Bicycle and Pedestrian Data Collection Manual - Draft

Minnesota Department of Transportation

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Office of Transit, Bicycle / Pedestrian Section

bikepedcounts.dot@state.mn.us

www.dot.state.mn.us/bike

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The Minnesota Department of Transportation is developing a statewide bicycle and pedestrian data collection program. This manual summarizes main elements of this program, including data collection goals, types of data to collect and best practices for sensor calibration and data analysis. The research phase of the program is expected to be completed in 2016, at which time the manual will be updated and issued as a final document.

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Bicycle and Pedestrian Data Collection Manual - Draft

Prepared by:
Erik Minge
Cortney Falero
SRF Consulting Group, Inc.

Greg Lindsey
Michael Petesch
University of Minnesota, Humphrey School

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Mark Flinner, MnDOT Office of Transportation System Management, Planning and Data Analysis Section

Mary Jackson, MnDOT Office of Transit, Bicycle/Pedestrian Section

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1 INTRODUCTION

The Minnesota Department of Transportation's (MnDOT) bicycle and pedestrian data collection program is a collaborative program with state and local agencies to collect bicycle and pedestrian traffic counts throughout the State of Minnesota. The general goal is to inform transportation planning, engineering, and management. The data is being collected following the same principles and using approaches similar to those used in vehicular traffic data collection. State and local agencies, engineering consultants, and others can use these data for many purposes, including pre-post analysis of projects, performance management, evaluation of polices such as Complete Streets, safety and crash analyses. The bicycle and pedestrian data collection program focuses on collection of traffic volume data, not turning movement data. This document is a draft and is part of an ongoing research program. The final manual is expected to be published in spring 2016.

This document supplements the 2013 Federal Highway Administration (FHWA) Traffic Monitoring Guide (TMG) and the 2014 National Cooperative Highway Research Program (NCHRP) Report 797 Guidebook on Pedestrian and Bicycle Data Collection. These documents present state-of-the-art practices and provide guidance on monitoring alternative modes of transportation. The FHWA established the first set of guidelines of the smart means and practices for bicycle and pedestrian data collection in the 2013 TMG. Minnesota is putting these new guidelines to use in this manual.

Figure 1: Morning Commuters on the Midtown Greenway

1.1 Purpose

Collection of bicycle and pedestrian data is currently in its infancy in Minnesota and throughout the United States. However there is use for this data and a lot to be learned about these modes of transportation. Potential uses of bicycle and pedestrian count data include:

- Determine baseline volumes of bicycle and pedestrian activity
- Track changes in bicycle and pedestrian activity levels by time of day, day of week, season, and under various weather conditions
- Track bicycle and pedestrian related performance measures
- Inform the public about bicycle and pedestrian activity and trends
- Prioritize bicycle and pedestrian projects
- Conduct risk or exposure analysis
- Inform Road Safety Audits
- Inform Intersection Control Evaluations
- Evaluate the effects of new infrastructure on pedestrian and bicycle activity

- Measure facility usage
- Model transportation networks and estimate annual volumes
- Identify variations in activity based on location or facility type and calculate context-specific expansion factors
- Develop models to predict future bicycle and pedestrian volumes at different locations

MnDOT is currently developing plans for statewide bicycle and pedestrian monitoring at a number of locations throughout Minnesota. The approach will be based on the bicycle and pedestrian counting methods put forth in this manual and involves establishment of permanent, continuous monitoring stations at a limited number of locations throughout the state along with a larger number of short duration monitoring locations.

The purposes of the permanent monitoring stations are to track trends in traffic over time, to provide insight into exposure to risk for safety analyses, to identify patterns in traffic that can be used to interpret and extrapolate short duration counts into annual traffic estimates, and to develop performance indicators to track progress relative to MnDOT goals and objectives.

The purposes of short duration monitoring are to document variations in traffic volumes on different types of roads, to provide broad geographic coverage across the state, and to assist with evaluation of transportation investments and innovative safety treatments.

MnDOT Central Office will manage the deployment and data collection from the continuous monitoring installations. Local agencies and MnDOT District offices will conduct and manage short duration counts with technical assistance from MnDOT Central Office.

1.2 Scope

This manual describes the manner in which bicycle and pedestrian data is collected and recorded. It provides information on count types, site selection, and basic calculation and analytic techniques.

The following subjects are addressed for each type of data collection technology:

- Site Design
- System Installation
- System Calibration
- Data Collection
- Maintenance and Troubleshooting

None of these subjects is meant to be covered exhaustively, rather this manual provides an overview and a list of references that may be consulted for more in depth information. Additions and changes may be made to this manual as new equipment and methods for bicycle and pedestrian data collection become available.

Figure 2: Rural Mixed-use Path

2 GLOSSARY & ACRONYMS

2.1 Glossary

Adjustment factor – Factors are used to process the data collected. Adjustment factors are developed from a representative data set, often from data collected at continuous count stations (TMG 2013). In this manual adjustment factors are typically day-of-week and month-of-year factors which can be applied to short duration counts to extrapolate to annual average volumes. Expansion factors and extrapolation factors are types of adjustment factors.

Automated count – collection of traffic data with automatic equipment which continuously records non-motorized traffic flow. Automated methods of data collection include both permanent and portable counters.

Average bicycle traffic volume – the amount of bicycle traffic passing a given point on an average daily basis computed over 180 days during the months of April through September. MINN STAT. 169.011 (2014).

Annual Average Daily Traffic – the total volume of traffic on a given roadway for a year divided by 365 days. Many agencies use the terms ADT and AADT to define non-motorized volumes.

Average Daily Traffic – the total volume of traffic during a specified but arbitrary time period given in a whole day (24 hours), greater than one day, but less than one year divided by the number of days in the time period; abbreviated ADT. MINN STAT. 169.011 (2014).

Bicycle – (a) a device propelled by human power upon which a person or persons may ride, having two tandem wheels either of which is over 16 inches in diameter, and including any device generally recognized as a bicycle though equipped with two front or rear wheels. MINN STAT. 169.011 (2014).

(b) All pedal powered vehicles: including unicycles, tandem bicycles, recumbent bicycles, three-wheelers, tag-alongs, trailers, and pedicab. Each vehicle counts as one count (MnDOT Manual Count Program, 2014).

Bicycle lane – a portion of the roadway or shoulder designed for exclusive or preferential use by persons using bicycles. Bicycle lanes are to be distinguished from the portion of the roadway or shoulder used for motor vehicle traffic by physical barrier, striping, marking, or other similar device. MINN STAT. 169.011 (2014).

Bicycle path – a bicycle facility designed for exclusive or preferential use by persons using bicycles and constructed or developed separately from the roadway or shoulder. MINN STAT. 169.011 (2014).

Bicycle route – a roadway or shoulder signed to encourage bicycle use. MINN STAT. 169.011 (2014).

Bikeway – a bicycle lane, bicycle path, or bicycle route, regardless of whether it is designed for the exclusive use of bicycles or is to be shared with other transportation modes. MINN STAT. 169.011 (2014).

Commute-mixed traffic – a facility that has similar volumes of traffic on weekdays and weekends with morning and evening peaks that do not indicate typical commuting.

Commuter traffic – a facility that has morning and evening peaks Monday through Friday and typically has higher use on weekdays than weekends.

Complete Streets – roadway planning tool used to help maximize the use of public roadways and right-of-way in order to provide a comprehensive and connected multimodal transportation system. This includes development of fully integrated transportation networks that accommodate bicyclists and pedestrians.

Continuous – count sites equipped with permanently installed automated counting sensor that collects data 24 hours a day, 7 days a week, 365 days a year. Ideally these count locations collect data every day, but due to equipment failure or other unforeseen impacts such as weather, there can be gaps in the data.

Cordon – vehicle and person surveys that provide time series data of traffic flow across a given set of screen lines (Source: adapted from the website of the New York Department of transportation Cordon Count Program)

Coverage counts – short duration counts that cover many different areas in a region. This data may often supplement continuous traffic counts.

Index locations – index locations are count locations that are selected to be illustrative of the counts statewide. These sites are not fully representative or inclusive of every roadway nor are they a statistically random sample. MnDOT is using this approach for establishing statewide trends.

Intersection counts – counts conducted where non-motorized facilities cross another facility of interest.

Manual count – method of counting by observation of number, classification and direction of travel. This counting may be performed in person at the site or by analyzing video. Data is typically tracked using a tally sheet or an electronic counting board.

Multipurpose-mixed – a facility that experiences higher volumes on weekends, although weekday traffic patterns show typical commuting peaks.

Multipurpose traffic – a facility with traffic volumes that peak during the afternoon and evening hours and have similar weekday and weekend traffic patterns with a slightly higher usage on weekends.

Peak volume – refers to when the highest traffic volumes are generated.

Pedestrian – (a) any person afoot or assisted. MINN STAT. 169.011 (2014).

(b) Any person afoot or assisted including walkers, joggers, skaters, Segways, wheelchairs, strollers, crutches, scooters, children being carried, and person walking a bicycle. MN state statutes definition of pedestrian does not classify skaters (inline, traditional, board) as pedestrians, but they are placed in this category for the purpose of this manual (MnDOT Manual Count Program, 2014).

Project counts – these counts are taken before and after construction projects to support planning and forecasting efforts and/or to determine the effectiveness of new infrastructure.

Screen line - imaginary line typically drawn along features such as rivers or railways at mid-block. Since these areas have a minimum number of crossing points it is more manageable to count traffic going from one side to the other. Although these are spot counts they are often applied to the full segment length to calculate pedestrian – miles traveled and bicycle – miles traveled (TMG, 2013).

Short duration – count sites that are either manual or automated counting locations that collect data for a specific period of time. Count durations can be anywhere from several hours to several weeks.

Stanchion – a sturdy upright fixture that provides support for some other object.

Traffic – pedestrians, ridden or headed animals, vehicles, streetcars, and other conveyances, either singly or together for purposes of travel. MINN STAT. 169.011 (2014).

Vehicle – every device in, upon, or by which any person or property is or may be transported or drawn upon excepting devices used exclusively by stationary rails or tracks. MINN STAT. 169.011 (2014).

2.2 Acronyms

ADT – Average Daily Traffic

AADT – Annual Average Daily Traffic

FHWA – Federal Highway Administration

MnDOT – Minnesota Department of Transportation

NBPD – National Bicycle and Pedestrian Documentation Project

NCHRP– National Cooperative Highway Research Program

TEM – Traffic Engineering Manual

TMG – Traffic Monitoring Guide

UMN – University of Minnesota

3 GENERAL PRINCIPLES

3.1 Bicycle and Pedestrian Data Collection Intended Audience

This manual provides guidance and methods for collecting bicycle and pedestrian data in Minnesota. This manual will be useful for MnDOT employees and other transportation professionals. This manual was created for individuals that range from experienced to those new to bicycle and pedestrian data collection. The following transportation professionals and entities can benefit from the information presented in the manual.

- City Planners and Engineers
- County Planners and Engineers
- State Planners and Engineers
- Health Professionals
- Department of Natural Resources
- Parks and Recreation Departments
- Traffic data collection practitioners
- Traffic data collection managers and staff
- Traffic operations practitioners
- Transportation agencies
- Transportation researchers
- Traffic detector vendors

Figure 3: Bicycles and Pedestrian on Mixed-use Path

3.2 Bicycle and Pedestrian Data Collection Attributes

Bicycle and pedestrian data is founded on the basic principles of motor vehicle traffic data collection. However, there are some key differences. Some of these differences include:

- Non-motorized volumes are more variable than motor vehicle volumes
- Bicycle and pedestrian trips tend to be shorter
- Experience with bicycle and pedestrian counting technology is more limited than motorized vehicle detection technology
- The scale of data collection is typically smaller than for motorized vehicles
- Non-motorized traffic typically has higher use on lower functional class roads and streets as well as shared use paths and pedestrian facilities
- Motorized vehicles tend to be easier to detect than bicycle and pedestrians
- Non-motorized travel is less confined to a fixed lane or path and sometimes makes unpredictable movements
- Bicycles and pedestrians sometimes travel in closely spaced groups which can result in counting errors
- Bicycles and pedestrians travel patterns are affected by weather more so than vehicular travel patterns
- Technologies for counting bicyclists and pedestrians are still evolving

3.3 Types of Data Collection

Annual average daily traffic (AADT) has traditionally been one of the main parameters for measuring motorized vehicular traffic. Bicycle and pedestrian volume metrics such as average daily traffic (ADT), AADT and peak volume provide information for traffic pattern modeling and expansion factors creation. Detailed volume data provides needed information on trails and other facilities to show variations in non-motorized traffic volume based on day, time of day, day of week and time of year. This data is valuable for prioritizing investments to the transportation system.

Determining which method and type of data collection to perform is the first step in facilitating the determination of ADT, AADT, and peak volume. The remainder of this section summarizes methods of counting, type of counting and travel patterns associated with bicycle and pedestrian data collection.

Figure 4: Bicycle Crossing Railroad Tracks

3.3.1 Methods for Counting Bicycle and Pedestrian Traffic

Methods for bicycle and pedestrian data collection include manual vs. automated and short duration vs. continuous counting (see the glossary for the definition of terms). Facility type, time of year and reason for collection will assist in determining type of count, length of deployment and which data collection technology is a good fit for the data collection needs.

3.3.2 Types of Counts

The two principal types of bicycle and pedestrian counts are volume counts and turning movement counts. Generally, volume counts are a measure of the number of bicycles or pedestrians that pass a screen line. Volumes may be taken on trail or street segments, or at intersections. Turning movement counts, on the other hand, record the number of bicycles or pedestrians that turn right, left or continue straight for each approach leg of an intersection. A full count at a four-leg intersection would generate four volume counts (one for each leg) and 12 turning movement counts (three for each leg). This manual focuses on volume counts that are taken when bicyclists or pedestrians cross screen lines in the location of interest.

The need for bicycle counts, pedestrian counts, or mixed-mode non-motorized counts are determined by the specific data collection need and facility type. Nationally, bicycle counts are more mature, more similar to motor vehicle counts, and have been studied and analyzed more than pedestrian counts. Currently MnDOT collects pedestrian data, but hopes to coordinate more closely with the MnDOT Pedestrian System Plan to enhance the value of collected data. Pedestrian counts are currently mostly used for warrants for crossings while mixed-mode non-motorized counts are used for trail usage. Bicycle counts are used for a variety of planning and design needs, similar to motorized traffic counts.

3.3.3 Peak Volume Determination

Peak volume is the highest traffic volume generated at a specific location. The hour in which peak volume occurs varies based on primary user, type of facility and adjacent land use. Additionally, weather events and time of year impact bicycle and pedestrian traffic in ways not typical of motorized traffic. Peak volume varies by type of non-motorized travel and location. MnDOT research has identified four distinct bicycle and pedestrian travel types, or patterns and are working to define more. These travel patterns include:

Commuter traffic – a facility that has morning and evening peaks Monday through Friday and typically has higher use on weekdays than weekends.

Commute-mixed traffic – a facility that has similar volumes of traffic on weekdays and weekends with morning and evening peaks that do not indicate typical commuting.

Multipurpose traffic – a facility with traffic volumes that peak during the afternoon and evening hours and have similar weekday and weekend traffic patterns with a slightly higher usage on weekends.

Multipurpose-mixed – a facility that experiences higher volumes on weekends, although weekday traffic patterns show typical commuting peaks.

Examples of these different patterns are shown in figures 5 - 8. Researchers are working to create adjustment factors based on these travel patterns. The ultimate goal is to have enough continuous count locations to be able to expand on these travel pattern types and create adjustment factors based on facility type and time of year.

