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DEVELOPMENT OF ESTIMATION METHODOLOGY FOR BICYCLE AND PEDESTRIAN VOLUMES BASED ON EXISTING COUNTS

Krista Nordback
Wesley E. Marshall
Bruce N. Janson

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16. Abstract
The Colorado Department of Transportation (CDOT) adopted the Bicycle and Pedestrian Policy directive in 2009 stating that "*...the needs of bicyclists and pedestrians shall be included in the planning, design, and operation of transportation facilities, as a matter of routine...*" While well intentioned, this policy directive remained difficult to fulfill without sufficiently accurate estimates of bicycle and pedestrian volume on CDOT facilities. This research project enables CDOT to answer the question of whether or not these road users are being adequately accommodated by establishing Colorado-specific methodologies for estimating bicycle and pedestrian volumes via a limited sample of existing counts. Because it is not economically realistic to collect continuous count data throughout the entire CDOT system, there is a need to establish procedures for handling bicycle and pedestrian data and calculations as well as methods for estimating annual bicycle and pedestrian use from short-term counts. This work will facilitate improved use of CDOT's existing investments in collecting continuous and short-term bicycle and pedestrian count data. It will also enable CDOT to better understand the needs of bicyclists and pedestrians as well as best allocate limited resources in order to properly meet those needs.

Implementation
Using the factoring method presented in this report, CDOT can automate the estimation of AADB and AADBP, just as is currently done for motor vehicle traffic. Since the method is essentially the same and the grouping of the sites can be automated, this should not require significant staff time. By publishing the non-motorized traffic counts and annual average daily bicyclists (AADB) and annual average daily bicyclists and pedestrians (AADBP) estimates on its website, CDOT can share this processed data with local agencies throughout the state.

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EXECUTIVE SUMMARY

The Colorado Department of Transportation (CDOT) adopted the Bicycle and Pedestrian Policy directive in 2009 stating that "*...the needs of bicyclists and pedestrians shall be included in the planning, design, and operation of transportation facilities, as a matter of routine...*" (CDOT 2009). While well intentioned, this policy directive remained difficult to fulfill without sufficiently accurate estimates of bicycle and pedestrian volume on CDOT facilities. This research project enables CDOT to answer the question of whether or not these road users are being adequately accommodated by establishing Colorado-specific methodologies for estimating bicycle and pedestrian volumes via a limited sample of existing counts. Because it is not economically realistic to collect continuous count data throughout the entire CDOT system, there is a mounting need to establish procedures for handling bicycle and pedestrian data and calculations as well as methods for estimating annual bicycle and pedestrian use from short-term counts. This work will facilitate improved use of CDOT's existing investments in collecting continuous and short-term bicycle and pedestrian count data. It will also enable CDOT to better understand the needs of bicyclists and pedestrians as well as best allocate limited resources in order to properly meet those needs. Local and regional agencies will benefit from this research via data usage as well as access to the procedures and methodologies.

In terms of preliminary background research, the team surveyed the state-of-the-practice literature for bicycle and pedestrian volume estimation and contacted local, state, and national agencies working with bicycle and pedestrian count data. We then collected and evaluated existing bicycle and pedestrian continuous count data from across the state of Colorado. After organizing and cleaning the data gathered, the analysis work first focused on developing and validating bicycle and pedestrian volume models based upon direction of travel, hourly peaking, seasonality, weather, and special events. In an effort to determine the best methods for CDOT, the research team tested various statistical estimation methods as well as factor-based methods recommended by the literature and state-of-the-practice. To assess the viability of applying existing motor vehicle factors to bicycle and pedestrian data, the research team also overlaid and compared variations in bicycle and pedestrian volumes to variations for motorized traffic volumes.

The literature review uncovered that much of the work on non-motorized traffic has been focused on how spatial variables – such as infrastructure and proximity to destinations – influence bicycling and walking. However, with improvement in continuous count technologies increasing available count data, some studies have investigated the impact of variables that vary with time, such as the hour of the day, the day of week, season, and weather. These studies find that such temporal variables, including temperature and precipitation, do indeed impact non-motorized traffic volumes. The National Bicycle and Pedestrian Documentation Project (NBPDP) even offers a set of expansion factors by climate zone, which they suggest can be used for estimating pedestrian volumes and combined bicycle and pedestrian volumes on trails [1]. However, work by Milligan, Poapst, and Montufar finds that factors developed from local motorized traffic more accurately estimate annual average pedestrian traffic than use of the NBPDP factors.

