values between 0.9 and 1.1 experience both types of traffic and are therefore considered to be 'mixed.'

The combination of AM/PM peak-to-midday and weekday-to-weekend ratios was used to classify each site as having a "Commute", "Non-Commute", or "Mixed" travel pattern, based on the ranges shown in Table A-1. The criteria can also be used to assign SDCs into factor groups. CDOT may wish to review the appropriateness of these thresholds as additional data is collected and evaluated.

Table A-1. Factor Group Assignment Matrix

		WEEKDAY-TO-WEEKEND RATIO		
		< 0.9	0.9 - 1.1	> 1.1
AM/PM PEAK-TO-MIDDAY RATIO	< 0.9	Non-Commute	Mixed	Mixed
	0.9 - 1.1	Mixed	Mixed	Mixed
	> 1.1	Mixed	Mixed	Commute

Tables A-2 through A-4 summarize the factor group assignments for the 24 active PCMS by pedestrian, bicycle, and combined counts.

Table A-2. Travel Patterns for Permanent Continuous Pedestrian Monitoring Sites

SITE ID	LOCATION NAME	2015 DAILY AVG.	WEEKDAY-TO-WEEKEND RATIO	AM/PM PEAK-TO-MIDDAY RATIO	RECOMMENDED FACTOR GROUP
B90008	Broomfield, Neighborhood Trail	76	1.2	0.44	Mixed
B90009	Arapahoe County, High Line Canal Trail	117	0.74	1.17	Mixed*
B90010	Pueblo, E 8th St WB	108	1.32	0.65	Mixed
B90011	Pueblo, E 8th St EB	68	1.24	0.62	Mixed
B90013	Adams County, Platte River Trail	234	0.72	0.91	Non-Commute
B90015	Copper Mountain, Tenmile Canyon Trail	104	0.7	0.58	Non-Commute
B90016	West Vail Pass, Tenmile Canyon Trail	65	0.86	0.47	Non-Commute
B90018	Grand Junction, Broadway Ave Path	31	1.17	0.77	Mixed
B90020	Fort Collins, Mason Trail	281	1.03	0.75	Mixed
B90021	Colorado Springs, Midland Trail	99	0.94	0.8	Non-Commute
B90023	Westminster, US 36	13	0.9	0.82	Mixed
B90024	Broomfield, US 36	16	0.93	0.84	Mixed
B00054	Denver, Cherry Creek Trail, Champa St (Ped)	730	1.06	0.54	Mixed

* Bicycle factor group is Non-commute for B90009.

Table A-3. Travel Patterns for Permanent Continuous Bicycle Monitoring Sites

SITE ID	LOCATION NAME	2015 DAILY AVG.	WEEKDAY-TO-WEEKEND RATIO	AM/PM PEAK-TO-MIDDAY RATIO	RECOMMENDED FACTOR GROUP
B00053	Denver, Cherry Creek Trail, Champa St (Bike)	2,285	1.02	1.91	Mixed
B90001-2	Durango, Hwy 550 SB/NB	55	1.07	0.88	Mixed
B90003	Steamboat Springs, Elk River Road	92	1.97	1.4	Commute
B90004	Boulder, US 36	370	0.49	0.68	Non-Commute
B90005-6	Arvada, W 72nd Ave WB/EB	11	0.73	0.72	Non-Commute
B90007	Aurora, Vaughn Street	45	2.39	3.12	Commute
B90008	Broomfield, Neighborhood Trail	57	1.02	1.49	Mixed
B90009	Arapahoe County, High Line Canal Trail	277	0.53	0.86	Non-Commute*
B90010	Pueblo, E 8th St WB	67	1.25	0.81	Mixed
B90011	Pueblo, E 8th St EB	37	1.25	0.64	Mixed
B90012	Lamar, Memorial Dr	18	1.55	1.01	Mixed
B90013	Adams County, Platte River Trail	155	0.48	0.88	Non-Commute
B90015	Copper Mountain, Tenmile Canyon Trail	195	0.45	0.13	Non-Commute
B90016	West Vail Pass, Tenmile Canyon Trail	115	0.31	0.13	Non-Commute
B90018	Grand Junction, Broadway Ave Path	73	1.06	1.1	Mixed
B90019	Steamboat Springs, Yampa Street	368	0.9	0.83	Mixed
B90020	Fort Collins, Mason Trail	1165	0.99	1.31	Mixed
B90021	Colorado Springs, Midland Trail	172	0.76	0.82	Non-Commute
B90022	Colorado Springs, Tejon St NB/SB	125	0.86	1.03	Mixed
B90023	Westminster, US 36	55	0.71	1.34	Mixed
B90024	Broomfield, US 36	98	0.66	1.19	Mixed

* Pedestrian factor group is Mixed for B90009.

Table A-4. Travel Patterns for Permanent Continuous Bicycle and Pedestrian (Combined) Monitoring Sites

SITE ID	LOCATION NAME	2015 DAILY AVG.	WEEKDAY-TO-WEEKEND RATIO	AM/PM PEAK-TO-MIDDAY RATIO	RECOMMENDED FACTOR GROUP
B00007	Denver, Cherry Creek Trail, W of Holly St	1,335	0.73	1.12	Mixed
B00008	Jefferson County, C-470 Trail, S of Ken Caryl Avenue	203	0.48	0.52	Non-Commute

Table A-5. Permanent Continuous Monitoring Site Factor Group and Index Site Classification

SITE ID	LOCATION NAME	FACTOR GROUP	INDEX SITE	CANDIDATE FOR RELOCATION
B00007	Denver, Cherry Creek Trail, W of Holly St	Mixed	Yes	No
B00008	Jefferson County, C-470 Trail, S of Ken Caryl Avenue	Non-Commute	Yes	No
B00053	Denver, Cherry Creek Trail, Champa St (Bike)	Mixed	Yes	No
B00054	Denver, Cherry Creek Trail, Champa St (Ped)	Mixed	Yes	No
B90001-2	Durango, Hwy 550 SB/NB	Mixed	No	Yes
B90003	Steamboat Springs, Elk River Road	Commute (Mountain)	No	No
B90004	Boulder, US 36	Non-Commute	Yes	No
B90005-6	Arvada, W 72nd Ave WB/EB	Non-Commute	No	Yes
B90007	Aurora, Vaughn Street	Commute	No	Yes
B90008	Broomfield, Neighborhood Trail	Mixed	No	Yes
B90009	Arapahoe County, High Line Canal Trail	Non-Commute	Yes	No
B90010	Pueblo, E 8th St WB	Mixed	No	Yes
B90011	Pueblo, E 8th St EB	Mixed	No	Yes
B90012	Lamar, Memorial Dr	Mixed	No	Yes
B90013	Adams County, Platte River Trail	Non-Commute	Yes	No
B90015	Copper Mountain, Tenmile Canyon Trail	Non-Commute (Mountain)	Yes	No
B90016	West Vail Pass, Tenmile Canyon Trail	Non-Commute (Mountain)	No	Yes
B90018	Grand Junction, Broadway Ave Path	Mixed	No	Yes
B90019	Steamboat Springs, Yampa Street	Mixed (Mountain)	Yes	No
B90020	Fort Collins, Mason Trail	Mixed	Yes	No
B90021	Colorado Springs, Midland Trail	Non-Commute	Yes	No
B90022	Colorado Springs, Tejon St NB/SB	Mixed	Yes	No
B90023	Westminster, US 36	Mixed	No	Yes
B90024	Broomfield, US 36	Mixed	No	Yes

In addition to the assignment of factor groups, locations were evaluated for their overall suitability to be an Index site. It is recommended that only locations with reasonably high volumes (greater than 100/day, preferably greater than 250/day) be considered as index site candidates for the purpose of annualizing short duration counts.