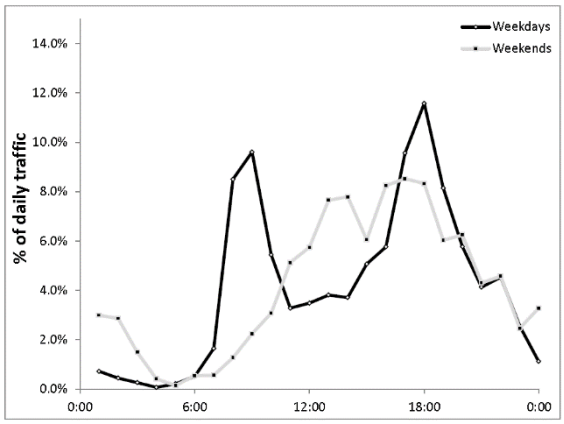


Figure 5: Commute Traffic Pattern

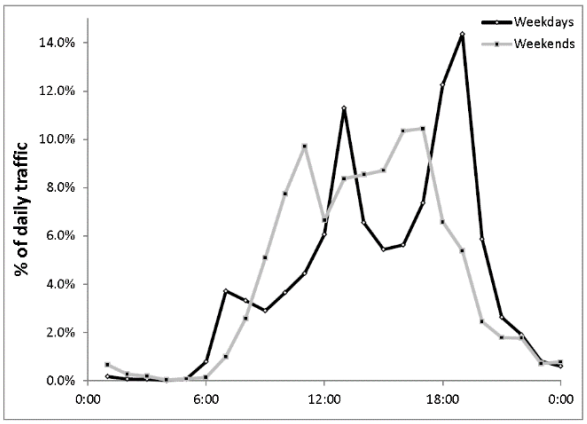


Figure 6: Commute-mixed Traffic Pattern

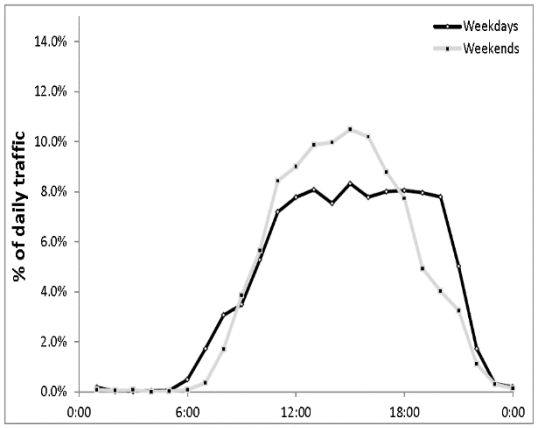


Figure 7: Multipurpose Traffic Pattern

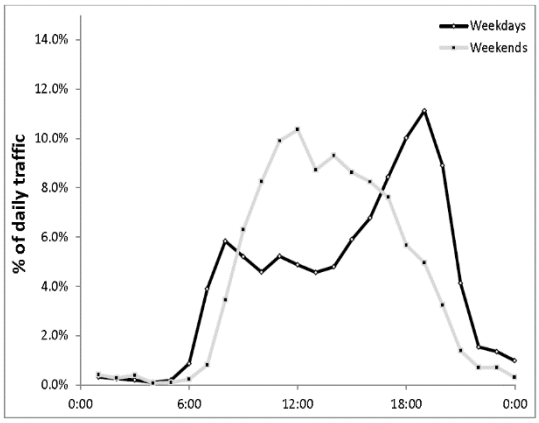


Figure 8: Multipurpose-mixed Traffic Pattern

Minnesota bicycle and pedestrian facilities experience highest use from May to September. An example of how average daily traffic changes based on time of year is shown in Figure 9. This figure illustrates the variation of volumes throughout the year at a variety of continuous monitoring sites in Minneapolis. The travel patterns at these sites range from multipurpose-mixed to commuter.

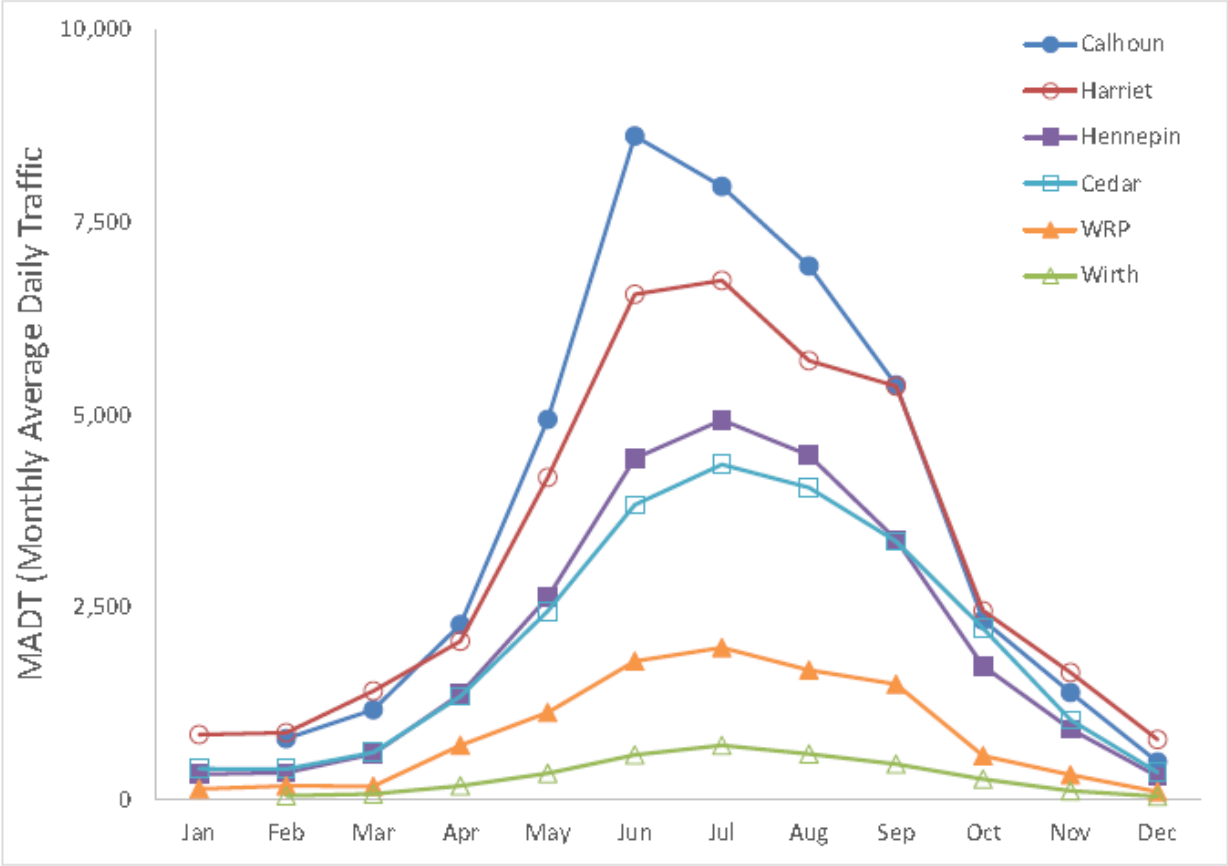


Figure 9: Average Daily Trail Traffic by Month at Various Minneapolis Monitoring Sites

3.4 Site Selection

The count purpose will determine where, when and how data collection should be performed. See Section 1.1 for potential data collection purposes. Understanding why the data is being collected will determine if short duration counts are sufficient or if continuous counting locations should be considered. Once the when and why have been determined items such as reviewing the facility type and selecting the data collection method can be performed. Defining the type of count location and determining if short duration or continuous counts are warranted is discussed in this section.

Count locations can be assigned to one of five categories. The data collection purpose will drive the selection of location type:

- **Targeted locations.** Targeted sites are selected on the basis of being associated with particular projects, facility types, or locations with particular characteristics. Target locations can be areas of safety concerns or areas with the highest expected volumes of bicycles and/or pedestrians. Target locations are often selected to support before and after studies. They are appropriate for either short duration or continuous counts.

- **Representative locations.** This approach balances available resources with spatial coverage. Identified sites, in aggregate, are representative of the traffic network as a whole. Representative locations are appropriate for short duration counts.
- **Control locations.** This approach compares sites affected by a project with unaltered sites (control locations) to determine how much of the observed change in demand can be attributed to the project. Control locations are appropriate for either short duration or continuous counts depending on the data usage.
- **Random locations**. This approach selects sites randomly. This approach may not capture strategic locations, nor select sites appropriate for automated counting. Selecting randomly from within categories of desired characteristics (stratified random sampling) is an alternative, however this method for choosing count locations is not recommended.
- **Index locations**. Index locations are illustrative of the counts statewide. These sites are not fully representative or inclusive of every roadway nor are they a statistically random sample. MnDOT is using this approach for establishing statewide trends.

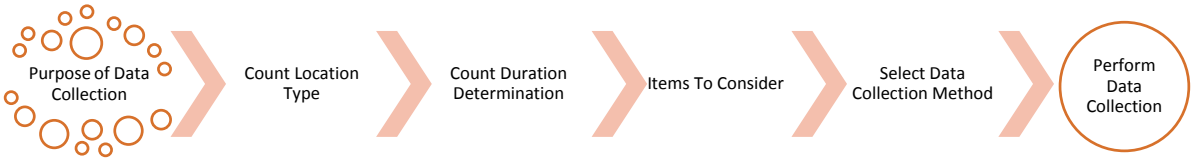
Consider the following considerations for all count locations:

- Facility type: roadway, bike lane, shoulder, protected bike lane, trail, protected trail
- Travel patterns (if known): commuter, commute- mixed, multipurpose, or multipurpose-mixed
- Facility area: urban, suburban, exurban, rural
- Land use: residential, commercial, school, green space
- Safety: of both data collection personnel and/or the data collection equipment
- Other agencies conducting short duration counts may be able to provide input on locations that are a good fit for continuous count site installations
- Exercise caution when working near traffic. Work with local traffic agencies to use traffic control devices if needed

Consider the following practical considerations for all count locations:

- Avoid areas where people tend to loiter such as areas near benches, drinking fountains, pedestrian crosswalk buttons or viewpoints/lookouts
- Observe the movements of bicycles and pedestrians in the area to develop a good understanding of the movements being made in the area before committing to installation

The graphic below illustrates the process to follow to select a count location and data collection plan. Short duration and continuous count location determination is discussed further in the remainder of this section.



3.4.1 Site Selection for Short Duration Counts

Short duration counts can be performed for a few hours or up to several months. The counts can be performed manually onsite, manually using video, or by using portable automated counting devices.

The 2013 TMG recommends a combination of targeted and representative locations for short duration counts. Locations that meet this criteria include:

- Pedestrian and bicycle activity areas or corridors (downtowns, near schools, parks, etc.)
- Representative locations in urban, suburban, and rural locations
- Key corridors that can be used to gauge the impacts of future improvements
- Locations where counts have been conducted historically
- Locations where traffic is funneled to a certain throughway because of geographic constraints such as a bridge crossing a river
- Locations where ongoing counts are being conducted by other agencies through a variety of means, including video recording
- Gaps, pinch points, and locations that are operationally difficult for bicyclists and pedestrians to navigate (potential improvement areas)
- Locations where either bicyclist and/or pedestrian collision numbers are high
- Locations that meet multiple criterion

3.4.2 Site Selection for Continuous Counts

Continuous or continuous count sites are locations equipped with an automated counting technology that collects data 24 hours a day, 7 days a week. The following factors should be considered when looking at locations to install continuous count equipment.

- Locations where short duration counts have been conducted historically
- Locations where traffic is funneled to a certain throughway because of geographic constraints such as a bridge crossing a river
- Representative locations in urban, suburban, and rural locations
- Key corridors that can be used to gauge the impacts of future improvements
- Areas of high volume and/or well established bicycle and pedestrian facilities

4 BICYCLE AND PEDESTRIAN DATA COLLECTION SENSORS

4.1 Sensor Overview

Selecting the appropriate counting technology is dependent on factors such as budget, facility type, and duration of count. The chart in Figure 10 is a modified version of Figure 4-1 from the 2013 TMG. This chart can help determine which count technologies are best suited based on duration and facility user.

1. What Are You Counting?

	Technology	Bicyclists Only	Pedestrians Only	Pedestrian & Bicyclists Combined	Pedestrian & Bicyclists Separately	Cost
Permanent	Inductance Loops[1]	●			◐	$$
	Magnetometer[2]	○				$-$$
	Pressure Sensor[2]	○	○	○	○	$$
	Microwave Sensor	○	○	○		$-$$
	Seismic Sensor	○	○	○		$$
2. How long?	Video Imaging: Automated	○	○	○	○	$-$$
	Infrared Sensor (Active or Passive)	○	●	●	◐	$-$$
	Pneumatic Tubes[3]	●			◐	$-$$
	Multi-Technology			●	●	$$-$$$
	Video Imaging: Manual	○	○	○	○	$-$$$
Short Duration	Manual Observers	●	●	●	●	$-$$$[4]

○ Indicates what technology is possible.
● Indicates a common practice.
◐ Indicates a common practice, but must be combined with another technology to classify pedestrians and bicycles separately.
$, $$, $$$: Indicates relative cost per data point
[1] Typically requires a unique loop configuration separate from motor vehicle loops, especially in a traffic lane shared by bicycles and motor vehicles.
[2] Permanent installation is typical for asphalt or concrete pavements; temporary installation is possible for unpaved, natural surface trails.
[3] Requires specific mounting configuration to avoid counting cars in main traffic lanes or counting pedestrians on the sidewalk.
[4] Useful for short duration counts, however cost prohibitive for long term.

Figure 10: Simplified Flowchart for Selecting Non-Motorized Count Equipment (Adapted from FHWA TMG 2013)

Table 1 serves as a quick reference guide of the strengths and limitation of currently available technologies. This table was modified from a table assembled by the FHWA for the 2013 TMG (Table 4-1). A more thorough overview of counting methods is located in Section 5.0. Note that at this time, only manual counts are able to differentiate between pedestrians and skaters; if the area being monitored has a high occurrence of skaters, and it is important to differentiate them from pedestrians, steps should be taken to ensure they are counted appropriately. Additionally, automatic count equipment is susceptible to vandalism. Care should be taken to properly secure all components left out in the field and check them regularly for signs of tampering.

Table 1: Commercially-Available Bicyclist and Pedestrian Counting Technologies (Adapted from FHWA TMG 2013)

Technology	Typical Applications	Strengths	Limitations
Inductive Loops	• Continuous Counts (saw cut or under pavement) • Short duration counts (tape down) • Bicycles only	• Accurate when properly installed and configured • Uses traditional motor vehicle counting technology	• Capable of counting bicyclists only • In-pavement installation requires professional installer to saw cut in existing pavement or to place pre-formed loops on sub-base prior to construction • May have higher error when detecting groups of bicycles • May be susceptible to electrical interference
Magnetometer	• Continuous Counts • Bicycles only	• May be possible to use existing motor vehicle sensors	• Commercially-available, off-the-shelf products for counting bicyclists are limited • May have higher error with groups
Pressure Sensor/ pressure mats	• Continuous Counts • Typically unpaved trail or paths	• Some equipment may be able to distinguish between bicyclists and pedestrians	• Expensive/disruptive for installation under asphalt or concrete pavement
Seismic Sensor	• Short-term counts on unpaved trails	• Equipment hidden from view	• Commercially-available, off the shelf products for counting are limited
Microwave Sensor	• Short-Term or continuous counts • Bicyclists and pedestrians combined	• Capable of counting bicyclists in dedicated bike lanes or bikeways	• Commercially-available, off the shelf products for counting are limited • Distance limitations
Automated Video Imaging -	• Short-term or continuous counts Bicyclists and pedestrians separately	• Potential accuracy in dense, high-traffic areas over manual counts	• Typically more expensive for exclusive installations • Algorithm development still maturing

Technology	Typical Applications	Strengths	Limitations
Active Infrared	• Short-Term or continuous counts • Bicyclists and pedestrians combined	• Relatively portable • Low profile, unobtrusive appearance	• Cannot distinguish between bicyclists and pedestrians unless combined with another bicycle detection technology • Very difficult to use for bike lanes and shared lanes • May have higher errors with groups
Passive Infrared	• Short-Term or continuous counts • Bicyclists and pedestrians combined	• Very portable with easy setup • Low Profile, unobtrusive appearance	• Cannot distinguish between bicyclists and pedestrians unless combined with another bicycle detection technology • Very difficult to use for bike lanes and shared lanes, requires careful site selection and configuration • May have higher error when ambient air temperature approaches body temperature range • May have higher errors with groups • Direct sunlight on sensor may create false counts
Pneumatic Tube	• Short-Term counts Bicyclists only	• Relatively portable, low cost • May be possible to use existing motor vehicle counting technology and equipment	• Capable of counting bicyclists only • Tubes pose tripping hazard to trail users • Greater risk of vandalism • Not for use in winter
Video Imaging - Manual Analysis	• Short-term counts • Bicyclists and pedestrians separately	• Can be lower cost when existing video cameras are already installed	• Limited to short-term use • Manual video reduction is labor-intensive
Manual Counts	• Short-term counts • Bicyclists and pedestrians separately	• Can be used for automated equipment validation	• Useful for short duration counts, but cost prohibitive for long term unless volunteer supported

4.2 Bicycle Detection Sensor Accuracy

The accuracy of the available technologies varies and is dependent to a large extent on proper installation and configuration. Table 2 summarizes the accuracy of several bicycle detection technologies. This table is a modified version of Table 4-1 from NCHRP Project 07-19. The average percentage deviation, or error relative to the totals counted manually from the video, ranged from 0.55% to more than 18%, depending on the technology unique characteristics of deployment. The averages of the absolute percentage differences were higher because false positives and false negatives do not offset each other.