We then researched the question of whether CDOT should apply existing factors from motorized traffic to the estimation of annual average daily bicyclists and pedestrians (AADBP) by comparing motor vehicle traffic patterns to non-motorized traffic patterns for four test cases occurring along the same roadway, corridor, or in the vicinity of each other. These analyses found that motorized and non-motorized traffic are sometimes, but not always, correlated and are sometimes inversely correlated. The highest correlation is with monthly patterns; however, motorized traffic has much less seasonal variation than non-motorized traffic. Even though some of the motorized and non-motorized count stations were on the same corridor, they did not necessarily share the same travel patterns, indicating that bicyclists and pedestrians may be using the corridor for different trip purposes than motorized users. For this reason, applying motorized factors to non-motorized traffic is not expected to lead to highly accurate estimates, except in specific circumstances. In such cases, the motor vehicle factor group with the most seasonal variation (CDOT Factor Group 3) appears to be the closest fit to non-motorized seasonal patterns.

Several other methods for estimating AADBP were investigated including: i) the factor method similar to that used for motor vehicles; and ii) multiple statistical models that incorporated hourly weather data. After exhaustive analysis of the Boulder bicycle count data, it was found that including weather data in a statistical model does increase the accuracy of the estimates; however, the additional work needed to incorporate such a method into CDOT's existing databases software does not warrant the marginal increase in accuracy at this time. Factoring methods are simpler, work well with CDOT's data management system, and require much less staff time to implement.

Additional analysis was performed to determine how to group Colorado's count stations, following the three factor group recommendations (i.e. commute, recreational/utilitarian, and mixed trip purposed) of Turner *et al.* [2]. We performed cluster analysis on the factors computed from the continuous bicycle and pedestrian counts. While data from the Broomfield station shows that bicyclists and pedestrians do have different travel patterns at the same location, the cluster analysis seems to indicate that at least for daily and monthly factors, bicyclist and pedestrian factors can be grouped with bicyclist only factors. Our analysis then found that using three groups is appropriate for the Colorado data: mountain non-commute, Front-Range non-commute, and commute. A simple method for determining the appropriate group for each continuous and short-term count station is presented.

Daily and monthly factors were computed for each factor group (presented in Table 18). The methods used to create the factors is presented and validated by comparing estimates to actual annual average daily bicyclist (AADB) values at one test site. Average error, given one week of short term counts, was estimated at approximately 20% for the test site. Error can be reduced with short-term counts collected during the months of May through October when non-motorized use is highest.

Implementation Statement

Using the factoring method presented herein, CDOT can automate the estimation of AADB and AADBP, just as is currently done for motor vehicle traffic. Since the method is essentially the same and the grouping of the sites can be automated, this should not require significant staff time. By publishing the non-motorized traffic counts and AADB and AADBP estimates on its website, CDOT can share this processed data with local agencies throughout the state, thus providing value added to all those local agencies that have provided motorized and non-motorized count data to CDOT. The factoring method and the factors themselves will also be of great interest beyond the state's borders – to other DOTs, researchers, and practicing transportation professionals – since CDOT would be the first DOT to create such factors. For this reason, the research team has presented parts of this work at national conferences and will work to publish relevant sections of this report.

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INTRODUCTION

In 2009, CDOT adopted a new bicycle and pedestrian policy directive stating that:

> *"It is the policy of the Colorado Transportation Commission to provide transportation infrastructure that accommodates bicycle and pedestrian use of the highways in a manner that is safe and reliable for all highway users. The needs of bicyclists and pedestrians shall be included in the planning, design, and operation of transportation facilities, as a matter of routine. A decision to not accommodate them shall be documented based on the exemption criteria in the procedural directive"* (CDOT 2009).

This directive was codified by the state legislature in 2010 and is now part of the Colorado Revised Code (Colorado Revised Statutes 43-1-120). While the CDOT directive is noteworthy for its intent, additional efforts and support with regard to bicyclists and pedestrians need to be put in place. In other words, before we are able to truly meet this policy directive, we must first understand the needs of bicyclists and pedestrians in the planning, design, and operation of transportation facilities.