Table A-5 shows the classification of each PCMS with respect to the factor group and suitability for consideration as an index site. Based on the similarity of the factor groups for pedestrian and bicycle activity found at each location (with the exception of site B90009), a combined factor group appears reasonable for extrapolation purposes. As additional PCMS are implemented in the future and further analysis allows for greater understanding of the differences in pedestrian and bicycle travel, CDOT may seek to develop mode-specific factor groups.

Counters at sites that do not meet the criteria for an index site should be relocated unless there are other compelling reasons to leave them in operation. These counters can be more effectively used at other sites, which can be identified through a review of data from past or future SDCs.

A final consideration in the analysis of potential index sites is whether a location is within the mountainous region of the state. Due to colder weather in these areas, bicycle travel is limited throughout much of the year. As a result, mountain locations should not be used as index sites for statewide purposes. Conversely, non-mountain index sites should not be used to develop annual estimates for SDCs from mountain locations. The development of a unique factor group for mountain locations is needed to address this problem.

Although mountain sites may show differing hourly and daily patterns, development of a single mountain factor group is most feasible, unless a significant number of new PCMS could be implemented in mountain locations. Out of the sites identified as potential index sites in Table A-5, the Copper Mountain and Steamboat Springs (Yampa St.) locations (B90015 and B90019) should be considered as candidates for development of a mountain factor group. The other Steamboat Springs location (B90003) may also warrant consideration as the observed daily volume (92) is near the threshold for suitability as an index site. Table A-6 summarizes the classification of existing PCMS, including consideration of mountain locations.

Table A-6. Summary of Permanent Continuous Monitoring Sites by Factor Group and Index Site Suitability

FACTOR GROUP	COUNT LOCATIONS	HIGH VOLUME (DAILY AVG. >250)	MODERATE VOLUME (DAILY AVG 100-249)	STATEWIDE INDEX SITES	MOUNTAIN INDEX SITES
Commute	2 (1)	0	0	0	0
Non-commute	8 (2)	1 (1)	5	5	1
Mixed	14 (1)	5 (1)	1	5	1

Note: Mountain locations are indicated in parentheses.

Factoring Methods

There are several approaches to factoring SDCs, and a consensus has not been reached on the appropriate method for bicycle and pedestrian counts. Whereas extensive research has been conducted on motor vehicle count factoring approaches, the same cannot be said for bicycle and pedestrian counts. Initial attempts at factoring bicycle and pedestrian counts have been modeled after approaches used for motor vehicle counts, particularly seasonal factoring. Recent research indicates that day-of-year factoring provides more accurate annual estimates, but has more stringent data requirements and may not be well suited for application on a statewide basis.[1] Both methods are described briefly below:

- **Day-of-week and month-of-year (seasonal) factoring**: This factoring method is based on the idea that annual travel patterns follow a predictable distribution throughout the year. For example, it may be the case that the daily volume of traffic on Saturdays and Sundays in July is typically three times the annual daily average. This ratio could then be used to annualize a SDC conducted over a weekend in July. For longer SDCs, such as a week or two weeks, the ratio of average monthly daily traffic to average annual daily traffic could be used to develop annual estimates. The seasonal factoring approach is fairly straightforward; however, it does not account for unique weather events. As a result, special attention should be paid to weather conditions during SDC deployment. Development of annual estimates from SDCs conducted during unusual weather events is not recommended.

- **Day-of-year factoring**: The day-of-year factoring method is a relatively recent innovation. Compared to the seasonal method, it has been shown to produce more accurate annual estimates, as it accounts for unique weather events that can significantly impact bicycling and walking. The method requires a full year of data from a comparable site to be used for factoring SDCs. The comparison site must not only be within the same factor group, but should also be within the same region in order to ensure weather patterns are comparable. Provided these criteria are met, SDCs conducted over a given time period can be annualized by developing a ratio of observed volume from the SDC to the observed volume at the comparison PCMS over the same time period, and multiplying that value by the PCMS annual total for that year. Further research and experimentation is needed to determine whether, and in what circumstances, the day-of-year factoring method should be used by CDOT.

Regardless of which factoring method is used, it is important to acknowledge the limitations of developing annual estimates from SDCs. All factoring methods result in estimates with a margin of error. To minimize this error, SDCs should be conducted over longer time periods whenever possible. One week is thought to be a reasonable minimum length, but sites with lower volume may require longer counts to obtain reliable estimates. The following resources provide a more thorough discussion of factoring methods:

- FHWA. Traffic Monitoring Guide. 2013.
  https://www.fhwa.dot.gov/policyinformation/tmguide/tmg_fhwa_pl_13_015.pdf

- Nordback et al. Exploring Pedestrian Count Procedures: A Review and Compilation of Existing Procedures, Good Practices, and Recommendations. 2016.
  http://www.fhwa.dot.gov/policyinformation/travel_monitoring/pubs/hpl16026/hpl16026.pdf

- Nordback and Sellinger. Methods for Estimating Bicycling and Walking in Washington State.
  http://www.wsdot.wa.gov/research/reports/fullreports/828.1.pdf

- Minge et al. MnDOT Bicycle and Pedestrian Data Collection Manual - Draft. 2015
  http://www.dot.state.mn.us/research/TS/2015/201533.pdf

- Ryus et al. NHCRP Report 797: Guidebook on Pedestrian and Bicycle Volume Data Collection.
  http://www.trb.org/Publications/Blurbs/171973.aspx

1 NHCRP Report 797: Guidebook on Pedestrian and Bicycle Volume Data Collection. 2014.

APPENDIX B: PEDESTRIAN AND BICYCLE VOLUME DATA COLLECTION TOOLKIT

Purpose of the toolkit

Developing a systematic approach to collecting pedestrian and bicycle volume data is a complex process that requires a range of tools to address the unique characteristics of active transportation. Transportation agencies have already developed robust systems for monitoring vehicle travel along the highway system and it is useful to model pedestrian and bicycle data collection around these lessons. However, there are a number of factors that require special attention to adapt appropriate technologies to effectively collecting pedestrian and bicycle volume data.

The nature of bicycling and walking poses some unique challenges in terms of detection based on user behaviors and facility types. Motor vehicles are all designed within a vehicle code that governs size, weight and performance, while people and their bicycles varied in sizes, attributes and capabilities. Additionally, there are less often less defined travel ways for bicyclists and pedestrians. Bicycling and walking along a shared-use pathway is easy to define and monitor, but the mix of sidewalks, often on two sides of a roadway, and on-street bicycle facilities that range from being fully separated from motor vehicle traffic to shared traffic roadways. These varied conditions require a flexible approach to data collection and a solid understanding of which technology is appropriate for specific conditions

Because of these challenges, there is no single-solution count device that can address the needs of systematic pedestrian and bicycle volume data collection. Rather a combination of technologies will need to be utilized in tandem to provide effective coverage of the varied user and facility types in Colorado.