Table 2: Accuracy and Precision Rates of Sensor Technologies (Adapted from: NCHRP Project 07-19, Table 4-1)

Sensor Technology	APD	AAPD	Pearson's r	Hours of Data	Hourly Volume (Avg./Max.)
Passive infrared	-8.75%	20.11%	0.9502	298	240/846
Active infrared	-9.11%	11.61%	.9991	30	328/822
Microwave	-18.18%	48.15%	.9503	95	129/563
Bicycle-specific pneumatic tubes	-17.89%	18.50%	.9864	160	218/963
Inductive loops (detection zone)*	0.55%	8.87%	.9938	108	128/355
Inductive loops (including bypass errors)*	-14.08%	17.62%	.9648	165	200/781
Piezoelectric strips	-11.36%	26.60%	.6910	58	128/283
Combination (pedestrian volume)	18.65%	43.78%	21.37%	47	176/594

Notes: APD = average percentage deviation, AADP= average of the absolute percent difference, r = Pearson's Correlation Coefficient, Avg. = average, Max.= maximum

*Detection zone results refer to the accuracy of the device with respect to the bicycle volume that passed through its detection zone. Errors are larger when comparing the device's count to the actual volume on the facility, including bicyclists that bypass the detection zone.

4.3 Sensors Currently in Use in Minnesota

The bicycle and pedestrian project team selected and deployed a variety of sensors in the summer of 2014 and 2015. Table 3 summarizes information for each of the seven sensors deployed, focusing on the level of difficulty to install.

Table 3: Sensors Currently in Use in Minnesota

Counter Type	Modes Counted	Level of Difficulty to Install	Agency	Vendor	Installation Instructions
Inductive Loops	Bikes	**DIFFICULT** - Equipment is saw-cut into road or trail surface by an experienced construction or consultant team. This install will require more stringent safety protocols (truck with flashing lights, vests, spotters, etc.). Calibrate by biking across the sensor and checking detection with software. Download data with a Bluetooth enabled device or it can be sent through the cellular network and accessed remotely. Data can be analyzed using proprietary software or in Excel.	MnDOT	EcoCounter	Eco-Zelt
Multiple Technologies	Bikes and Peds Differentiated	**DIFFICULT** - Equipment is saw-cut into road or trail surface by an experienced construction or consultant team. This install will require more stringent safety protocols (truck with flashing lights, vests, spotters, etc.). Calibrate sensors by biking and walking across them and checking detection with software. Download data with a Bluetooth enabled device or it can be sent through the cellular network and accessed remotely. Data can be analyzed using proprietary software or in Excel.	MnDOT and Rails to Trails	EcoCounter	Eco-Multi
Pneumatic Tubes	Bikes	**INTERMEDIATE** - Equipment secured to road or trail surface with road nails or stakes. Installation may require more stringent safety protocols (truck with flashing lights, vests, spotters). A computer and software needed to set up counters. Data post processing needed to classify traffic and identify bikes.	Hennepin County	TimeMark	

Counter Type	Modes Counted	Level of Difficulty to Install	Agency	Vendor	Installation Instructions
Pneumatic Tubes	Bikes	**INTERMEDIATE** - Equipment secured to road or trail surface with road nails or stakes. Installation may require more stringent safety protocols (truck with flashing lights, vests, spotters). A computer and software needed to set up counters. Data post processing needed to classify traffic and identify bikes.	Hennepin County	MetroCount	MC5600 Operator Guide Installation Videos
Active Infrared	Bikes and Peds Undifferentiated	**EASY** - Equipment attached to posts or poles on both sides of a trail. Calibrate sensor by walking across IR beam. Download data with a special collector, process with proprietary software and export to Excel for analysis.	Minneapolis Park & Recreation Board	TrailMaster	TM 1550 Data sheet
Passive Infrared	Bikes and Peds Undifferentiated	**EASY** - Equipment attached to post or pole on one side of a trail. Calibrate sensor by walking within range of IR beam and checking detection with software. Download with a Bluetooth enabled device or it can be sent through the cellular network and accessed remotely. Data can be analyzed using proprietary software or in Excel.	MnDOT	EcoCounter	Eco-Pyro
Microwave	Bikes and Peds Differentiated	**EASY** - Equipment attached to posts or poles on both sides of a trail. Calibrate sensor by walking and biking across microwave beam. Download data from integrated bike and pedestrian data loggers and process with Excel.	MnDOT	Chambers Electronics	RadioBeam People-Bicycle Counter (RBBP)

5 HOW TO PERFORM COUNTS

In 2013 MnDOT paired with UMN to determine the most effective means of collecting bicycle and pedestrian volume data in areas throughout Minnesota. An investigation into the commercially available technologies was performed. Six technological approaches were selected for investigation and are recommended in the remainder of this manual for deployment in Minnesota.

- Manual/Video
- Pneumatic tubes
- Microwave
- Inductive loop
- Infrared
- Inductive loop + Infrared

Appendix A provides a quick reference flow chart for sensor selection based on count duration and facility type.

The sections that follow present a general overview, consult manufacturer documents for specific installations guidelines. Also, safety of installation personnel needs to be considered. Note that a professional installation is needed for some devices, particularly loops that are saw cut into pavement or preform loops that are installed in sub base before paving.

5.1 Manual Counts

Manual counts are performed by personnel either positioned at the desired count location who tally the bicycle and/or pedestrian traffic, or via video recorded onsite and reviewed and tallied at a later time. These counts can be performed using the MnDOT Counting Form (see Appendix B) or an electronic counting pad. Counts are taken in 15 minute increments for a pre-determined amount of time with a separate tally recorded for bicyclists and/or pedestrians. Manual counts are a good way to capture data beyond volume including age (adult vs. child), gender, helmet use, and direction of travel. The use of video tools allow the counter to speed up or slow down the video playback for accurate manual counts and makes long duration manual counts possible.

Manual counts can be used as standalone count data or can be used as a baseline to identify errors and/or correction factors for automated counting devices.

MnDOT began the bicycle and pedestrian count research project with manual counts. Going forward the MnDOT program will focus on using technology. Local jurisdictions may elect to conduct manual counts to understand their community better. Manual counts allow for the collection of information about other attributes such as helmet use, gender and age. Manual counts have a history with the National Bicycle and Pedestrian Data Collection project.

Figure 11: Manual Count being Performed Along Roadway

MnDOT developed a training program for conducting manual bicycle and pedestrian counts as part of the MnDOT and MDH Bicycle and Pedestrian Counting initiative. Local communities can easily manage the collected data with spreadsheets.

5.1.1 Site Design

The person or camera collecting data should be located where viewing is minimally impeded by infrastructure or curves. Mid-block locations are suitable. If intersection counts are performed, it may be necessary to have more than one person or camera collecting data. If using video, consider the time of day and how the sunlight will affect the camera's view.

The count area should be considered a "transportation work zone." The person conducting the count should be placed out of the traveled way and not interfere with traffic flow. Make sure that field personnel understand that safety is a primary concern and they should not take risks to collect the counts. Provide field personnel with the count manager's contact information for any questions or onsite issues that may arise. Field personnel should wear approved high visibility clothing.

Once site locations for counts have been selected, visit the site to determine where the best line of sight for the counts to be performed is located, before the counts take place. Weather should also be accounted for so that a backup or rain day is planned in case of inclement weather.

If utilizing cameras, the cameras must be attached to a pole, fence or other permanent structure that can offer a place to secure the video monitoring device with chain and lock to prevent theft and tampering. A sticker or tag stating who owns and operates the device and contact information should be attached to the device. Good quality video requires appropriate lighting conditions and camera placement. Use a small video monitor or computer connected to the video recording device to verify the camera view is sufficient. Ensure the camera will not rotate or move by securing with zip ties or hose clamps at several places along the camera pole. Make sure all connections are made correctly and the data storage device is collecting the video data before leaving the site.

Figure 12: Mix of Bicycle and Pedestrians on a Path

5.1.2 Calibration

Personnel should be trained with the methods contained in the MnDOT Manual Count Training Manual. A clear definition of bicycles and pedestrians ensures all counting personnel will perform counts in a uniform manner.

- Bicycle – all pedal powered vehicles including unicycles, tandem, recumbent, three wheelers, tag-alongs, trailers, pedicab. Each person counts as one count.
- Pedestrian – each person on foot or assisted including people using walkers, skates, Segways, wheelchairs, strollers, crutches, scooters, children being carried, person walking a bicycle.

5.1.3 Data Collection

Every pedestrian or vehicle that passes through the screen line or intersection should be counted. If directionality or any other data collection parameters are being collected, they should also be recorded for every tally. If multiple counts will be conducted at the same area, the same location should be used for observation.

A MnDOT data collection form has been created for performing manual screen line or cordon counts (See Appendix B). MnDOT typically collects data in 15 minute increments for two hours. The form should be completely filed out including the areas for name, date, and location ID. There is additional space at the bottom of the form to document any unusual occurrences that may impact the count.

Items to provide in addition to training for personnel conducting manual counts:

- Instructions
- Location map
- Clipboard
- Data Collection Forms
- Pen/pencils and spares
- Watch/phone/timepiece
- Public information sheet or “Traffic Count in Progress” sign
- High visibility clothing

The public may interact with personnel onsite and distract them from counting. Providing professional and polite answers to the public’s questions, as well as providing information sheets to people that stop for more information is a useful tactic that will allow the counter to stay focused on counting (Figure 13). The person conducting the count should note if and when any counts are interrupted for any reason. At the end of the shift the counter should have clear direction on where to return the count forms and other materials.

Bicycle and Pedestrian Counting Program

We are participating in a research project to study bicyclist and pedestrian traffic volumes. For more information, you may contact *insert count manager contact information here*. I will be happy to answer your questions if possible, but I must keep focused on counting to ensure our counts are as accurate as possible. Thank you for your interest in our program.

Figure 13: Example Public Information Sheet for Counters

A traffic monitoring camera allows manual counts to be performed at a later time by viewing the video and tallying the information. The accuracy of the data depends on careful deployment and analysis.

Figure 14: Video Recorder, camera and recorded video

The manual tally of the video can be performed in three ways; using the MnDOT Data Collection Form, utilizing a mechanical/electronic count board, or a computer keyboard and the accompanying software. At most two keystrokes are needed to record a passing bicycle or pedestrian. An example mechanical/electronic count board, COUNTpad, is shown in Figure 15.

Figure 15: Electronic Count Board Used With Video Data Processing

Using the video playback for manual counts has advantages such as the ability to play back any recorded time. This allows an operator to return to the exact spot in the video that they previously stopped working from, or allows others to review uncertainties by recording the time at which the

subject in question passed. Another feature is the ability to speed up and slow down the video playback. This provides the opportunity to slow down the video to allow for accurate counting of bicycles and pedestrians passing by in quick succession, if needed, or speed up the video during periods of little activity.

5.1.4 Maintenance and Troubleshooting

Maintenance and troubleshooting for manual counts are minimal. Counts performed by personnel can be reviewed by the count manager. A questionnaire may give an indication of the quality of the count and may ask the following questions:

- Were you able to document everything you wanted?
- Were the traffic volumes overwhelming?
- Do you think your location onsite was at the best location for counting or do you have other suggestions?

Based on this information, the site counters could be re-positioned, additional staff could be added, or the count equipment could be changed to the use of a hand tally (click counter), video monitoring, or other automated technologies.

Maintenance and troubleshooting for traffic monitoring cameras includes ensuring that the battery is charged, that it can hold a charge long enough to record video for the desired amount of time and has enough data storage for the data collection needs. If the camera battery or amount of storage available will not last for the desired amount of data collection time, plans should be made for personnel to visit the site and swap in new batteries or data storage until the data collection effort is complete.

5.2 Pneumatic Tube Counters

Pneumatic tube counters detect wheeled vehicles that pass over rubber tubes. As the wheel passes over the rubber tube, a pressure pulse is created and the pressure change is detected by the data recorder. Tubes for detecting bicycles are typically thinner than those used for motor vehicle detection for increased safety and detection accuracy.

5.2.1 Site Design

Pneumatic tube counters may be installed as either short duration or semi- continuous detectors on paved surfaces. They may be used on some gravel surfaces, however this installation is not recommended. Rubber tubes are stretched taught across the surface to be detected. Pneumatic tubes function in most weather conditions although snow or ice buildup around the tube may cause the tube to not compress and pressurize the air to record the detection. Winter deployment is not recommended as snowplows will rip up the tubes. Also be aware of street sweepers and their routes so that they don't harm the tubes.

Figure 16: Pneumatic Tube Installation on Roadway

Various configurations of tubes can be used to capture different types of data. A common tube configuration is to place two tubes perpendicular to the travel direction spaced equidistance apart. As wheeled vehicles pass over the tubes, the direction can be determined by the sequence of the tube "hits". The speed of the vehicle can be determined by the timing of the tube hits and vehicle classification is determined by measuring axel spacing. Ideal location are ones with only bicycle traffic, however in some cases it is necessary to include a roadway with motor vehicle traffic as well.

When selecting a location for pneumatic tubes:

- Stay away from signalized/stop-controlled intersections and from parking areas to minimize the chance of vehicles/bikes stopping on the equipment
- Avoid hilly areas where one direction of bikes travel uphill
- Avoid areas where vehicles/bikes are changing lanes, such as a "major intersection" where it is common for users to turn

Follow the manufacturer's installation instructions for placing the pneumatic tubes and data recorder. Be sure to plan your route to the locations and inventory equipment (hoses, counters, and installation tools) before leaving to set up the equipment.

Other installation items:

- Exercise caution when working near traffic. Work with appropriate traffic agencies to use traffic control devices if needed
- Document the relevant information: equipment number, travel direction, and sketch of the setup with north arrow
- Secure equipment on roadway to minimize chance of it being disturbed
- Apply tension to hoses (pull 10-15% of the slack tube length before anchoring the end closest to the counter)
- Knot ends of tubes or plug them to keep the dust out and to reduce bounce back signals
- If the tubes cross a parking lane, set out traffic control devices (usually traffic cones) to prevent vehicles from parking on top of the tubes

5.2.2 Calibration

Pneumatic tubes require calibration to determine if the air switch sensitivity needs to be adjusted. Tubes require precise installation in cases where dual tubes are used. It is important to set the tubes parallel to each other at a measured distance apart. This distance is programmed into the detector for speed determination.

After setup, the detector should be monitored for several activations to ensure that detections for common vehicle types are properly recorded. Plug the counter into a laptop and bike over or step on the tubes to make sure the counts are being registered correctly. Bring an extra computer battery or a car charger, especially if multiple sites and counters are to be set up in one day.

Figure 17: Tube Calibration

5.2.3 Data Collection

Data is automatically collected by the data recorder attached to the tubes. Data can be downloaded to a computer. Verify that the data recorder has sufficient memory to store data throughout the desired data collection interval.

5.2.4 Maintenance and Troubleshooting

Pneumatic tubes require little maintenance although they should be checked periodically depending on the risk of the tubes detaching from the surface due to site conditions, traffic, or vandalism. If the tubes detach from the surface, they could become a safety hazard until they are fully removed. In semi-continuous tube installations, the pneumatic tube setup should be checked frequently (at least every three days) for proper performance.

Upon placement, tubes should be checked for holes. Blow air through hoses to check for holes and to remove dust – this is a major problem as equipment is used over several installations. Over time and use, tubes wear out and need to be replaced. A supply of spare tubes should be kept available.

5.3 Microwave

Microwave detectors use radio waves to detect bicycles and pedestrians, they are commonly called radar detectors. Depending on detector selected, they may be able to count bicycles and pedestrians separately, together or configured to omit one or the other. They may be a single detector adjacent to the traveled way or a dual detector with a signal and receiver installed on each side of the facility being monitored.

Figure 18: Microwave Detector Installation

5.3.1 Site Design

Microwave detectors must be set up directly adjacent the path or trail. Detectors are typically placed at a height of two to five feet. If there is no trailside infrastructure that can be used to mount the detector, a sturdy stanchion to support the detector may be installed.

In cases where unconventional modes of transportation are used, such as an equestrian trail, the detector should be placed at a height for detection of that subject. Be aware of the distance limitations stated by the manufacturer and take those limitations into consideration when selecting a site.

Follow the manufacturer's instructions for installing the detector.

5.3.2 Calibration

Microwave detectors require little calibration, but should be tested upon setup by verifying that several subjects are correctly detected. If the detector misses subjects, it may need to be installed at a different height, angle, or location.

5.3.3 Data Collection

Data is automatically collected by the detector. Data can be downloaded from the detector to a computer.

5.3.4 Maintenance and Troubleshooting

Detectors require little maintenance. Basic maintenance and troubleshooting steps should be performed to verify battery level and/or electrical connections and check for signs of vandalism or tampering.

5.4 Inductive Loop

Inductive loops are typically made by forming three to five turns of loop wire that are installed in a channel that is saw cut into pavement. Another installation method is temporary preformed loops that are affixed on top of the paved traveled way. Inductive loops can be installed directly into existing pavement for continuous counts, installed with new construction at the time of paving, or temporally affixed atop the pavement for short duration counting of bicycles.

Figure 19: Installing an Inductive Loop in a Saw Cut on a Multi-purpose Path

Inductive loops are an induced current detection system which sense metal objects that pass over the in-ground "loop." Data is logged by a data collection unit nearby. This technology cannot be used for pedestrian detection as they do not induce a current in the loop wire.

Professional installation is required for saw cut loops and preform loops that are installed on a sub base before paving. Tape-down temporary loops do not require special training or equipment to install.

5.4.1 Site Design

Inductive loops are placed in the roadway/trail spanning the traveled way. Loops can be placed in bike lanes, on road shoulders, or on multi-purpose paths. Finding locations where the loop will detect the entire path or bike lane is critical so bicycles cannot ride outside of the detection zone. Depending on the manufacturer, a source of power may be required which may limit deployment locations. Determine if the site is affected by electrical influence; such as adjacent to power lines as this can interfere with the loop current.

Installing these devices during construction or reconstruction of bicycle facilities is the most cost effective. When a trail is reconstructed any existing loops must be replaced. Loops and conduit can be laid when the pavement is installed to avoid the need to saw cut the pavement.

Follow the manufacturer's instructions for installing the detector.

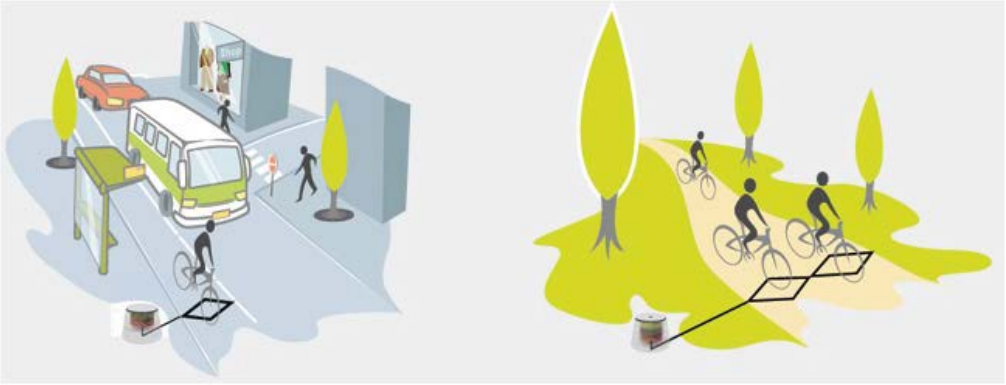


Figure 20: Eco Counter Zelt Loop (from Eco-Counter)

5.4.2 Calibration

Inductive loop detectors may need to be calibrated to detect bicycles and may have higher error when detecting groups of bicyclists. If installed in lanes adjacent to a motorized vehicle traveled roadway, further calibration and manual counts may be needed to the determine level of interference caused by vehicles.

After calibration, the detector should be monitored for several activations to ensure that bicycle detections are properly recorded.

Figure 21: Calibration Performed before Sealing the Saw Cut to Ensure Proper Performance

5.4.3 Data Collection

Data is automatically collected by the data recorder. Depending on the type of data collection device used, data can be downloaded to a computer remotely through a cellular connection or onsite via Bluetooth or a hardwire connection. Verify that the data recorder has sufficient memory to store data throughout the desired data collection interval.

5.4.4 Maintenance and Troubleshooting

Inductive loops require little maintenance although they should be checked periodically for deteriorating pavement around the loop. Over time the pavement around the loop may wear out and need to be replaced or resealed.

In a semi- permanent inductive loop installations, the loop setup should be checked monthly for proper performance.

5.5 Infrared

Infrared detectors use invisible radiant energy to detect bicycles and pedestrians. Depending on detector selected it can be active infrared or passive infrared. Active infrared requires mounting a receiver and a transmitter on each side of the detection area and bicycles or pedestrians are detected when the infrared beam is broken. Passive infrared is a side-fire technology mounted on one side of the detection zone which identifies the changes in temperature as a bicycle or pedestrian move through the detection zone.

Figure 22: Sealed in-pavement Inductive Loop

Figure 23: Infrared Installation

This technology typically does not distinguish between user types; consider dual technology if using this technology on a multi-purpose path that needs separate pedestrian and bicycle counts.

5.5.1 Site Design

Infrared detectors must be set up directly adjacent the path or trail. Detectors are typically placed at a height of two to three feet. If there is no trailside infrastructure that can be used to mount the detector, a sturdy stanchion to support the detector may be installed.

In cases where unconventional modes of transportation are used, such as an equestrian trail, the detector should be placed at a height for detection of that subject. Be aware of the distance limitations stated by the manufacturer and take those limitations into consideration when selecting a site.

Follow the manufacturer's instructions for installing the detector.

5.5.2 Calibration

Infrared detectors require little calibration, but should be tested upon setup by verifying that several subjects are correctly detected. If the detector misses subjects, it may need to be installed at a different height, angle, or location.

5.5.3 Data Collection

Data is automatically collected by the detector. Data can be downloaded from the detector to a computer.

5.5.4 Maintenance and Troubleshooting

Detectors require little maintenance. Basic maintenance and troubleshooting steps should be performed to verify battery level and/or electrical connections and check for signs of vandalism or tampering.

5.6 Inductive Loop and Infrared

In this dual technology approach, a short duration or permanent loop is paired with infrared technology to detect both bicycles and pedestrians. Data is logged by a data collection unit nearby with a tally of both bicycles and pedestrians.

5.6.1 Site Design

Inductive loops are placed in the shared use path spanning the traveled way. Finding locations where the loop will detect the entire path or bike lane is critical so bicycles cannot ride outside of the detection zone. Depending on the manufacturer, a source of power may be required which may limit deployment locations. Infrared sensors must be set up directly adjacent the path or trail. Detectors are typically placed at a height of two to five feet. If there is no trailside infrastructure that can be used to mount the detector, a sturdy stanchion to support the detector may be installed.

Figure 24: Inductive Loop and Infrared on Urban Multi-purpose Path

In cases where unconventional modes of transportation are used, such as an equestrian trail, the detector should be placed at a height for detection of that subject.

It is ideal to install these devices during construction or reconstruction of bicycle facilities. Loops and conduit can be laid when the pavement is installed to avoid the need to saw cut the pavement.

Follow the manufacturer's instructions for installing the detector.

5.6.2 Calibration

Inductive loop detectors may need to be calibrated to detect bicycles and may have higher error when detecting groups of riders. Infrared detectors require little calibration, but can be adjusted for sensitivity and they should be tested upon setup by verifying that several subjects are correctly detected. If the detector misses subjects, it may need to be installed at a different height, angle, or location.

After calibration the detectors should be monitored for several activations to ensure that detections are properly recorded. Installation of a video recording device for a short time period such as 24 hours for validation or error determination at a loop and infrared location is recommended.

Figure 25: Calibration after Installation

5.6.3 Data Collection

Data is automatically collected by the data recorder. Depending on the type of data collection device used, data can be downloaded to a computer remotely through a cellular connection or onsite via Bluetooth or a hardwire connection. Verify that the data recorder has sufficient memory to store data throughout the desired data collection interval.

5.6.4 Maintenance and Troubleshooting

Inductive loops require little maintenance although they should be checked periodically for deteriorating pavement around the loop. Over time the pavement around the loop may wear out and need to be replaced or resealed.

In a semi-permanent inductive loop installations, the loop setup should be checked monthly for proper performance.

Infrared detectors require little maintenance. Basic maintenance and troubleshooting steps can verify battery level, electrical connections, and signs of vandalism or tampering.

Figure 26: Infrared and Short Duration Inductive Loop Installation on Multi-purpose Path

6 DATA MANAGEMENT AND ANALYSIS

Key steps in management and analysis of bicycle and pedestrian counts include

- Site identification and description;
- Count validation,
- Data analysis, including computation of descriptive statistics and use of adjustment factors; and
- Data archiving and sharing.

Each step is essential to ensure the data used in planning, engineering and decision-making are valid and as informative as possible.

Figure 27: Manual Data Collection in Duluth

State DOTs and many local jurisdictions have long established programs and protocols for data management and analysis. However, just as bicycle and pedestrian data collection programs in Minnesota are new and still evolving, so too are procedures for data management and analysis. At the time this guide was written, most bicycle and pedestrian data management and analysis programs in Minnesota have been developed ad hoc. Although a long-term goal of FHWA and MnDOT is to integrate bicycle and pedestrian traffic data into vehicular traffic management databases, this goal will be many years in realization. However, the principles of data management outlined in the FHWA Traffic Monitoring Guide and used by MnDOT to manage motorized traffic data can be used to inform state and local management of non-motorized traffic data.

This chapter presents a general overview of important elements of data management and analysis. As data become available, MnDOT, local agencies, and consultants will complete more analyses. Better procedures for management and archiving bicycle and pedestrian counts will be developed, and these general steps will be refined.

6.1 Site Identification and Description

Site identification is the process of assigning a unique identifier or number to each counting location so that counts collected at each site can be maintained over time. Site description involves recording and archiving attributes of each location such as latitude-longitude, street address (if relevant), and number of traffic lanes.

MnDOT is working to define a numbering system that is unique for each location in the state and is compatible with existing MnDOT systems. Until that method is identified, the recommendation is to track site locations with basic information including:

- Simple numbering to uniquely identify sites
- Latitude

- Longitude
- Street address (if one exists)
- Location description – road or street name and nearest cross street
- Facility types (sidewalk, off-street path, bike lane, shared use path, protected bike lane, etc.)
- Direction of Route
- Direction of Travel
- Facility Type
- Type of Sensor
- Date and Time
- Count Interval

Recording these site attributes is essential so data users can determine the location of a count, understand how it was collected, and interpret its meaning.

These attributes are consistent with Federal and State protocols for site identification for automated motorized vehicular counts. Chapter 7 of FHWA's Traffic Monitoring Guide outlines data requirements for the reporting data to the federal Travel Monitoring and Analysis System (TMAS). The FHWA has a naming convention to ensure each counting location has a unique identifier. Other attributes may be desired to provide additional information on count sites. These include:

- Agency that conducted the count
- Agency reference file number (if one)
- Road Classification (collector, arterial, frontage road, etc.)
- Annual Average Daily Traffic (AADT)
- Count description (monitoring, special study, special event)
- Land use characteristics (population densities, land use density, etc.)
- Land use type (suburban, urban, rural)
- Traffic generators (public parks, shopping malls, sports complexes, churches, etc.)
- Condition – Typical, construction, holiday, special event, etc.
- Travel pattern (commuter, commuter-mixed, multipurpose, multi-purpose mixed)
- Specific attributes and characteristics of bicyclists and pedestrians (i.e. ages, sex, travel direction, bike type, etc.)
- Photos of the site and equipment installation
- Maps detailing installation locations
- Weather Information

FHWA is establishing a standard format for counts to be included in TMAS. Agencies that wish to have their data included in TMAS will be required to follow TMAS protocols, include required information, and submit all data in specified formats.

While the structure of an agencies or organizations data management system depends on its existing systems, the availability of resources, and the purposes for which the data will be used, all systems require collection and archiving of basic information for site identification and archiving.

6.2 Count Validation

Count validation is the systematic process of ensuring the accuracy of the counts that are collected and recorded. This guide focuses on approaches for validation of continuous counts taken with automated sensors, although some of the procedures also are relevant for validation of manual counts.

Important steps in validation include (1) confirmation of counter operations; and (2) identification and correction for systematic counter error.

6.2.1 Confirmation of Sensor Operation

The first step in count validation is to ensure counters are operating properly and recording counts accurately. This step must be performed each time portable equipment is setup. Manufacturers of each type of automated sensor recommend specific procedures for ensuring proper operation. These procedures typically involve installation of the sensors and then observation of devices when bicyclists or pedestrians pass to ensure they are being counted. Manufacturers of some devices (e.g., Eco-counter) include software specifically designed for validation of sensors in the field. Field validation for some devices is more ad hoc. For example, with some devices (e.g., TrailMaster), counts are visible on a screen, and the numbers of people passing can be compared to the count on the device in real time. For other devices (e.g., MetroCount pneumatic tube counters), icons can be observed that reflect axle base, which enable observers to differentiate bicycles from cars, but a running total of bicycles is not presented.

Figure 28: Validation of Microwave Sensor

Regardless of the type of sensor, personnel responsible for installation should plan for validation of counts in the field. The amount of time required for field validation depends on the device, the experience with installation and operations, and traffic flows. For example, if an individual is installing a device for the first time, more time will be required for validation than if an individual is responsible for a fleet of sensors and has years of experience operating them. In situations where volumes of bicycle traffic are low, a practical approach involves taking a bicycle and testing the device. This approach, however, requires two individuals, one to ride and one observe the monitor.

Periodic field validation of permanent automated sensors also is important. The frequency of field validation required depends on the type of device and the duration for which the sensor will be installed. In recent study, for example, field checks of sensor operations every three to six months or, at minimum, once per year were recommended (NCHRP 2014).

Periodic validation also includes a review of counts to check for suspected errors. This step includes inspection of data for unusually high counts or prolonged periods of zero counts. For example, sometimes hourly counts are observed that are several times larger than the average count for that particular hour of that day-of-week in that month. The analyst then faces the decision of determining whether the count is valid. While it may be valid (e.g., an estimate of the number of runners on a track team that happened to run by), it may not be. Similarly, prolonged periods of zero counts (e.g., 12 hours or more) may be

encountered. This situation would be considered unusual in vehicular traffic monitoring, and the period would be "flagged" for an error-check. For non-motorized traffic, however, this may be accurate (e.g., on a cold, windy day). Federal and state guidelines and protocols have been developed for checking for these types of errors in motorized traffic data, but the same types of protocols have not been developed for non-motorized traffic.