This toolkit provides an overview of current technology, as identified in the recent NCHRP 797 “Guidebook on Pedestrian and Bicycle Volume Data Collection.” The following section describes the factors and considerations that help determine the best approach and appropriate technologies for planning and implementing an effective bicycle and pedestrian count system. The toolkit is not prescriptive, rather it is intended to provide a range of options to allow CDOT to best consider which tools and technologies will best suit the program needs moving forward.

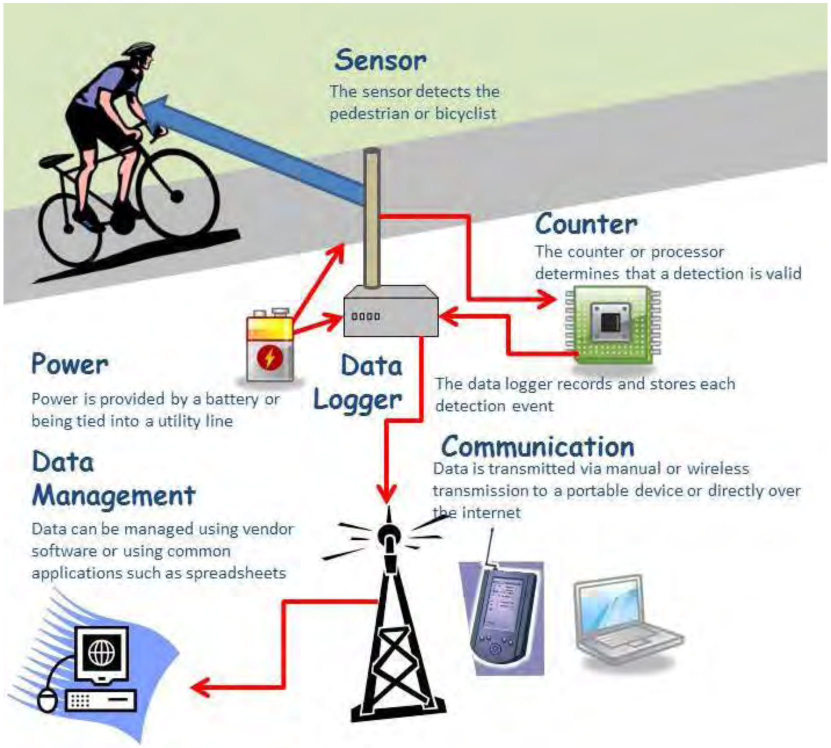
Understanding Count Technology

With the exception of manual counts (data collected manually by human observers in the field), all pedestrian and bicycle count technologies are comprised of components that sense, process, classify, store, and transmit data. Understanding these elements is helpful in evaluating the characteristics of various technologies and understanding the trade-offs associated with each.

The following is a brief description of the key components of automated pedestrian and bicycle counters:

- **Sensor** – The sensor is the external detection element of the device. For pedestrian and bicycle counters sensors include active or passive beams, video, pneumatic tubes, or imbedded loops or strips. The sensor receives input as pedestrian and bicycle traffic encounters the detection zone.
- **Count Processor** – The processor is the brains of the technology that processes the detected information and classifies count events based on the parameters of the equipment. Some processors simply detect motion or movement and record events, while others use a series of algorithms to interpret the events and determine attributes to classify or dismiss the data.
- **Data Logger** – The data logger is the storage unit for the device where the count data. Data may be stored by time stamp or in bins of 15 minute, hourly, or daily data. The storage capacity of the logger and the type of data determine the capacity for storing data over time. Some devices have limits to the maximum number of events or length of time that data can be collected and stored.
- **Data Transmission** – All count devices need to be able to transmit the data collected, either by manual field data retrieval or by cellular (web-based) transmission. The type of

Figure A-1. Diagram of Basic Components of Automated Count Technology



data transmission is important in determining the schedule of maintenance and routine data collection that might be required for a device. A device that automatically transmits data to a web-host via cellular transmission will decrease the need to manually collect data in the field and allow for quality monitoring of daily activity to identify anomalies that may indicated device malfunctions. However, cellular transmission may also include costs for continuous transmission (similar to cellular phone plans) and contribute to battery fatigue for the device.

- **Power Source** – All detection systems require some form of power supply, which in most cases, is a battery with varied life based on the type of sensor, processing and transmission associated with the device. The type of power source, and longevity is a key consideration for longer-term and permanent count installations.
- **Data Management** – Many vendors include software and or web-based applications for managing the stored data. Data management and the available data formats is a key consideration in determining the appropriate technologies, particularly when combining numerous types of technologies, as required for systematic data collection.

Summary of Current Pedestrian and Bicycle Volume Data Collection Technologies

The following is a summary of currently available technologies and approaches for collecting pedestrian and bicycle volume data. Each includes a brief description and a table summarizing the various attributes and operational characteristics associated with the device. This summary is developed based on the technology and not specific vendor products.

There do exist some features and capabilities with each technology that is vendor specific, and due to the rapid pace of research in this field, many new innovations and features continue to be developed. CDOT should seek to update the data included in the toolkit every few years to include these developments.

	MODE TYPE					FACILITY TYPE			
TECHNOLOGY	PEDESTRIAN AND BICYCLE MIXED	PEDESTRIAN AND BICYCLE BY MODE	PEDESTRIAN ONLY	BICYCLE ONLY	BICYCLE IN MIXED MOTOR VEHICLE TRAFFIC	SHARED USE PATH	SIDEWALK	ON-STREET BIKE LANE	ON-STREET MIXED TRAFFIC
Passive infrared detectors	●		●			●	●		
Active infrared detectors	●		●			●	●		
Radio beam detectors	●	●	●			●	●		
Pneumatic tubes				●	●	●		●	●
Inductive loop detectors				●	●	●		●	●
Piezoelectric sensors				●		●		●	
Automated video	●	●	●	●	●	●	●	●	●
Combination inductive loop/ infrared detectors	●	●	●	●		●	●		
Manual field data counts	●	●	●	●	●	●	●	●	●

Passive Infrared Detectors

Passive infrared (IR) technologies detect bicyclists and pedestrians by use of heat signature associated with human body temperature (Ryus, et al., 2014). Passive IR sensors are small and generally quite portable being typically installed along exclusive bicycle and/or pedestrian facilities. The sensors record bicyclists and pedestrians as mixed traffic and are unable to distinguish one from the other without combining other sensor technologies, such as inductive loops or pneumatic tubes to extract the number of bicyclists from the mixed traffic total.

Passive IR detectors are fairly common in use (Ryus, et al., NCHRP Web-Only Document 205: Methods and Technologies for Pedestrian and Bicycle Data Collection, 2014), due to the relative low cost and out-of-the-box capability. Passive IR counters are subject to undercounting due to occlusion (two or more bicyclists and pedestrians travelling side-by-side counted as one) that can be adjusted using correction factors (Ryus, et al., NCHRP 797 Guidebook on Pedestrian and Bicycle Volume Data Collection, 2014).