6.2.2 Assessment of Sensor Accuracy

Overview and Recent Findings

Assessment of sensor accuracy is a systematic process to ensure that the counts obtained from automated sensors are valid and are acceptably accurate measures of actual bicycle and pedestrian traffic volumes. The National Cooperative Highway Research Program (NCHRP) Report 797, "Guidebook on Pedestrian and Bicycle Volume Data Collection" (Ryus, Paul et. al.) studied sensor accuracy. In addition, the MnDOT research project has followed the same procedures and plans to publish the results in the next version of this manual. Consumers of data collected from these sensors can choose to use the information as is, or apply correction factors.

Because of technological limitations and the complexity of traffic flows, no type of automated counter records bicycle or pedestrian traffic volumes with 100% accuracy. This true with motor vehicle counts as well. Error is present in all counts obtained with automated sensors. From a practical perspective, the presence of some error is not a problem unless the error is so great that it potentially affects the outcome of decisions made with the data. For this reason, it is important to quantify and understand the relative accuracy of the counts collected with the sensors.

The process of assessing sensor accuracy, or data validation, typically involves manual or video observations of traffic flows and comparison of totals with sensor estimates of traffic. The most comprehensive report on sensor accuracy published to date is the NCHRP Report 797 referenced above. This report summarizes methods and technologies for collecting and analyzing bicyclist and pedestrian data and reports the results of field tests to assess sensor accuracy. The NCHRP validation process involved collection of many hours of video at counting locations, manual reduction of video (i.e., counting of bicyclists and pedestrian in the video tape), comparison of hourly totals from the video and sensors, and calculation of both relative error and absolute error. The time required for validation varies, but for specific technologies multiple hours are required to assess error associated with different conditions such as variation in traffic flows.

The NCHRP Report 797 lists several reasons why errors in automated counting occur and observed totals differ from totals from automated sensors. These include:

- *Occlusion* - When two or more people cross the detection zone simultaneously, an undercount occurs because the device only detects the person nearest the sensor.
- *Environmental Conditions* - Environmental conditions, such as weather and lighting, may cause counting inaccuracies in different counting technologies.
- *Bypass Errors* – Even though a counter may accurately count the pedestrians or bicyclists that pass through its detection zone, it may still not count all of the users if it is possible for users to bypass the detection zone.

- *Mixed-Traffic Effects* – Motorized vehicles may be counted as bicycles when both are present in the detection area. This error is primarily a concern for pneumatic tube counting.

Due to these errors, automated counters tend to bias towards undercounting the number of people biking and walking. NCHRP Report 797 found that the average percentage deviation, or error relative to the totals counted manually from the video, ranged from 0.55% to more than 18%, depending on the technology unique characteristics of deployment. The averages of the absolute percentage differences were higher because false positives and false negatives do not offset each other. See Table 3 for summarized findings from NCHRP Report 797.

MnDOT has followed procedures used in the NCHRP Study to assess the accuracy of different counters and anticipates reporting the results of a University of Minnesota research study to validate other technologies in 2015. Because the accuracy of automated counters depends on care taken during installation, maintenance, and variations in site-specific factors such as traffic flows, validation is important for all newly-installed sensors. The decision to adjust counters to account for systematic error depends both on the accuracy of the specific device and the purposes for which the data will be used. If data are to be adjusted, site-specific correction equations are preferred. To date there are no general, "all-purpose" estimates of accuracy or widely-accepted correction equations have been published in the transportation engineering literature, even for specific technologies.

If an organization purchases equipment that has not been validated in the NCHRP or MnDOT study, or would like to use site specific correction factors, please refer to the steps in Appendix C.

6.3 Data Analysis

Data analysis involves a variety of procedures used to inform planning, engineering, and decision-making. The most common of these procedures include computing standard statistics used in traffic engineering such as peak hourly volume and estimation of adjustment factors from continuous monitoring data for purposes of calculating measures such as annual average daily traffic. These procedures are well-developed for motorized traffic, and both the TEM and the TMG discuss standard approaches for comparing and computing data and establishing correction and extrapolation factors. These standard approaches can be adapted for analyses of non-motorized traffic, but because non-motorized traffic varies more in response to changes in weather, new procedures are being developed that take into consideration this daily and seasonal variation. For example, non-motorized traffic volumes tend to be highest on warm, dry and sunny days and lowest on very cold and snowy days. If these effects of weather are not reflected in methods of extrapolation, estimates of traffic volumes may include greater error.

Because the field is still gaining experience in collection and analysis of non-motorized traffic data, formal protocols for analysis have not been established. Researchers in the United States, Canada, and other countries currently are collaborating with state and local agencies to develop new methods for analysis and factoring of non-motorized traffic data, and a number of important developments and case studies have been reported. More generally, the case studies at the end of this chapter from communities in Minnesota illustrate approach to analysis and use of non-motorized traffic data.

6.3.1 Standard Descriptive Statistics

Standard descriptive statistics used in transportation planning and engineering include average daily traffic (ADT), annual average daily traffic (AADT) and peak hour volume. Statistics such as peak hour are often calculated for each day of the week in each month of the year, as averages for weekdays and weekends in each month of the year, or for seasons. For example, average weekday peak hour volumes during summer months may be useful in engineering analyses to determine traffic controls at intersections.

The steps in computing statistics such as these varies depending on several factors, including the duration of the count, the quality of the data, the type of reporting options available with specific devices, and the engineering application. Many devices include both standard reports and the option to export data into spreadsheets or databases for customized analyses. Because the procedures for computing basic statistics vary according to device and need, this manual does not attempt to address all potential applications. Figures 27 - 29, however, illustrate basic descriptive information that is generated from traffic counts and used in transportation planning and engineering.

Figure 27 is a screenshot of an Eco-counter web interface that summarizes daily bicycle and pedestrian counts on the Lake Walk Trail in Duluth, Minnesota for the period of September 1, 2014 – December 31, 2014. The graph illustrates daily variation in traffic flows, seasonal variation in traffic flows, and mode share. Daily traffic volumes in September sometimes exceeded 2,500, while daily traffic volumes in December, which were much lower, still were as high as five hundred people per day. The counts were taken using an Eco-multi sensor which includes a passive infrared sensor that is integrated with an inductive loop in the asphalt trail.

Figure 28 is a screenshot of a summary of daily bicycle counts on Trunk Highway 13 in Eagan, Minnesota for the same period (September 1, 2014 – December 31, 2014) that were taken with an Eco-counter Zelt inductive loop cut into the asphalt road shoulders on either side of the highway. Daily traffic volumes show similar daily and seasonal variation, with a steady decline in daily traffic through the fall months.

Figure 29 is a screenshot of a summary of hourly bicycle counts taken on Central Avenue, north of Lowry Street in Minneapolis for the period September 1 to 7, 2014. The counts were made using an Eco-Zelt inductive loop cut into the asphalt in both northbound and southbound bicycle lanes. The graph illustrates peak hour bicycle flows and includes evidence of commuting traffic, including reverse flows in mornings and late afternoons, along with some mid-day traffic. Peak-hour volumes at this location are modest, rarely reaching as many as 10 bicycles per hour.

These three graphs are illustrative of the types of descriptive statistics that can be developed from continuous, automated bicycle and pedestrian monitoring data. They illustrate that monitoring technologies can be adapted for different types of infrastructure, such as shared use paths, road shoulders, and bicycle lanes in streets. The screenshots also illustrate the types of interfaces for data analysis that are available for automated counters.

Many other data analysis studies can be done once these basic volume metrics are calculated. These include risk analysis, safety audits, health impacts, before and after studies, and other studies as described in Section 1 of this manual.

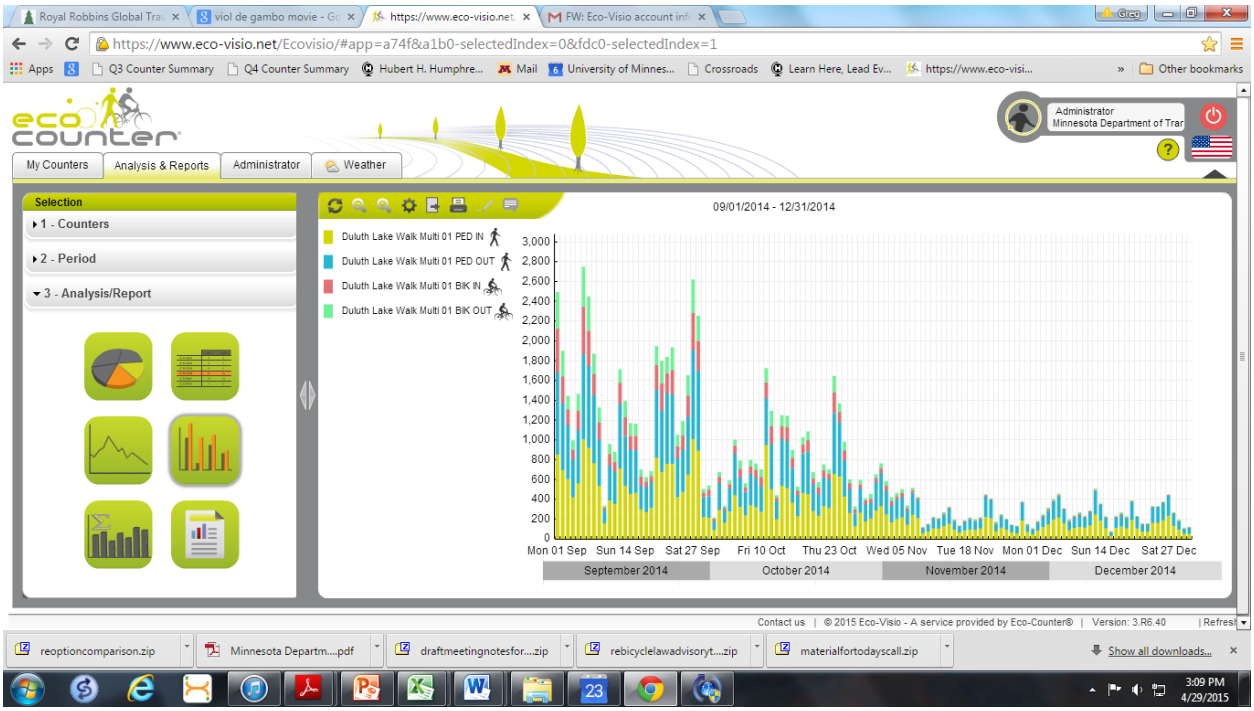


Figure 29: Duluth Lake Walk: Bicycle and Pedestrian Counts, September – December 2014

Figure 30: Trunk Highway 13, Eagan: Bicycle Counts, September – December 2014

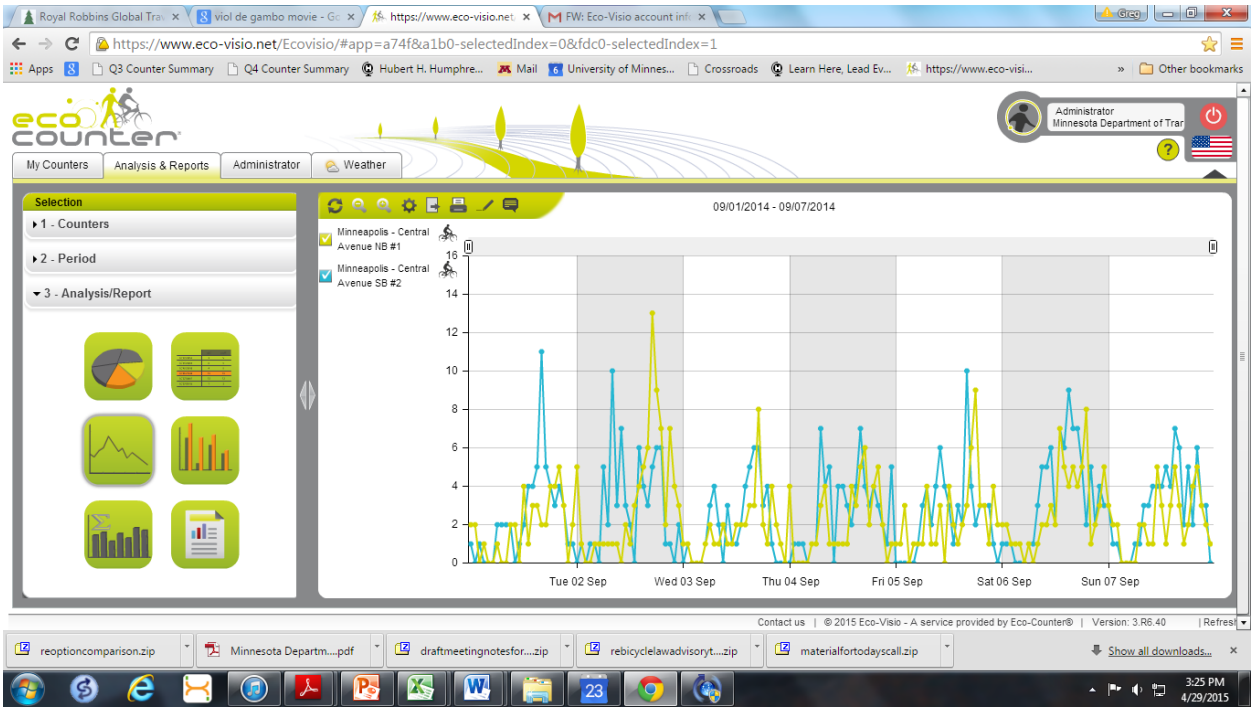


Figure 31: Central Avenue Bike Lanes, Minneapolis: Daily Bicycle Traffic September 1-7, 2014

6.3.2 Adjustment Factors

Adjustment factors are statistics or ratios derived from continuous monitoring results to extrapolate short-term monitoring results into estimates of longer-term monitoring results. These factors can be computed from short duration counts of virtually any length (e.g., one-hour, two-hour, 48 hours, one-week, ten days). For optimal accuracy and to assess traffic pattern types, MnDOT recommends when possible to count for a minimum of seven days using automated equipment.

MnDOT expects to provide adjustment factors from analyzing data from a network of continuous count location. These adjustment factors may be grouped by facility type, geographic location, adjacent land use, population size, traffic patterns or other attributes.

For examples of the development of factor groups see Appendix D.

6.4 Data Archiving and Sharing

Staff at MnDOT Central Office will manage the data collected from a network of continuous counters deployed throughout the state. At this time, local agencies and districts interested in bicycle and pedestrian traffic monitoring are responsible for collecting and maintaining their own data.

The MnDOT system will utilize software provided by the sensor vendor to upload, store and analyze data from the continuous count locations. Local agencies and districts can use equipment from vendors that provide these tools or collect data with other devices.

Advantages to using sensors that include data management tools:

- Time savings in storing and analyzing data

Advantages to using other devices may include:

- Using existing or standard traffic equipment that can be setup to count either motor vehicles or bicycle traffic.
- Using infrared equipment that is inexpensive to purchase and very easy to setup.
- Cost savings through initial capital investment and annual data management fees.

A screen shot of the vendor's software that MnDOT is using is provided in figures 27 - 29 in the previous section. When using manual counts or sensor equipment that is not integrated into a central data management system, the data must be collected and analyzed manually.

Sensor data:
All vendors provide a method to save the data from the device and export it to a spreadsheet format. The data will be in either of two formats: timed stamped for each event, or binned in an interval of time. Unless provided as part of the vendor's software package, the end user must create their own tables and graphics illustrating trends and observations.

Manual count data:
Data collected from manual counts should be stored in spreadsheets as well.

The City Minneapolis, which has counted bicycles and pedestrians for nearly a decade, maintains an integrated set of spreadsheets for archiving and sharing of data. Table 4 is an example of how an end user may organize data based on the approach used by the City of Minneapolis. Table 5 is an example of a table that summarizes trends in counts of bicyclists. Figures 30 and 31 illustrates different types of reports prepared from count data. The purpose of these examples is to show that many different types of reports can be prepared and to underscore the fact that the type of report needed depends on the specific planning or engineering problems that is being addressed.

Table 4: Example of Summarized Data for Multiple Count Locations

BICYCLIST TRAFFIC

ID	LOCATION	FACILITY 2011	FACILITY 2012	FACILITY 2013	DATE 2011	DATE 2012	DATE 2013	METHOD 2011	METHOD 2012	METHOD 2013	% WOMEN 2011	% WOMEN 2012
1	Ash St. Bridge over River	shoulder	shoulder	bike lane	9/13/2011	9/10/2012	9/14/2013	manual	manual	manual	20%	25%
2	1st Av north of Main St.	none	none	none	9/13/2011	9/10/2012	9/14/2013	manual	trailer master	trailer master	10%	15%
3	1st St S west of 3rd Av S	shoulder	shoulder	shoulder	9/13/2011	9/10/2012	9/14/2013	manual	manual	eco counter	20%	23%
4	Cty Rd J over Hwy 169	side walk	side walk	side walk	9/13/2011	9/10/2012	9/14/2013	manual	manual	manual	40%	40%
5	River Parkway north of Main S	shoulder	shoulder	protected bike lane	9/13/2011	9/10/2012	9/14/2013	manual	trailer master	trailer master	20%	20%
6	Lake Ave west of 2nd Ave.	bike lane	bike lane	bike lane	9/13/2011	9/10/2012	9/14/2013	manual	manual	manual	30%	30%
7	Lake Trail west of River Trail	trail	trail	trail	9/13/2011	9/10/2012	9/14/2013	manual	manual	eco counter	45%	45%

Table 5: Examples of Report on Trends in Counts of Bicyclists

BICYCLIST TRAFFIC

		2 HOUR COUNT TOTAL									
ID	LOCATION	2007	2008	2009	2010	2011	2012	2013	2014	Change Since Previous	Change Since 2007
1	Ash St. Bridge over River	9	11	11	10	11	12	14	8	-43%	-11%
2	1st Av north of Main St.	32	29	31	29	39	40	43	36	-16%	13%
3	1st St S west of 3rd Av S	2	2	2	2	3	3	4	2	-50%	0%
4	Cty Rd J over Hwy 169	9	11	11	9	11	9	7	7	0%	-22%
5	River Parkway north of Main St.	24	33	28	18	27	25	32	33	3%	38%
6	Lake Ave west of 2nd Ave.	5	11	7	7	28	21	29	27	-7%	440%
7	Lake Trail west of River Trail	10	12	14	7	10	14	19	27	42%	170%
	Total	91	109	104	82	129	124	148	140	-5%	54%
	Change Since 2007	0%	20%	14%	-10%	42%	36%	63%	54%		
	Change Since Previous Year	0%	20%	-5%	-21%	57%	-4%	19%	-5%		

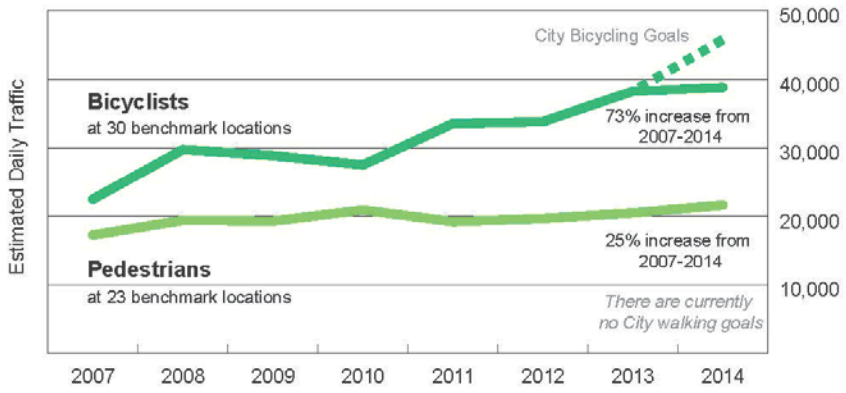


Figure 32: City of Minneapolis: Examples of Reports of Bicycle and Pedestrian Monitoring Results

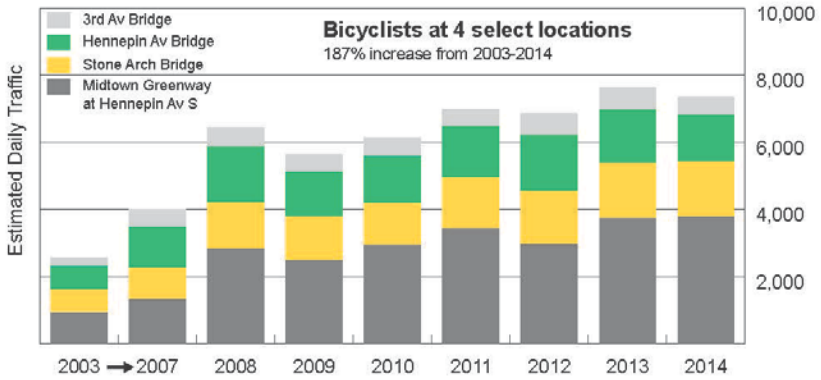


Figure 33: City of Minneapolis: Examples of Reports of Bicycle Counts Results

6.5 Case Studies

The main goal of collecting bicycle and pedestrian traffic data is to increase the efficiency and safety of local transportation systems and facilities for all users. The data are useful because they help transportation planners and traffic engineers make better decisions about investments and management of facilities. The impact of better data on the desired outcomes – more efficient transportation, fewer crashes, and fewer injuries and deaths – is difficult to document because, outcomes like deaths are relatively rare and because there are so many factors that affect these outcomes it is difficult to demonstrate cause and effect. However, it is possible to show that planners and engineers use bicycle and pedestrian traffic data to inform decision-making if data are available.

The cases presented here are brief examples of situations in Minnesota in which planners and engineers have used bicycle and pedestrian data to make better decisions. These cases illustrate different ways in which data can be used and why better data matters to the end-users – the people who use our transportation facilities.

6.5.1 Need for Mid-block Crossings in Mankato, Minnesota

Problem. Pedestrian crossings on Monks Avenue near Minnesota State University in Mankato, Minnesota.

Agencies. City of Mankato, Blue Earth County State Health Improvement Program (SHIP)

Approach. Volunteers counted pedestrians for 25 hours in January 2015 to assess need for mid-block crossings as part of street reconstruction project slated for summer 2015. Reconstruction project already included other complete streets elements, including traffic slowing measures, bicycle lanes, and sidewalks.

Figure 34: Monks Avenue, Mankato – Need for Mid-block Crossing

Results. Counted 1,915 pedestrians crossing Monks Avenue in mornings without crossing treatments. Mankato City Engineering Department incorporated plans for three mid-block crossings in plans sent for bid for reconstruction project.

Source. Personal communication, Amber Dallman, Minnesota Department of Health; Kristin Friedrichs, Blue Earth County SHIP.

6.5.2 Validation of Pneumatic Tubes for Counting Bicycles in Mixed Traffic Flows

Problem. Assess potential for traffic monitoring agencies to use pneumatic tubes to count bicycle traffic in mixed traffic flows.

Agencies. Hennepin County, MnDOT, University of Minnesota

Approach. Deployed TimeMark and Metrocount pneumatic tube counting devices in different configurations. Video-taped traffic flows, counted bicycle traffic on video manually, and compared counts from video and tubes counters using different classification algorithms. Estimated correction equations, and assessed potential for use of tubes to characterize bicycle traffic.

Results. The tube counters generally undercounted bicycles: relative error rates (i.e., differences in totals from tube counters and manual counts) for the observation periods ranged from 6% to 57% depending on the location, configuration of deployment, type of device, and classification algorithm (Table 6). Absolute error rates were substantially higher than relative error rates because false positive and negative errors sometimes offset each other. Inspection of video indicated most false negatives (i.e., undercounts) were due to occlusion, or bikes and vehicles crossing the tubes simultaneously. Calibration equations were estimated to adjust results. The practicability of using tube counters to count bicycles in mixed traffic flows depends on the applications and the relative need for accuracy in measurement. Deployment should be limited to bike lanes and no more than one traffic lane. Hennepin County used the results of the validation experiment to invest in new pneumatic tube counters to launch its new bicycle traffic monitoring program.

Table 6: Validation of Pneumatic Tube Counters for Bicycle Traffic in Mixed Traffic Flows

	Counter	Classification Algorithm*	Absolute Error	Relative Error
Portland Avenue	**MetroCount**	**ARX-Cycle**	**-16.70%**	**-6.30%**
		ARXm	**-12.10%**	**-9.80%**
		BOCO	**-25.30%**	**5.90%**
University Avenue Bike lane + 1 lane	MetroCount	ARX-Cycle	-65.20%	-26.50%
		ARXm	-71.00%	-24.60%
		BOCO	-65.80%	-19.30%
	TimeMark	15 Minute Bins	N/A	-48.30%
University Avenue Bike lane + 3 lanes	MetroCount	ARX-Cycle	-64.80%	-40.10%
		ARXm	-64.40%	-38.90%
		BOCO	-68.00%	-34.00%
	TimeMark	15 Minute Bins	N/A	-57.30%

*Results from tube counters include estimates of wheel base and speed that can be classified using different algorithms into bicycles and vehicles. ARX-Cycle is a classification algorithm for bicycles. ARX-m is an algorithm developed to separate bicyclists from the motorcycle classification using wheel based and speed. BOCO is a classification algorithm developed by a county engineer and a county planner in Boulder County, Colorado to extract bicycles from multiple vehicular classifications. TimeMark custom binned counts of bicycles were used with no additional reclassification.

Source.
Brosnan, M., Petesch, M., Pieper, J., Schumacher, S., and Lindsey, G. (2015, forthcoming). "Validation of Bicycle Counts from Pneumatic Tube Counters in Mixed Traffic Flows," *Transportation Research Record. Journal of the Transportation Research Board*.

Figure 35: Tubes in Hennepin County

6.5.3 Stop Signs on the Midtown Greenway

Problem. Determine traffic controls needed to minimize exposure to risk at five mid-block, at-grade crossings between a multiuse trail and residential cross streets.

Agency. Minneapolis Department of Public Works (DPW), Minneapolis, MN.

Approach. The Minneapolis DPW used inductive loop bicycle counters installed in the trail to count bicycle traffic and then compared bicycle traffic volumes to vehicular traffic volumes to determine whether trail traffic or the crossing road traffic should have the right of way.

Results. Counts revealed that average daily traffic on the Greenway trail was higher than the vehicular traffic at four of the five crossings (Table 7). The Minneapolis DPW changed traffic controls at each of the five crossings. At the four crossings where bicycle traffic exceeded vehicular traffic, stop signs facing the trail were removed, and different controls facing the street were installed. At three of the sites, stop signs facing the street were installed, and additional lighting was recommended. At the fourth site, a yield sign with, an overhead flasher was installed. It also was recommended that four travel lanes be reduced to two travel lanes.

Table 7: Midtown Greenway Traffic Control Options (adapted from Anderson 2010)

Crossing	Type of X-ing	Street Class	Traffic Control Options[1.]	Street ADT[2.]	Grnwy EDT[3.]	Rec. Control	Other Recs.
James Avenue S	Mid-block Crossing	Local Street	Stop/Yield Sign Facing Path –or– Stop/Yield Sign Facing Street	420	3,280	Stop Signs Facing the Street	Remove Stop Signs facing Trail Move Ex NB Stop Sign further North
Irving Avenue S	Mid-block Crossing	Local Street	Stop/Yield Sign Facing Path –or– Stop/Yield Sign Facing Street	2,026	3,280	Stop Signs Facing the Street	Remove Stop Signs facing Trail Install Overhead Lighting Move NB Stop Sign Further North
Humboldt Avenue S	Mid-block Crossing	Local Street	Stop/Yield Sign Facing Path –or– Stop/Yield Sign Facing Street	2,400	3,280	Stop Signs Facing the Street	Remove Stop Signs facing Trail Install Overhead Lighting
5th Avenue S	Mid-block Crossing	Local Street	Stop/Yield Sign Facing Path –or– Stop/Yield Sign Facing Street	1,680	2,900	Yield Signs Facing the Street	Remove Stop Signs Facing Trail
E 28th Street	Mid-block Crossing	B Minor Arterial	Stop Sign Facing Path –or– Traffic Signal	7,267	2,740	Overhead Flasher	Reduce Road from 4-Lanes to 2-Lanes at Crossing

Source.

Anderson, M. 2010 (February 15). "Memo: Midtown Greenway At-Grade Crossings." Minneapolis Department of Public Works, Traffic and Parking Services, Minneapolis, Minnesota.

Figure 36: Stop Signs on Midtown Greenway

6.5.4 Performance Measures for Multi-use Trails in Minneapolis

Problem. Determine annual average daily trail traffic (AADT) and trail miles traveled (TMT) on 80-mile multiuse trail network in Minneapolis.

Agencies. Minneapolis Park and Recreation Board (MPRB); Minneapolis Department of Public Works; University of Minnesota.

Approach. Implemented traffic monitoring protocols outlined in the FHWA *Traffic Monitoring Guide* using active infrared monitors. Monitoring was completed in 2013. Obtained mixed-mode traffic counts (i.e., undifferentiated or combined bicycle and pedestrian) for all segments in trail network. Used adjustment factors derived from six permanent, continuous monitoring sites to extrapolate short duration continuous counts on each segment. Estimated AADTT for each segment, and calculated TMT by multiplying segment AADTs times segment lengths.

Results. AADT on segments ranged from about 40 to more than 3,700, with summertime average daily traffic more than double AADT (Figure 34). Total distance traveled on the Minneapolis trail network in 2013 exceeded 28,000,000 miles.

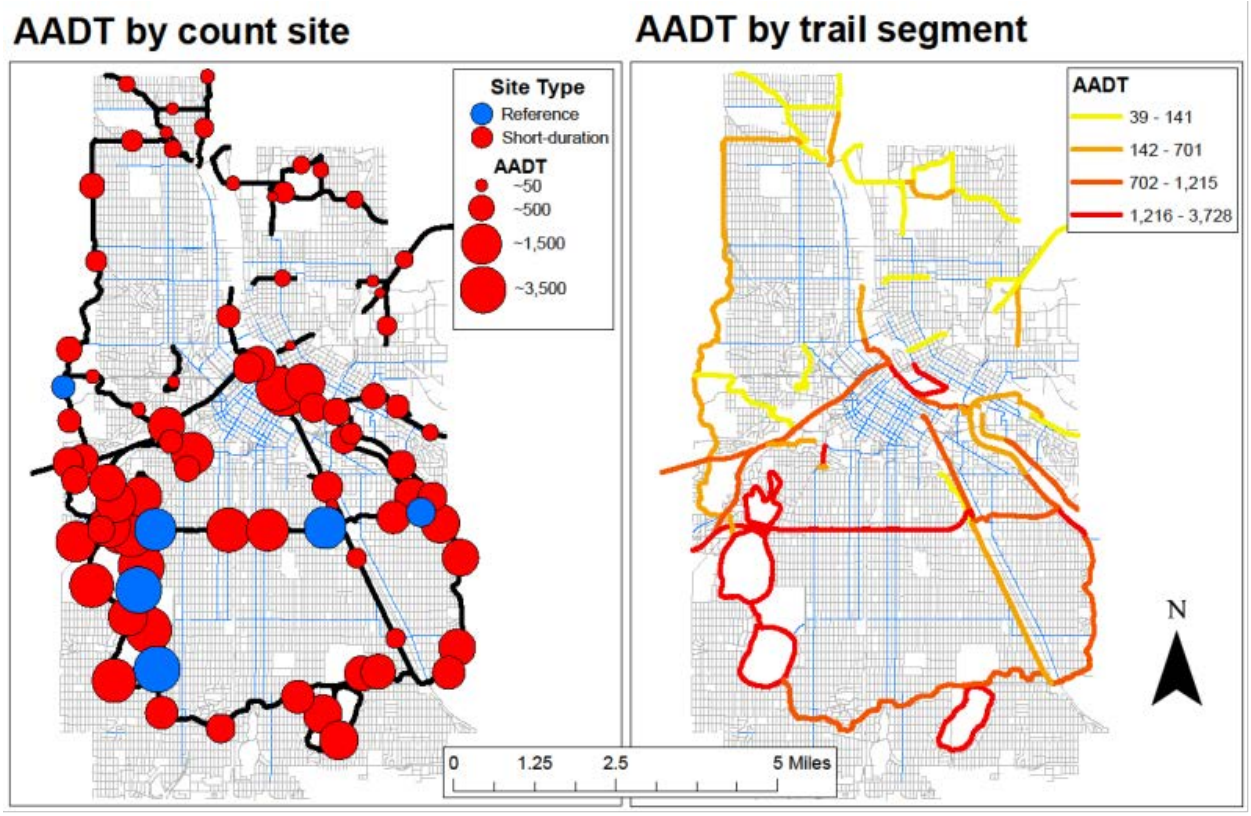


Figure 37: Minneapolis Trail AADTs by Count Site and Trail Segment (Lindsey et al. 2014)

Source.