Figure A-2. Example of Passive IR Device Mounted at Sidewalk Location

Figure A-3. Field Data Collection from a Passive IR Counter

Table A-7. Passive Infrared Detectors

USER TYPES	
All Users	YES
Pedestrian Only	YES (Sidewalk locations)
Bicycle Only	
Pedestrian vs. Bicycle	
Bicycle vs. Motor Vehicle	
FACILITY TYPES	
Shared Use Path	YES
Sidewalk	YES
On-Street Bicycle Lane	
On-Street Mixed Traffic	
ADDITIONAL CHARACTERISTICS	
Direction of Travel	YES
Duration of Count	longer duration (2 weeks to continuous)
Portability	High
Site Preparation	Minimal (possible post installation)
Detection Width	up to 20’
Installation	Quick/some equipment mounting (hardware included)
Special Considerations	Sensitive to ambient background temperatures (uses human heat signature for detection)
	Install on an exclusive pedestrian walkway for “pedestrian-only” data
	Sensor should be mounted at the edge of path about between 30 to 40 inches above ground (some overhead models available)
	Sensor should be directed perpendicular to the path of travel
Things to avoid	Directing sensor at doors, windows, or metallic surfaces in direct sunlight
	Directing sensor at vegetation or objects prone to movement
	Locations where pedestrians are likely to linger (bus stops, entryways, kiosks, etc.)
	Locations where snow storage or debris may block sensor

Active Infrared Detectors

Active infrared (IR) devices operate similar to Passive IR, with the exception that the sensor beam is sent between two devices (sender and receiver), sensing bicyclists and pedestrians when the beam transmission is broken. Like, Passive IR devices, Active IR detectors can collect bicycles and pedestrians as mixed traffic, but cannot distinguish mode classification without the use of second detectors, and are subject to undercounts due to occlusion.

Table A-8. Active Infrared Detectors

USER TYPES	
All Users	YES
Pedestrian Only	YES (Sidewalk locations)
Bicycle Only	
Pedestrian vs. Bicycle	
Bicycle vs. Motor Vehicle	
FACILITY TYPES	
Shared Use Path	YES
Sidewalk	YES
On-Street Bicycle Lane	
On-Street Mixed Traffic	
ADDITIONAL CHARACTERISTICS	
Direction of Travel	YES
Duration of Count	longer duration (2 weeks to continuous)
Portability	High
Site Preparation	Minimal (possible post installation)
Detection Width	up to 20’
Installation	Quick/two mounting locations perpendicular to path of travel
Special Considerations	Sender receiver mounted perpendicular to path of travel
	Install on an exclusive pedestrian walkway for “pedestrian-only” data
Things to avoid	Locations where any motorized traffic can travel between the sender/receiver
	Locations where pedestrians are likely to linger (bus stops, entryways, kiosks, etc.)
	Locations where animals are likely to encounter the sensor
	Locations where snow storage or debris may block sensor

Radio Beam Detectors

Radio beam devices use radio wave signals sent between devices (sender and receiver) mounted on opposite sides of a walkway or path. The operational characteristics are similar to the Active IR, in terms of recording events based on breaks in the beam. Radio beam detectors are only capable of classifying direction when a multiple frequency model is used, which reduces the maximum detection distance from 20 to 13 feet (Ryus, et al., NCHRP 797 Guidebook on Pedestrian and Bicycle Volume Data Collection, 2014).

Table A-9. Radio Beam Detectors

USER TYPES	
All Users	YES
Pedestrian Only	YES (Sidewalk locations)
Bicycle Only	
Pedestrian vs. Bicycle	Some two-frequency models
Bicycle vs. Motor Vehicle	
FACILITY TYPES	
Shared Use Path	YES
Sidewalk	YES
On-Street Bicycle Lane	
On-Street Mixed Traffic	
ADDITIONAL CHARACTERISTICS	
Direction of Travel	Some two-frequency models
Duration of Count	longer duration (2 weeks to continuous)
Portability	Moderate (requires sender and receiver mounting)
Site Preparation	Minimal (possible post installation)
Detection Width	Up to 20’ (single frequency) 13’ (multiple frequency)
Installation	Quick/two mounting locations perpendicular to path of travel
Special Considerations	Sender receiver mounted perpendicular to path of travel
	Install on an exclusive pedestrian walkway for “pedestrian-only” data
	Use of multi-frequency models can allow for distinguishing pedestrians from bicycles and travel direction
Things to avoid	Locations where any motorized traffic can travel between the sender/receiver
	Locations where pedestrians are likely to linger (bus stops, entryways, kiosks, etc.)
	Locations where animals are likely to encounter the sensor
	Locations where snow storage or debris may block sensor

Pneumatic Tubes

Pneumatic tubes are appropriate for bicycle-only data collection, as they do not detect foot traffic. The pneumatic tubes used to collect bicycle data operate similar to traditional pneumatic tubes for motor vehicles, whereby two tubes are stretched across the travel way and detect the pulse of air pressure caused by traveling over the tube. There are additional types of pneumatic tube technology appropriate for collecting bicycle data in mixed-vehicle traffic situations, where data is processed based on force of the pulse and rate between two tubes to classify bicycles from motor vehicle traffic.

Pneumatic tubes can be ideal for short duration counts, as they are portable and relatively easy to deploy. Due care should be used to avoid damage from vandalism or routine maintenance, such as street-sweeping or snow plowing. Pneumatic tubes are not appropriate for data collection during the snow season.

Figure A-4. Pneumatic Tube Installation

Figure A-5. Pneumatic Tube Installation on a Bicycle Lane

Table A-10. Pneumatic Tubes

USER TYPES	
All Users	
Pedestrian Only	
Bicycle Only	YES
Pedestrian vs. Bicycle	
Bicycle vs. Motor Vehicle	YES
FACILITY TYPES	
Shared Use Path	YES
Sidewalk	
On-Street Bicycle Lane	YES
On-Street Mixed Traffic	YES
ADDITIONAL CHARACTERISTICS	
Direction of Travel	YES
Duration of Count	Short duration (several days to a month)
Portability	High
Site Preparation	Minimal
Detection Width	up to 20'
Installation	Quick/some equipment mounting; staking tubes
Special Considerations	Surface of detection area should be relatively flat and perpendicular to travel flow
	Specific procedures for shared roadways vs. bike lanes or shoulders
	Not appropriate for use during snow season
	Sometimes prone to vandalism, or avoidance where tubes are installed conspicuously. Additional installation equipment (tools) needed
Things to avoid	Locations where stopping may occur (intersections, traffic control locations, etc.)
	Locations where vehicles may park or trucks may load/unload (parking areas, bus stops, loading zones, etc.)
	Locations where vehicles may park or trucks may load/unload (parking areas, bus stops, loading zones, etc.)
	Installation in locations or in ways that may cause bicyclists to navigate around the tubes

Inductive Loop Detectors

Inductive loops are also a bicycle-specific data collection technology. Like traditional loop detectors used for signal detection and volume data collection, inductive loops are imbedded into the travel way using diamond-shaped pavement cuts. The sensors detect the presence of metal parts of a bicycle to classify count events. Many inductive loops can work in both shared-use path and on-street mixed traffic situations. Inductive loops are not re-usable so only suitable for permanent count locations. Because the loops use magnetic fields for detection they are sensitive to utility lines, either overhead or buried, so careful planning is needed to avoid installation in locations where the devices will not function properly.

Figure A-6. Installing an Inductive Loop Detector in Minneapolis, MN

Figure A-7. Example of Inductive Loop on Shared Use Path

Table A-11. Inductive Loop Detectors

USER TYPES	
All Users	
Pedestrian Only	
Bicycle Only	YES
Pedestrian vs. Bicycle	
Bicycle vs. Motor Vehicle	YES
FACILITY TYPES	
Shared Use Path	YES
Sidewalk	
On-Street Bicycle Lane	YES
On-Street Mixed Traffic	Sometimes depending on site conditions
ADDITIONAL CHARACTERISTICS	
Direction of Travel	YES
Duration of Count	Continuous permanent counts
Portability	None (One-time permanent installation)
Site Preparation	Surface and utility considerations (requires pavement cut)
Detection Width	Up to 20’
Installation	Requires work crew to install (pavement cutting; manhole for logger)
Special Considerations	Best in locations with predictable path of travel for bicycle traffic (bike lane; path, etc.)
	Presence of overhead or buried utilities may interfere with the inductive loop
	May require permitting
	Temporary or “surface Loops” are available to avoid cuts where needed (less permanent installation)
Things to avoid	Locations with overhead or buried utilities
	Locations where bicyclists may ride outside of the loop detector

Piezoelectric Sensors

Piezoelectric devices consist of two strips imbedded in the pavement perpendicular to travel that emit pulses that are altered as bicycle pass over the two sensors. The devices are capable of measuring bicycle volume, direction and travel speeds. The technology is not widely used in North America, possibly due to the complexity of installation that includes high precision cuts and installation of a utility box to house the processing and data storage equipment. The sensors are limited to detecting bicyclists and not appropriate for on-street mixed traffic locations.

Figure A-8. Piezoelectric Sensor in Arlington, VA

Table A-12. Piezoelectric Sensor

USER TYPES	
All Users	
Pedestrian Only	
Bicycle Only	YES
Pedestrian vs. Bicycle	
Bicycle vs. Motor Vehicle	
FACILITY TYPES	
Shared Use Path	YES
Sidewalk	
On-Street Bicycle Lane	Only locations where vehicles cannot travel in lane
On-Street Mixed Traffic	
ADDITIONAL CHARACTERISTICS	
Direction of Travel	YES
Duration of Count	Continuous permanent counts
Portability	None (permanent)
Site Preparation	Surface and utility considerations (requires pavement cut, and installation of utility box)
Detection Width	Up to 20’
Installation	Requires precision cut installation including utility box for storing logger
Special Considerations	Appropriate for locations where motor vehicles are prohibited
	May require permitting
	Install perpendicular to bicyclist path of travel
Things to avoid	Locations where motor vehicles may travel across sensor

Automated Video

Automated video is an emerging technology that utilizes algorithms to process video data and classify moving objects. Most market-available technology requires that video data be submitted to a vendor to be processed and returned as data based on hourly rates. Because of the proprietary nature and need for third party processing the full accuracy and effectiveness of the technology is unknown. However, there is strong potential for the use of video, particularly for short-duration data collection events or where specific attributes, such as user movements or characteristics are desired. The ability to maintain the video data for further observation is a benefit, and many agencies may find value in collecting video data to reduce manually for project specific data collection applications.

Figure A-9. Installing a Video Camera for Video Data Collection

Figure A-10. Video Cameras can be Mounted to Capture a Wide Area of Activity

Table A-13. Automated Video

USER TYPES	
All Users	YES
Pedestrian Only	YES
Bicycle Only	YES
Pedestrian vs. Bicycle	YES
Bicycle vs. Motor Vehicle	YES
FACILITY TYPES	
Shared Use Path	YES
Sidewalk	YES
On-Street Bicycle Lane	YES
On-Street Mixed Traffic	YES
ADDITIONAL CHARACTERISTICS	
Direction of Travel	YES
Duration of Count	Short Duration (up to 48 hours, depending on battery life and data storage of video equipment)
Portability	High
Site Preparation	Minimal/may require special mounting hardware and tamper resistant equipment
Detection Width	Up to 75' depending on quality of image
Installation	Quick/dependent on type of equipment used
Special Considerations	Mounts overhead at angle/ can be used for screenline or intersection counting
	High cost/hour of data collection, but with optimal attribution
	lighting and weather conditions can effect video image
	May be restrictions based on privacy concerns
Things to avoid	Locations with poor lighting conditions (glare, heavy shadowing, etc.)
	Locations where temporary obstructions may occlude data collection (delivery truck parking, etc.)

Combination Inductive Loop/Infrared Detectors

As mentioned previously with the description of the passive IR detectors, there are few devices capable of detecting bicycles and pedestrians and classifying by mode. One solution is the integration of multiple sensor devices, such as the Inductive loop and passive IR sensor at a single location. By integrating the two technologies the detector is able to obtain a total mixed traffic (bicycle and pedestrian) count and extrapolate the totals by mode by subtracting the bicycle only count from the loop detector. It is possible for agencies to deploy multiple devices to replicate this effort with post process analysis of data, but working with an integrated processor unit, it is possible to get the mode specific raw data from the count device. These are ideal solutions for shared use path locations.

Figure A-11. Combination Passive IR/Inductive Loop Detector in Delaware

Table A-14. Combination Device (Loop & Passive IR)

USER TYPES	
All Users	YES
Pedestrian Only	YES
Bicycle Only	YES
Pedestrian vs. Bicycle	YES
Bicycle vs. Motor Vehicle	
FACILITY TYPES	
Shared Use Path	YES
Sidewalk	Where bicyclists use sidewalks
On-Street Bicycle Lane	
On-Street Mixed Traffic	
ADDITIONAL CHARACTERISTICS	
Direction of Travel	YES
Duration of Count	Continuous permanent counts
Portability	None - Permanent
Site Preparation	Surface and utility considerations (requires pavement cut and post installation)
Detection Width	Up to 20’
Installation	Requires work crew to install (pavement cutting; post installation for passive IR sensor and logger)
Special Considerations	Best in locations with predictable path of travel for mixed traffic (pinch points or bridge approaches best)
	Presence of overhead or buried utilities may interfere with the inductive loop
	May require permitting
Things to avoid	Locations with overhead or buried utilities
	Locations where pedestrians and bicyclists may travel outside of the loop detector or sensor