Lindsey, G., Hankey, S., and Marshall, J. (2014) "New Performance Measures for Urban Trails." (Unpublished manuscript: in review in *Journal of Park and Recreation Administration.* (Contact G. Lindsey, University of Minnesota, Humphrey School of Public Affairs, Minneapolis, Minnesota).

6.5.5 Signal Warrants at Urban Trail Crossings in Minneapolis (ongoing)

Problem. Assess need for traffic controls at all at-grade trail-road crossings in Minneapolis.

Agencies. Minneapolis Park and Recreation Board (MPRB); Minneapolis Department of Public Works; University of Minnesota.

Approach. Used 2013 trail traffic monitoring results of mixed-mode traffic (i.e., combined pedestrians and bicyclists) to apply warrants for traffic signals and high intensity activated crosswalks (HAWK beacons) in the Manual of Uniform Traffic Control Devices. Calculated annual and summertime peak hour trail traffic volumes by segment from short duration monitoring results. Determined peak hour vehicular traffic volumes from published data. Determined street-crossing widths by measuring from curb cut to curb cut in Google Earth. Compared estimates of peak hour trail traffic with peak hour vehicular traffic at 184 at-grade trail-road crossings. Applied MUTCD warrants, and compared assessment of need to existing controls. A limitation of the assessment is that MUTCD warrants are for pedestrians and only mixed-mode trail counts were available.

Preliminary Results (Figure 35). Trail AADT exceeded street AADT at 8% of crossings, and summertime ADT exceeded street AADT at 12% of crossings. Peak hour trail traffic exceeded peak hour vehicular traffic at 15% of crossings, and summertime peak hour trail traffic exceeded peak hour vehicular traffic at 19% of crossings. Most crossings that exceed warrants have existing signals. Using estimates of peak hour trail traffic based on trail segment AADTs, 35 crossings (19%) exceed the HAWK warrant; 8 of these crossings currently do not have signals. Using peak hour estimates of trail traffic from summertime ADTs, 50 crossings (27%) exceed the HAWK warrant; 15 of these crossings currently do not have signals. Field investigations are underway to confirm preliminary results.

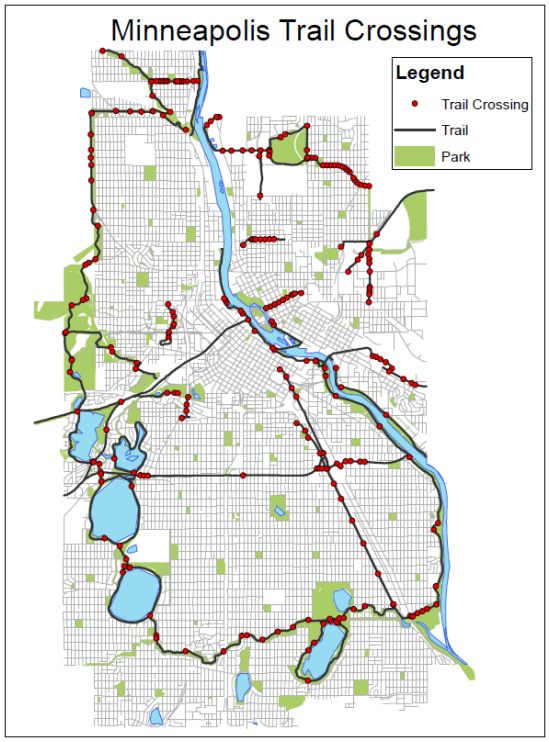


Figure 38: Assessment of Minneapolis Trail Crossings: Preliminary Results (Lindsey et al., 2015)

Table 8: Assessment of Minneapolis Trail Crossings: Preliminary Results (Lindsey et al., 2015)

		Traffic Signal Warrant (n=184)	HAWK Signal Warrant Assessment (Street Crossing Width)			
			< 35 Feet (n=67)	35 - 50 Feet (n=49)	51 - 72 Feet (n=32)	> 72 Feet (n=36)
AADT	Exceeded Warrant	4	0	9	11	15
	Existing Signal	4	0	5	7	15
	Potential Need for Controls	0	0	4	4	0
Summer ADT	Exceeded Warrant	17	0	12	13	25
	Existing Signal	13	0	5	9	21
	Potential Need for Controls	4	0	7	4	4

Source.
Lindsey, G., Peterka, M., and Hankey, S. (2015). "Assessing the Need for Traffic Controls Using Trail Monitoring Data: Preliminary Results." Unpublished analyses: Contact G. Lindsey, University of Minnesota, Humphrey School of Public Affairs, Minneapolis, MN).

7 CONCLUSION AND NEXT STEPS

Bicycle and pedestrian data collection is currently in its infancy. This collaborative program strives to join state and local agencies to collect bicycle and pedestrian traffic counts throughout the state. Recent work by the Federal Highway Administration and National Cooperative Highway Research Program has provided the foundation to make this program possible by providing state-of-the-art practices and providing guidance on monitoring alternative modes of transportation.

MnDOT strives to integrate alternate modes of transportation into its day-to-day business and culture and continues to be a leader as one of the most bicycle friendly states in the country. Coordination among agencies and participation in this program allows Minnesota to build on these goals. This document is a draft and is part of an ongoing research program. The final manual will be published in spring 2016.

7.1 Continuous Reference Sites Plan

MnDOT is currently developing plans for statewide bicycle and pedestrian monitoring at a number of locations throughout Minnesota. The approach will be based on the bicycle and pedestrian counting methods put forth in this manual and involves establishment of permanent, continuous monitoring stations at a limited number of locations throughout the state along with a larger number of short duration monitoring locations.

The purposes of the permanent monitoring stations are to track trends in traffic over time, to provide insight into exposure to risk for safety analyses, to identify patterns in traffic that can be used to interpret and extrapolate short duration counts into annual traffic estimates, and to develop performance indicators to track progress relative to MnDOT goals and objectives.

The purposes of short duration monitoring are to document variations in traffic volumes on different types of roads, to provide broad geographic coverage across the state, and to assist with evaluation of transportation investments and innovative safety treatments. Because of resource limitations, the plan does not propose comprehensive monitoring for the entire state. Instead, the plan proposes a limited number of permanent “index” sites and a greater number of short duration monitoring sites that can inform transportation planning and engineering in each district or region of Minnesota.

7.1.1 Permanent Index Monitoring Sites

MnDOT proposes to establish a network of 30 to 40 permanent index monitoring sites throughout the state, with 3-5 locations in each region or MnDOT district. The goals for location of the index sites are to include a range of types of bicycle and pedestrian infrastructure (e.g., arterials, collectors, county roads and local streets with bicycle lanes or shoulders, protected bike lanes and multi-use trails) in a range of settings (e.g., urban, suburban, rural) that are near different types of land uses that may generate different traffic patterns (e.g., commercial, mixed-use, universities.)

The index sites will be selected in consultation with MnDOT district staff and representatives of local, regional, and state agencies in each district. MnDOT will assist with and coordinate development of the network of index sites, but may not install or maintain all sites. Implementation of the network will depend on partnerships established with local agencies. To facilitate maintenance, there may be advantages to locating index sites in communities where MnDOT district offices are located. The network will include permanent monitoring sites established in 2014 in Duluth (Lake Front Trail; Scenic 61

shoulder), Eagan (Trunk Highway 13 shoulder), and Minneapolis (Central Avenue bike lane; West River Parkway Trail). MnDOT anticipates archiving monitoring results from the index sites, developing performance indicators from the results, and providing guidance to local jurisdictions in interpretation and use of data in engineering applications such as application of signal warrants.

7.1.2 Short Duration Monitoring Sites

The University of Minnesota as part of the MnDOT research project proposes to undertake short duration monitoring at a number of locations in districts throughout the state in 2015-16 to provide greater understanding of variations in bicycle and pedestrian traffic volumes in different contexts and to identify different types of traffic patterns that can be used to establish “factor groups” for purposes of analysis and extrapolation. Factor groups are groups of sites with similar hourly or seasonal traffic patterns such as commuter patterns with morning and evening peaks on weekdays or multipurpose patterns with even traffic flows throughout weekends and weekdays. In addition, short duration sites may be selected to provide other information such as traffic volumes before and after installation of new bicycle or pedestrian facilities. All short duration sites will be selected in consultation with local and regional agencies and MnDOT district staff.

Short duration sites generally will be continuously monitored for five to seven days between May and October because research indicates that error in extrapolation to annual traffic volumes is minimized with samples of this duration during periods when traffic volumes are highest. This period is longer than short duration monitoring for vehicles (i.e., 48 hours) because bicycle and pedestrian traffic varies more in response to weather.

Ongoing management of short duration counts will be the responsibility of local agencies and districts. MnDOT expects to offer training annually to share new developments in bicycle and pedestrian traffic monitoring.

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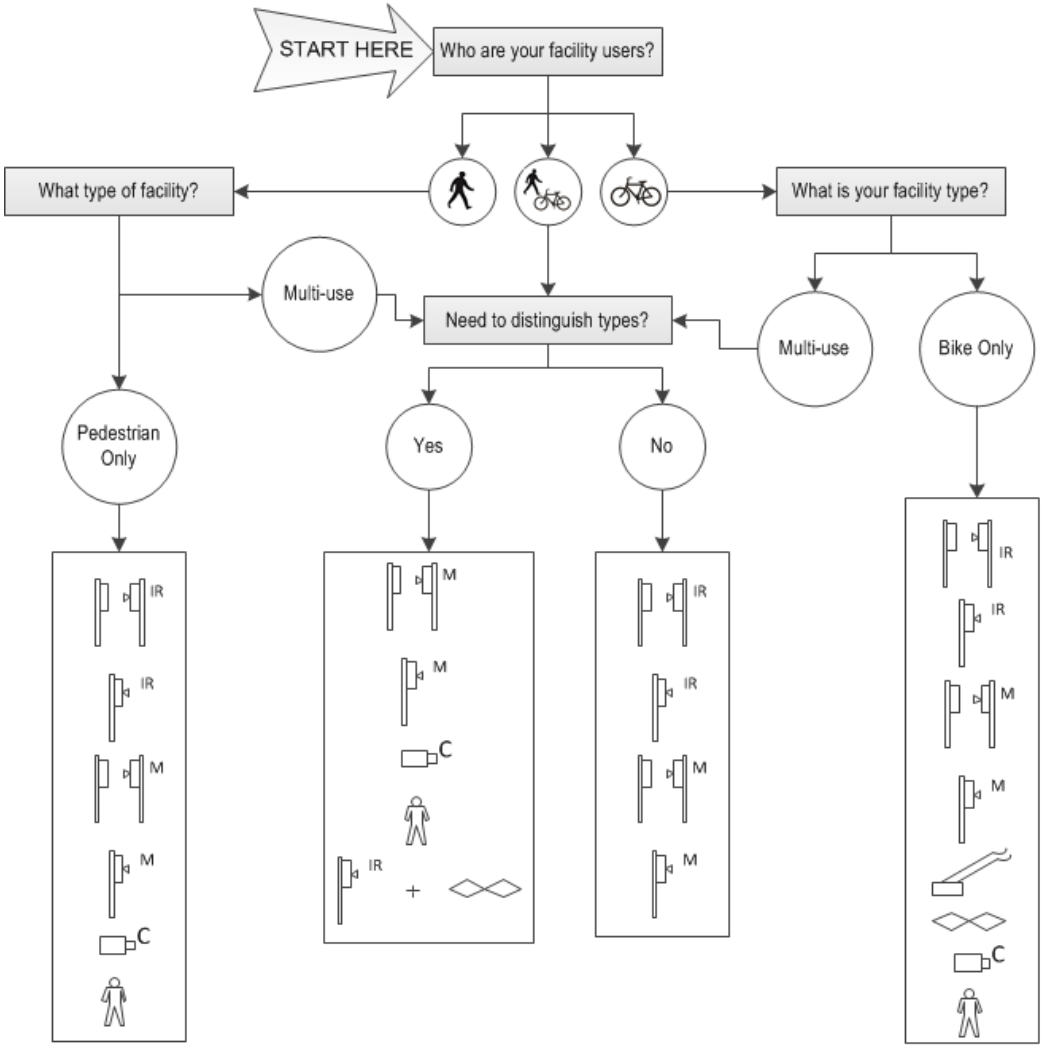
Appendix A – Sensor Selection Flow Chart



LEGEND

Active Infrared - Requires mounting equipment on each side of detection area. Review site to ensure it can accommodate sensor and receiver placement. Use for permanent or short duration counts.

Camera Images - Manual observation of video. Use for short duration counts; cost prohibitive for permanent counts.

Dual Microwave - Requires mounting equipment on each side of detection area. Review site to ensure it can accommodate sensor and receiver placement. Use for permanent or short duration counts.

Inductive Loop - Typically requires a unique loop configuration separate from motor vehicle loops, especially in a traffic lane shared by bicycles and motor vehicles. Use for permanent counts when sawcut in pavement; temporary counts for unpaved surfaces or if taped to pavement.

Manual - Use for short duration counts; cost prohibitive for permanent counts.

Microwave - Requires specific mounting configuration to avoid detection of background movement (nearby cars, bicycles or pedestrians). Ensure the product chosen is able to distinguish user type if installing on a mixed use trail or consider using dual technologies. Use for permanent or short duration counts.

Passive Infrared - Requires specific mounting configuration to avoid detection of background movement (nearby cars, bicycles or pedestrians). Ensure the product chosen is able to distinguish user type if installing on a mixed use trail or consider using dual technologies. Use for permanent or short duration counts.

Pneumatic Tubes - For bicycle detection only. Requires specific site configuration to avoid detection of motorized vehicles. Use for short duration counts; not robust for permanent installation.

Appendix B – MnDOT Standard Manual Screenline Count Form

MNDOT STANDARD MANUAL SCREENLINE COUNT FORM *DRAFT July 23, 2012*

Time		Bicyclists				Pedestrians							
						Unassisted				Assisted (skaters, wheelchairs, etc.)			
		Male		Female		Male		Female		Male		Female	
Hour	Minutes	Adult	Child	Adult	Child	Adult	Child	Adult	Child	Adult	Child	Adult	Child
	:00-:15												
	:15-:30												
	:30-:45												
	:45-:00												
Hour 1 Subtotal													
	:00-:15												
	:15-:30												
	:30-:45												
	:45-:00												
Hour 2 Subtotal													
Hour 1 + Hour 2 Total													
Two Hour Total – All Attributes													

2012 Fall Pilot Form

Appendix C – Sensor Accuracy Assessment

Whether manual counts are made in the field or in the office from video, the key steps in assessing sensor accuracy include:

1. Compare hourly totals from the manual and automated counts,
2. Calculate the percentage difference for each hour, and
3. Compute the average percentage error per hour.

The average percentage error provides a useful estimate of the relative accuracy of the sensor.

A useful step in the validation process is to create a scatterplot of the hourly automated and manual plots so their relationship can inspected visually. For example, Figure C1 is a scatterplot of counts from pneumatic tubes in two locations in Minneapolis and manual counts from video. As is evident from looking at the values of points in the graph, the hourly totals from the tube counters are lower than the hourly manual counts. In other words, the tube counters are undercounting. From inspection of the video, researchers determined occlusion – or multiple bicycles and/or vehicles passing simultaneously.

Figure C1 also includes lines that illustrate the relationship between the automated and manual counts. The equations for the lines can be interpreted as hourly "correction" equations. That is, the hourly totals from the automated counters can be adjusted using the equations to obtain a better estimate of the actual bicycle traffic volumes. Separate equations are included for each of the locations, and a more general equation based on combined data from both sites also is included. If an analyst wanted to adjust automated counts from a particular site, the equation for that site would be the best equation to use, but if, for example, an analyst wanted to adjust data from a third site for which no validation counts had been taken, the equation based on the combined data might be a better choice. The case studies in Section 6.5 of this guide includes more details on the use of correction equations.