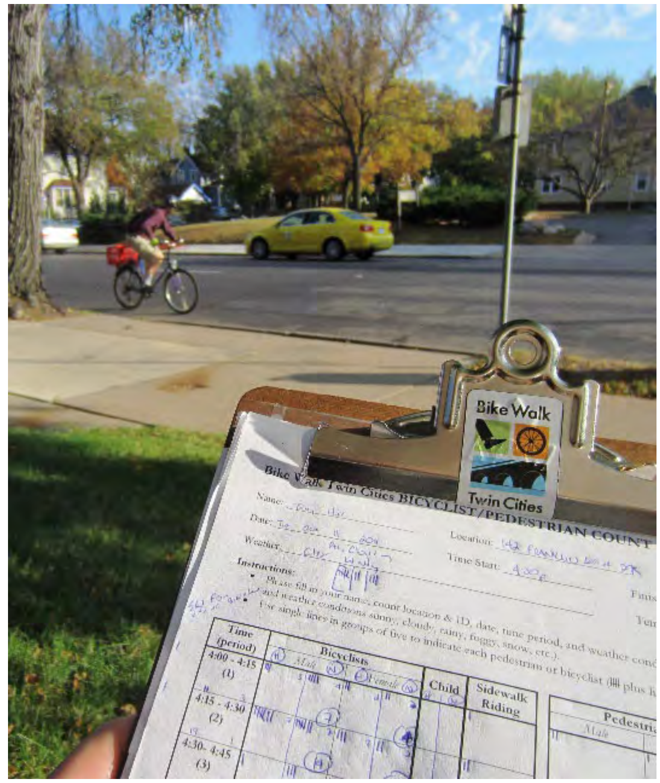
Manual Field Data Counts

While not actually a technology, Manual counts are an important tool for collecting pedestrian and bicycle volume data. Since the development of the ITE Bicycle and Pedestrian Documentation project[1], numerous agencies have initiated manual count programs as an entry point to developing a better understanding of bicycle and pedestrian travel in their respective communities. These efforts are conducted under a number of protocols for how to count, when to count and for what duration. Generally conducted in two to four hour intervals focused on peak travel hours and weekday traffic, manual counts are useful for developing baseline user information about pedestrian and bicycle travel.

Manual counts can be quite resource intensive when considering the training of field data collectors, observation time, and data entry. Additionally human factors can limit the accuracy and duration of counts (due to fatigue). Additionally it is important to consider the safety and comfort of manual observers when performing field counts.

Other benefits of manual counts are the ability to observe user behaviors and attributes (such as wearing helmets, using headlights, walking with aid of assistive devices, bicycling on sidewalks, etc.) that are not readily identified through automated technologies. While automated technologies are essential for collecting the long duration data and understanding the temporal and seasonal travel patterns, manual data remains an important tool for observing user behavior and even calibrating the automated count devices.

Figure A-12. Manual Count in Minneapolis,



1 http://bikepeddocumentation.org/

Table A-15. Manual Counts

USER TYPES	
All Users	YES
Pedestrian Only	YES
Bicycle Only	YES
Pedestrian vs. Bicycle	YES
Bicycle vs. Motor Vehicle	YES
FACILITY TYPES	
Shared Use Path	YES
Sidewalk	YES
On-Street Bicycle Lane	YES
On-Street Mixed Traffic	YES
ADDITIONAL CHARACTERISTICS	
Direction of Travel	YES
Duration of Count	Short (two to four hours)
Portability	High
Site Preparation	None
Detection Width	Varies based on sightline
Installation	None
Special Considerations	Locations where observer can safely and comfortably track travel
	Locations need to be clearly defined with imaginary screenline (should document with site map)
	Locations where bicycle and pedestrian travel paths are predictable
Things to avoid	Locations where conditions for observer may be unsafe (due to traffic or environmental conditions)
	Locations where pedestrians or bicyclists may be inclined to take short cuts or avoid screen line
	Locations where pedestrians are likely to linger (bus stops, entryways, kiosks, etc.)

APPENDIX C: STAKEHOLDER SURVEY AND INTERVIEW RESULTS

Introduction

A survey and interviews were conducted to identify the needs and priorities for improving bicycle and pedestrian counting in Colorado. This appendix provides a summary of the findings from this outreach effort and provides a snapshot of count practices used by the Colorado Department of Transportation (CDOT) and other agencies throughout the state.

Data Collection

Stakeholder Survey

A survey was sent to 82 stakeholders on February 9, 2016, including staff within several CDOT divisions, local and regional organizations with counting programs, and others interested in collecting or using count data. The survey was administered online through Survey Gizmo and was open for two weeks to anyone with the link. A total of 46 surveys were completed for a 56 percent response rate. Representatives from the following agencies participated:

- CDOT (Division of Transportation Development, Region 2, Region 3)
- Colorado Department of Public Health and Environment (CDPHE)
- Aurora Police Department
- Boulder County Transportation and Environment
- City of Arvada
- City of Aurora
- City of Fort Collins
- City of Glenwood Springs
- City of Grand Junction
- City of Greeley
- City of Salida
- City of Steamboat Springs
- Town of Vail
- Town of Pagosa Springs
- Denver Parks and Recreation
- Denver Public Works
- Downtown Denver Partnership
- Kaiser Permanente
- North Front Range Metropolitan Planning Organization (NFRMPO)
- Grand Valley MPO (GVMPO)
- Denver Regional Council of Governments (DRCOG)
- Mesa County
- Summit County Open Space and Trails
- Jefferson County
- Pitkin County
- Colorado State University (CSU)
- Portland State University (PSU)
- Roaring Fork Transportation Authority (RFTA)
- Routt County Riders
- Swedish Medical Center
- Bicycle Colorado
- PeopleForBikes
- WalkDenver
- Wheat Ridge Active Transportation Advisory Team

The survey asked of respondents' awareness of CDOT's count program, impacts of the CDOT count data, an overview of existing manual and automatic count programs in their respective agencies, desired uses for data, obstacles to counting, and any assistance needed to begin or to be more effective in counting or using count data.

Stakeholder Interviews

Stakeholder interviews were conducted following the online survey. The goal of the stakeholder interviews was to gain a better understanding of current count programs and needs, as well as a broader perspective on how count data fits into the transportation planning process.

The following people were interviewed in March 2016:

- Jeff Sudmeier, CDOT Multimodal Planning
- Erik Sabina, CDOT Information Management

- Ben Beall, City of Steamboat Springs
- Aaron Buckley, NFRMPO
- Dean Bressler, GVMPO
- Brett Meredith, RFTA
- David Kemp, City of Boulder
- Jeremy Raw, Federal Highway Administration (FHWA) Central Office
- Alex Bettinardi, Oregon Department of Transportation (ODOT)
- Krista Nordback, Portland State University

This group of stakeholders was selected for their knowledge and understanding of CDOT's existing programs, their responses to the survey and use of count data (Steamboat Springs, GVMPO), representation of diverse agencies and count programs (NFRMPO, Boulder), provision of a researcher's perspective (PSU), their experience as a state DOT using user-generated data (ODOT), or their interest in using CDOT count data (FHWA). The following section outlines the information gathered through these conversations.

Survey and Interview Findings

Key Findings

The stakeholder outreach conducted for this project provides a thorough understanding of CDOT's existing non-motorized count program, as well as activities undertaken by other agencies throughout the state. Additionally, survey respondents and interviewees have identified several needs and priorities for improving count data collection in Colorado. The key findings are summarized here and explained in greater detail in the following section. Awareness of CDOT's non-motorized count program is generally good, but there is less understanding of the details of the program and how stakeholders may benefit or contribute.

- Both manual and automated count methods are used, though more agencies use automated methods.
- A wide variety of data storage formats are used, which presents challenges for data sharing and transferability of analysis approaches across jurisdictions and projects.
- Agency count programs are generally funded through existing programs and projects. Staff time is the largest expense.
- The majority of counting is tied to projects and is completed on an as-needed basis. Monitoring trends is another common use and is a goal for most programs.
- Count data has been successfully used to support grant funding applications and to demonstrate the value of infrastructure improvements.
- Count data supports evaluation of progress toward broader agency or community goals, such as changes in mode split/reduced automobile travel, walking or biking to school, improved health outcomes, or increased recreational activity.
- Challenges related to non-motorized counting programs in Colorado include lack of strategic direction, limited staff time, equipment or maintenance costs, lack of understanding about count technologies and implementation practices, decentralized data storage and different data formats, and lack of data quality control measures.
- There is a need for both short-duration and long-term counts to support a variety of uses.
- Due to inherent challenges in collecting count data, other data sources should be explored including crowdsourced data; however, consideration should be given to privacy and potential biases that may arise with the use of new data sources.
- A centralized data sharing system would be highly valuable for agencies across Colorado.
- Technical assistance is needed to help agencies establish or improve their count programs.

Awareness and Use of CDOT's Count Program

The vast majority of survey respondents (92 percent) are aware that CDOT collects non-motorized counts. Fifty-six percent have requested or used CDOT data. Of those who have not, it was due to being unaware of the option (28 percent) and being unclear on how to use the count data (11 percent).

Despite relatively high awareness of CDOT's non-motorized count program, there is uncertainty surrounding the details of the program, such as how to obtain counts at specific locations and whether or not counts exist in certain geographic areas (e.g., "Frontage Roads and Vail Pass" or "locations of interest," said a respondent from Pitkin County and an advocate from Denver, respectively).

Overview of Other Count Programs and Data

In addition to asking respondents about their understanding of CDOT's count program, several survey questions were asked to gain a better understanding of the count programs managed by other agencies. Non-CDOT program details were also explored in the subsequent interviews.

Current Count Practices

The overall approach to non-motorized counting (manual or automated) as well as the specific technology used has significant implications for what types of data can be collected, their reliability, and how they may be used. There is great variation in count practices across the state, though there are some common themes:

- More organizations use automatic counts than manual counts (67 percent versus 50 percent of those who collect non-motorized counts). This may be due to a lack of staff time/resources or may reflect a preference for longer duration counts. At least one community (Boulder) conducts automatic counts for the AM and PM peaks.
- Tube counts are the most common automated count technology in use (41 percent), followed by passive infrared (35 percent), then active infrared (29 percent).
- Of the agencies that are doing manual counts, the majority are counting on both trails and streets. Automatic counts are more common on trails (67 percent).
- The majority of counting is performed to evaluate projects, such as before and after counts for a new trail or set of bike lanes, and is completed on an as-needed basis.
- Some agencies conduct a mix of short-duration and long-term counts.

Data Storage

Non-motorized count data storage is an important topic as all count collection efforts, and especially automated counters, generate large amounts of data. Processing and analyzing this data can be a barrier for some agencies, although most equipment vendors also provide software to facilitate these processes.

Of the survey respondents that do collect counts, 62 percent maintain a database of counts. Software programs reportedly used for data storage include:

- Microsoft Access
- EcoVisio and TDMS by MS2
- Microsoft Excel
- GIS
- Google Docs
- PostgreSQL
- Trafx Internet software, which converts into Excel

The pedestrian advocacy organization, WalkDenver, has helped develop WALKscope data which is stored on their website for anyone to download as a CSV or shapefile. Technically, WALKscope does not include bicycle and pedestrian volume data, but an analysis of the walking network and environment.

Agencies interviewed also noted that their approach to data storage has evolved over time and that multiple file types may be used by a given agency. For instance, prior to last year, RFTA downloaded count data from TrafX as a text file and stored it in Excel. In 2015 they purchased the Data Net system from TrafX when they bought new counters, so they now use Excel files, text files, and TrafX Data Net. Other agencies, including Boulder and GVMPO, develop reports for count data collected on a project-specific basis. This data is then shared across the agency or with other stakeholders using shared drives or by email. Interestingly, Boulder's permanent count sites began as project-based count sites.

Cost

Interviewees were asked for an approximation of their annual budget for non-motorized data collection or an estimate of annual staffing time. No agency interviewed reported having a specific line item for counting as it has been incorporated into other programs and projects (Boulder, GVMPO), although some agencies monitor expenses for equipment and staffing commitments. Apart from the purchase of counters (the City of Boulder invested $25-30K in 2015 on counting equipment and the NFRMPO spent $19K in 2015 on five counters), staff time is the largest expense. The City of Boulder uses an outside contractor to conduct the majority of their counting, though they still use staff time to coordinate count efforts. RFTA estimates that their count efforts accumulate to only 22 hours per year, including data harvesting two or three times each year plus roughly ten hours to work with the data. The City of Steamboat Springs uses summer interns to conduct counts. The City does not have a price estimate for counts that are conducted as part of other studies.

Use of Count Data

Survey and interview questions were aimed at understanding the uses of count data to learn how count data relates to the mission, goals, and decision-making within agencies.

Project Evaluation and Justification

Based on the survey results, the most common use of non-motorized count data is to gain a better understanding of existing levels of bicycling and walking in relation to specific infrastructure projects. For example, CDOT indicated it used count data to support development of a TIGER II grant application for the I-70B Grand Junction - 24 3/4 Road to Rimrock Avenue Reconstruction Project. Similarly, count data demonstrating use of the Colorado Riverfront Trail is being used on an on-going basis by the City of Grand Junction to maintain and build support for future projects to complete the few missing sections of the riverfront trail.

Additional examples of how non-motorized volume data was used to support new bicycle and pedestrian projects:

- City of Denver, Public Works: Bike counts have helped demonstrate whether additional bike and pedestrian facilities should be included in project scopes.
- City of Aurora: Installation of bicycle detection at an intersection was in direct response to data collected at East 6th Avenue and Vaughn Street.
- City of Steamboat Springs: Non-motorized needs were considered for the Yampa Street Improvements project and will be considered for a larger Downtown Improvement project that the City will be working on over the next three years. The Yampa Street counter averaged 368 bicycles per day in 2015 according to the CDOT counting unit. The peak day counted 1,786 bicyclists.

Mission/Goals

Non-motorized count data supports the evaluation of progress toward broader agency and community goals. These can include goals related to changes in mode split/reduced automobile travel, walking or biking to school, improved health outcomes, or increased recreational activity. The City of Boulder noted that non-motorized count data relates back to the Transportation Master Plan goal of increasing bicycling, walking, and transit. Count data allows the City to justify its programs and show the change in mode split. The City of Steamboat Springs has also used count data to support area plans, sidewalk plans, the Community Plan, and the City's Circulation Plan.