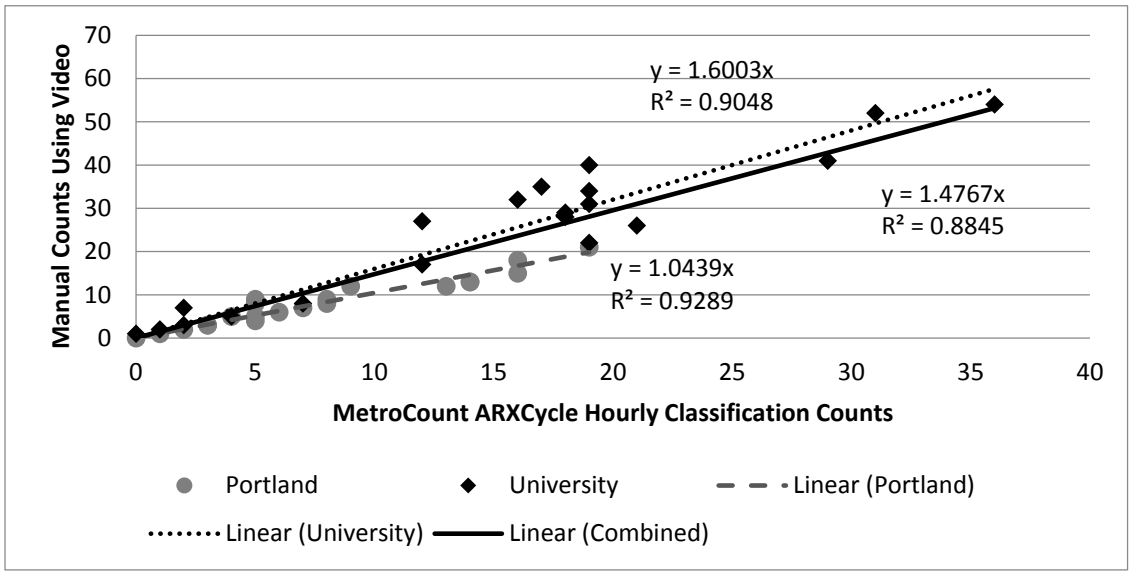


Figure C1: Scatterplot of validation counts for tube counters at two locations

Additional Considerations in Assessing Sensor Accuracy

The three general steps in assessing accuracy listed above (comparing hourly totals from automated and manual counts, computing percentage differences, and calculating the average hourly error) hold for any device, but implementation of these steps may vary depending on the features of the sensor and the ways in which the sensor stores and reports data. For example, some sensors report the exact time a cyclist or pedestrian was counted, while other sensors only report data in 15-minute, hourly, or other time "bins" (e.g., 8:00 a.m. – 8:14:59 a.m.). Some devices (e.g., integrated bicycle and pedestrian sensors) provide separate counts for cyclists and pedestrians), while pneumatic tube counters used to classify vehicles in mixed traffic flows typically offer users their choice of classification algorithms to interpret air pulses and classify traffic, including bicycles. Understanding of these types of factors is important in validating counts and assessing accuracy.

Data validation generally is easiest and potentially more accurate if time stamped rather than "binned" data is used. This is because observers can determine and compare time stamps from the sensor and video and be more precise in determination of which traffic events were counted. For example, some pneumatic tube counters can be set to report traffic events with the individual time stamps (to the second) or in 15-, 30-, or 60-minute bins. For purposes of operations, many agencies set the devices to report hourly totals because this minimizes the post-processing step of aggregating time stamps into hourly totals for analysis. However, if only hourly totals are available, the quality of validation that can be accomplished is relatively low because observers cannot determine why counts were missed (or over-counts occurred). Some devices (e.g., Eco-counters) only report binned data. If working with binned data, it is best to select the shortest period available for purposes of validation (e.g., 15 minutes). These totals then can be aggregated after data validation is complete.

An additional time-related factor that complicates validation has to do with differences in time between the sensors internal clocks, the video tape recorders internal clock, and the watches or time-pieces used by observers. Prior to initiating observation or taping, it is important to compare times so that small differences, which can affect outcomes, can be reconciled. Knowing these time differences can speed up the identification of matches and overall validation process.

Different technologies present different options for classifying and reporting traffic events. In general, three general types of output will be generated, depending on the technology and the needs of the user:

- Mode-specific traffic counts. These types of counts provide estimates of traffic volumes for specific modes. Examples include bicycle counts from inductive loops in streets and separate bicycle and pedestrian counts from microwave systems or integrated infrared and inductive loop systems. These counts cannot be reclassified, although the estimates can be adjusted for systematic under- or over-counts.

- "Mixed-mode" traffic counts that cannot be differentiated. These types of counts yield information about traffic volumes but not mode (e.g., bicycle or pedestrian, or bicycle or motorized vehicle). For example, mixed-mode counts are generated by infrared (active or passive) sensors that are used to count on facilities where there is both bicycle and pedestrian traffic. Similarly, when single tubes are deployed on roads with mixed traffic flows, they may count bicycles as part of overall traffic, but the number bicycles cannot be determined (dual tubes

are required for classification counts). From the perspective of monitoring non-motorized transportation, mixed-mode counts on shared use paths or sidewalks will be encountered and used most often.

- "Mixed-mode" traffic counts that can be classified into separate modes using classification algorithms. For example, manufacturers of pneumatic tubes typically include multiple algorithms for classification of output (i.e., axle base, vehicle speed) from tubes. Some of these classification algorithms include criteria for separating bicycles from motorized vehicles. For example, while some algorithms classify all vehicles with axle bases less than six feet as motorcycles, some classify all vehicles with axle bases less than four feet as bicycles and use other criteria to classify motorcycles. The instruction manuals for tube counters like MetroCount and TimeMark devices contain information regarding specific vehicle classification methods.

Analysts also can develop their own classification algorithms for interpreting counter output. County staff in Boulder County, Colorado, for example, developed algorithms for identifying bicycles from a variety of different vehicle classifications. When validating counts from devices that require classification of output to obtain mode-specific information, results will vary depending on the specific classification algorithm that is used. The case study of the use of counts in 6.5.1 illustrates the results of validation using different classification algorithms.

Appendix D – Adjustment Factors

This appendix illustrates the development and estimation of factor groups for non-motorized transportation by drawing on an example from analyses of counts of mixed-mode traffic on shared-use paths in Minneapolis that also is featured in FHWA's TMG (FHWA 2013).

The Minneapolis Park and Recreation Board (MPRB), the Minneapolis Department of Public Works (DPW), and the University of Minnesota have collaborated to count bicyclists and pedestrians on shared-use paths (i.e., multiuse trails) in Minneapolis since about 2010. In addition to other outputs such as daily, monthly, and annual traffic volumes, the collaboration has included:

- Estimation of day-of-week and month-of-year factors for selected permanent monitoring sites in 2011;
- An experiment in 2012 to compute standard day-of-week and month-of-year adjustment factors and compare accuracy in estimation of AADT with estimates from a novel "day-of-year factoring approach that better takes into consideration the weather conditions that affected traffic flows on each day of the year; and
- An exercise in 2013 to estimate AADT and trail miles traveled on the entire 80-mile trail network (see case study 6.5.4).

One of the useful outputs from this monitoring is a table that summarizes day-of-week and month-of-year factors for trail traffic 2011 (Table D1). Table D1 originally was prepared for inclusion in FHWA's *Traffic Monitoring Guide* as part of an example to illustrate the ratios can be used as adjustment factors to extrapolate results from short duration samples. (http://www.fhwa.dot.gov/policyinformation/tmguide/tmg_2013/traffic-monitoring-for-non-motorized.cfm).

The data in Table D1 summarize variation in monthly traffic relative to AADT. For example, the ratio of monthly average daily traffic in July (4,099) to AADT (1,975) is 2.08. This ratio means that, at this particular location, monthly traffic in July – the month with the highest traffic – is on average twice the AADT. In comparison, January average daily traffic is only about 12% of AADT. The example in the TMG illustrates how samples of different duration can be extrapolated to estimate AADT using these types of ratios. A long-term goal on the bicycle and pedestrian counting initiative in Minnesota is to develop similar tables of ratios and factors for different factor groups.

Another useful example from the same collaboration includes an experiment to assess the effect of the length of short duration samples on the accuracy of estimates of AADT (Hankey et al. 2014). This experiment also compared the accuracy of estimates of AADT using different extrapolation methods. Figure D1 includes three graphs that show traffic ratios computed from year-long monitoring results at six permanent infrared monitors on Minneapolis trails. These graphs show the ratios of average day-of-week traffic to AADT, average monthly traffic to AADT, and day-of-year traffic to AADT. For example, the day-of-week ratios show that, on average, both Saturday and Sunday traffic, are higher than AADT while weekday traffic is lower than AADT. The graph of monthly ratios shows visually what Table D1 shows, namely, that summertime traffic is about double AADT. The effects of weather on traffic volumes can be seen clearly in the day-of-year ratios, with traffic on some days as high as five times AADT.

Table D1. Mixed Mode 2011 Traffic Volume Measures for Midtown Greenway near Hennepin Avenue, Minneapolis, Minnesota												
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Monthly Average Daily Traffic	239	354	586	1,807	2,753	3,699	4,099	3,896	2,805	1,960	886	495
Sunday Average Traffic / Monthly Average Daily Traffic	0.89	1.33	0.89	1.55	0.88	1.29	1.18	1.34	1.06	1.20	0.75	1.11
Monday Average Traffic / Monthly Average Daily Traffic	1.01	0.66	1.10	1.10	0.98	0.95	0.98	0.87	1.22	0.96	1.00	1.08
Tuesday Average Traffic / Monthly Average Daily Traffic	1.10	0.74	0.91	0.96	1.27	0.89	0.91	0.74	0.86	1.03	1.01	1.07
Wednesday Average Traffic / Monthly Average Daily Traffic	1.15	0.96	0.93	0.76	1.11	0.96	0.94	1.07	0.99	0.87	1.03	0.97
Thursday Average Traffic / Monthly Average Daily Traffic	1.06	1.00	1.03	0.88	0.93	0.96	0.90	1.03	0.85	0.87	0.97	0.92
Friday Average Traffic / Monthly Average Daily Traffic	0.97	1.04	0.84	0.78	0.79	0.96	0.95	0.88	0.87	0.82	1.31	0.91
Saturday Average Traffic / Monthly Average Daily Traffic	0.88	1.27	1.34	1.03	1.02	1.02	1.09	1.15	1.23	1.16	0.91	0.98
Annual Average Daily Traffic	1,975	1,975	1,975	1,975	1,975	1,975	1,975	1,975	1,975	1,975	1,975	1,975
Monthly Average Daily Traffic / Annual Average Daily Traffic	0.12	0.18	0.30	0.92	1.39	1.87	2.08	1.97	1.42	0.99	0.45	0.25

Figure D2 shows the effects of both duration of sampling and method of factoring on estimates of AADT (Hankey 2013). For samples of between five and seven days, error in estimates of AADT can be as low as 10% - 15%. The key insights from Figure D2 are:

- The optimal length of short duration samples is between five and seven days because samples from longer time periods do not greatly increase the accuracy of estimates of AADT: and
- Use of "day-of-year" factors results in greater accuracy than the standard approach to factoring used to extrapolate short duration counts of motorized traffic. This result occurs because the day-of-year factors better reflect weather.

Other studies also have shown that sample periods of five to seven days and use of day-of-year factors result in greater accuracy in estimates of AADT (Nordback XX; Miranda). A limitation of the day-of-year factoring approach is that a year's worth of data that includes the sample periods is needed to development the factors. The standard approach, which involves estimation of factors based only on the day-of-week and month (and does not consider weather) is more general and can be applied using historical data across years. Figure D2 also illustrates that, within a fixed time period, the number of monitors required to implement a short duration count program depends on the duration or length of sampling.

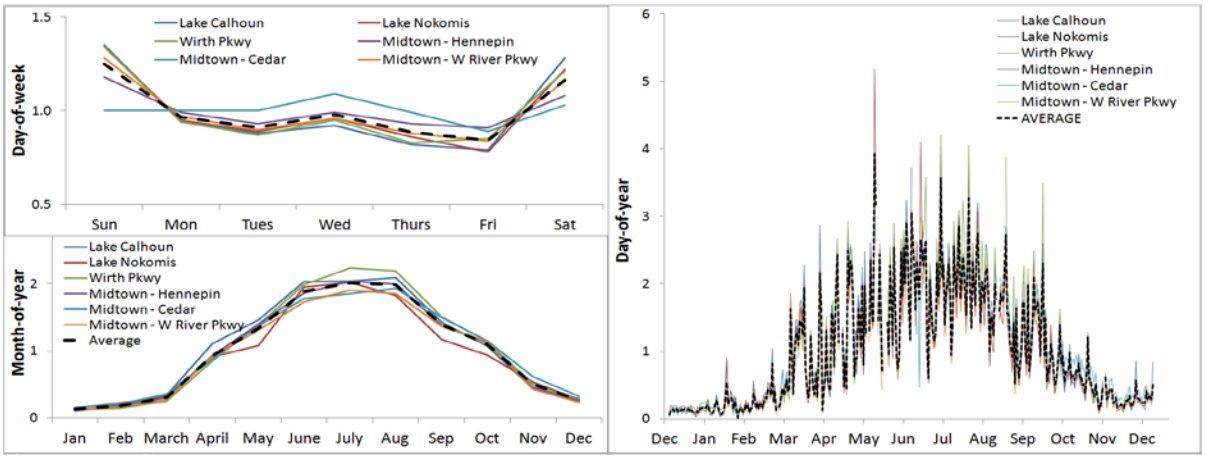


Figure D1: Day-of-week, month-of-year, and day-of-year traffic ratios at permanent monitoring stations on trails in Minneapolis

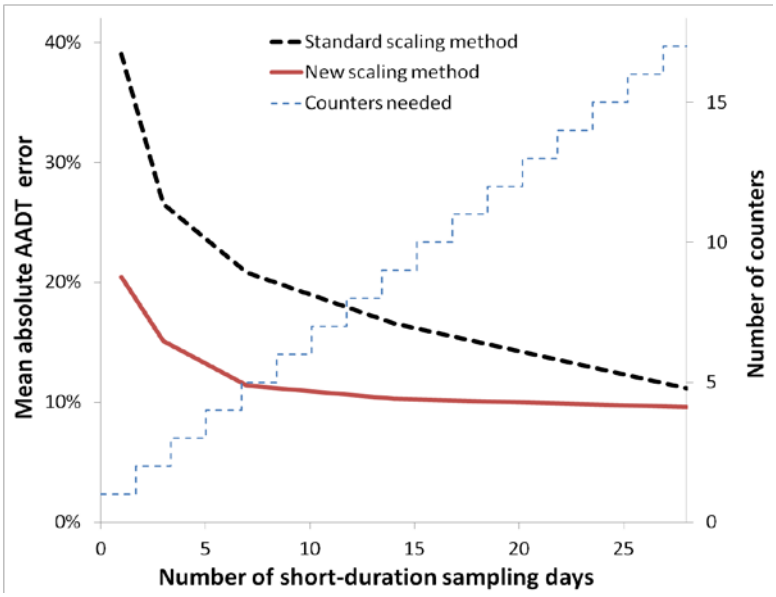


Figure D2: Effects of length of sample and extrapolation method on error in estimate of AADT (Hankey et al. 2013).

A third example that builds on these results was an exercise in 2014 to estimate AADT and trail miles traveled on an 80-mile network in Minneapolis. This exercise, which involved application of principles for factoring outlined in the TMG and used by MnDOT for factoring of motorized counts, showed that AADT on trail segments ranged from approximately 40 to more than 3,700 and that cyclists and pedestrians traveled more than 28,000,000 miles on the network in 2013. A detailed example of the use of adjustment factors is presented in the case study in Section 6.5.4.