RFTA offers another perspective on using non-motorized data to support agency goals. Although RFTA is a transportation authority and is a bus service provider first and foremost, they are also interested in improving bus-to-trail options. The Rio Grande Trail enhances people's mobility and one day may become a corridor for transit use. Therefore, trail count data helps RFTA to understand trail access to bus stops and other areas throughout the region.

Other Uses

While all survey respondents reported using non-motorized count data to support project-level decision-making, 75 percent also indicated monitoring volume trends as an important use of the data.

According to the survey results, non-motorized count data is not commonly being used in safety studies or research purposes in Colorado. However, Boulder data was used in a 2012 dissertation to better understand bicycle exposure data and cycling safety.[1]

Another use for non-motorized count data, indicated by CDOT staff, is to validate travel demand model outputs.

Challenges

Non-motorized count programs in Colorado and in

1 Nordback, Krista L. 2012. Estimating Annual Average Daily Bicyclists and Analyzing Cyclist Safety at Urban Intersections.

other states face several important challenges. Survey respondents listed staff time, equipment or maintenance costs, and a lack of understanding about count technologies as the top three obstacles to collecting counts. CDOT staff also noted an overarching challenge is that while there is a recognized need to obtain data for the whole state, it is also important that CDOT has the data needed to inform decisions surrounding state-maintained facilities. The interviews allowed people to further elaborate on these challenges.

The following specific challenges were noted in the surveys and interviews:

- **NFRMPO:** Lack of understanding of counting equipment, implementation practices, analysis techniques and data uses.
- **City of Boulder:** Counts are sporadic and infrequent; data storage is not centralized.
- **RFTA:** Low confidence in some automated counter results. Too difficult to validate data due to lack of benchmarks and appropriate comparisons; difficult to interpret count data in a bigger context, such as to understand trip patterns.
- **PSU:** Lack of protocols surrounding data quality control; integration of different data formats.

Feedback/Needs/Wants

Count Data Needs and Preferences

Interviewees were asked, "If you had to make a choice, would you rather have a lot of data at a few locations or a little data at many locations? Why?" and "In an ideal world, what non-motorized volume data would be available to you, and how would you access it?" Answers varied, though generally interviewees recognized the need to balance the various desired uses of count data with the resources available to collect and process data.

CDOT staff and others noted that non-motorized count data collection should in some ways be analogous to data collection for automobiles. This would allow CDOT to understand current usage levels, changes over time, and changes in types of use. Further, integration of non-motorized count data into the same data storage platforms as are used for other highway programs would offer the greatest benefit.

Respondents had varied opinions with respect to their preference for shorter counts at more locations versus longer counts at fewer locations. CDOT staff suggested that a more complete understanding of a few locations would be more valuable than a small amount of data at many locations. On the other hand, staff from NFRMPO and RFTA indicated a preference for collecting data at a large number of sites, with only a few continuous counters. While the scale of counting differs between an MPO and a state DOT, it is interesting to understand the types and volumes of data that are most valued between the different organizations. The City of Boulder recognized the challenge and importance of balancing these needs and that there is not a perfect solution. Permanent bike count stations throughout the community would help the City with enforcement, education, and encouragement, help show how biking is increasing or decreasing, and identify trends and high-use periods that are outside the traditional commuter peak periods.

Krista Nordback's research on bicycle crash rates in Boulder also highlights the importance of using a combination of permanent and short-duration counts. This research relied on continuous counters to establish adjustment factors and develop models that could then be applied to specific sites where three hour counts had been conducted. A challenge noted in this interview is that the geography and size of Colorado make development of a comprehensive count program difficult. The use of unconventional datasets such as crowdsourced data, wifi signals, and pedestrian push buttons was offered as a way of supplementing count data to provide a more complete picture of bicycle and pedestrian activity. These emerging topics areas are being explored; for instance, GVMPO has used Strava data (screenshots of high uses corridors) in its long-range planning efforts to demonstrate facility usage.

More advanced uses of Strava data are coming from ODOT who purchased a year's worth of Strava for $20,000. ODOT called this data both "helpful and impressive." The state only has three to four permanent counters so the Strava data has greatly augmented their count data. Strava data has helped the state in selecting locations for permanent counters and helped to verify trip patterns. It has also helped inform different conversations about bicycle usage and treatments (such as the use of rumble strips along state roads). It has also been used by Travel Oregon for scenic bikeway info. At present, cities and MPOs within Oregon have expressed an interest in using this data for their bicycle planning and ODOT plans to purchase more Strava data.

Outside of the data collection needs for its agency, RFTA identified a need for statewide information that could help RFTA place its counts into context and to demonstrate broader impacts of non-motorized modes, such as economic impacts. Several interviewees reported that web-based access to count data would be useful. Additionally, processing and analysis, such as heat maps would be useful, along with the ability to monitor statewide trends.

Desired Uses for Data

A survey question asked, "How would your agency be most likely to use pedestrian or bicycle count data?" The top answer was to track changes in bike/pedestrian travel volume over time. Other high priority data uses identified were for project prioritization and safety analyses, and developing risk/exposure rates based on travel volume.

CDOT expressed that count data would help the state establish high-use corridors, bike corridors, a bike network, and trend data. NFRMPO noted other possible uses would be to inform repaving or widening of bike facilities, helping with calls for projects and funding requests, and to demonstrate project impacts. Count data could also support broader travel demand management and city planning efforts, such as bike rack placement.

Data Sharing Desired

A total of 84 percent of survey respondents reported that their agency is interested in sharing count data to a central data repository. The City of Boulder would like to see the existing EcoVisio site opened to the public. It reported positive results from sharing count data related to an infrastructure project (Folsom Street project). The City purchased counters and allowed the public to log on and see what was happening in real time. Boulder also contributes to a research project being conducted at PSU, which is assembling count data from disparate sources. CDOT has also been invited to submit counts to this dataset. This approach may be worth exploring further to determine whether and how CDOT could benefit from participating or if there are lessons learned that could be incorporated into CDOT's internal efforts.

At a Federal level, FHWA will be encouraging states to submit non-motorized counts to its Travel Monitoring Analysis System (TMAS). Ultimately, this information will help states and FHWA integrate pedestrians and bicyclists into the performance-based planning process.

Assistance Needed

Survey respondents identified a need for several types of assistance as they seek to improve their count data collections programs. The survey asked, "What assistance would you need to begin or be more effective in collecting and using pedestrian and bicycle count data?" The top responses include:

- Access to a repository for collected data (56 percent)
- Support for developing reports and analyzing pedestrian and bicycle trends (53 percent)
- Training on data management and count analysis (53 percent)
- Training on data collection technologies (47 percent)
- Access to loaner equipment to collect data (47 percent)
- Program funding (47 percent)

The NFRMPO will be training representatives from each of their member jurisdictions on how to complete short-duration counts. Similarly, the City of Boulder has a training program for staff responsible for traffic data collection so that non-motorized counts are integrated into routine data collection. This program could serve as a model for other agencies around the state. Additionally, there are several publicly-available resources that can provide agencies with a good understanding of counting practices.