Part of that understanding is quantifying existing bicycle and pedestrian use and behavior. Accordingly, CDOT initiated a program in 2009 to begin collecting continuous bicycle and pedestrian count data, and in mid-2010, CDOT acquired six mobile, short-duration counters. Since that time, these counters have been used on street and trails throughout the state of Colorado for durations as short as 24 hours to as long as two months. Such data collection has been indispensable in beginning to plan for and accommodate bicyclists and pedestrians; however, the data collected is only appropriate in the locations where the counts have been taken. Furthermore, it is not economically realistic to collect continuous count data throughout the entire CDOT system. Thus, there is an increasingly mounting need to establish procedures for handling bicycle and pedestrian data and calculations as well as for methods estimating annual bicycle and pedestrian use from short-term counts.

This baseline usage information will not only help enable CDOT operations and maintenance staff to better meet the needs of existing users, but it will also facilitate a more complete understanding of changes in the quantity and pattern of bicycle and pedestrian use over time and in relation to key issues such as safety. The resulting quantitative measures will begin to allow estimates of future use as well as potential use on both existing and new facilities. As stated in the CDOT Research Study Proposal, "*CDOT cannot adequately meet the demands outlined in the Bicycle and Pedestrian Procedural and Policy Directives due to a lack of bicycle and pedestrian volume data and established estimation methods.*"

Accordingly, the primary research objective of this study is to generate models for estimating bicycle and pedestrian volumes using short-term count. Overall, the key project tasks include:

- Survey the state-of-the-practice literature for bicycle and pedestrian volume estimation;
- Contact local, state, and national agencies working with bicycle and pedestrian count data;
- Collect and evaluate existing bicycle and pedestrian count data from around the state of Colorado;
- Overlay and compare variations in bicycle and pedestrian volumes to variations for motorized traffic volumes;
- Develop and validate bicycle and pedestrian volume models based upon direction of travel, hourly peaking, seasonality, weather, and special events;
- Document standard bicycle and pedestrian statistical estimation methods in a procedures report for CDOT facilities; and
- Nationally disseminate findings in peer-reviewed journal papers and presentations at key conferences.

This research will provide a means of estimating existing bicycle and pedestrian volumes as well as enhance our ability to estimate future usage. Such information will enable transportation planners and engineers to better plan the complete streets for all modes of transportation that they have been tasked with designing. Furthermore, this work will help CDOT, as well as other local and regional agencies, to best allocate their limited resources with a more thorough understanding of bicyclists and pedestrians. This research will not only be disseminated in academic journals and with presentations at conferences, but the goal is also to work toward establishing CDOT as a national leader in this field.

The contents of the following report adhere to the tasks put forward in the research proposal submitted in September, 2011, which was subsequently presented and approved by the CDOT study panel in January, 2012.

TASK 1: BACKGROUND RESEARCH AND DATA GATHERING

Task 1A: Literature Review and State of the Practice

The intent of the literature review is to set the work in the appropriate context not only by providing sufficient background but also by using the existing research to inform this effort. The first section focuses on existing work in the realm of counting pedestrians and bicyclists. This includes an overview of the automated count techniques that have been used in Colorado. The next section reviews the literature that considered seasonal factors in bicycle and pedestrian count estimation. This section is divided into those that looked just at bicycles, just pedestrians, or both combined. The last portion of the literature review focuses on the existing work on estimating bicycle and pedestrian volumes from spatial variables as opposed to using count data. While these studies are somewhat tangential to the temporal variation focus of this work, it may be a topic that is of interest to CDOT in the future.

The subsequent components of Task 1A include: i) contacting agencies known for bicycle and pedestrian data for information and methods relevant to this study and reviewing the related work; and ii) contacting key city and county agencies to help define Colorado specific methodologies for factoring. Each set of these stakeholder engagement efforts will not only provide the research team with additional information about current work being done in this area, but it will also help establish early knowledge of our research project with those most likely to apply the results of this project.

Task 1A: i) Literature Review

Counting Pedestrians and Bicyclists

Counting bicycles on roadways, paths, and at intersections provides facility level data on bicycle use, which cannot be gathered from surveys and is necessary to understand the safety impact of facility design and other spatial variables. The research team conducted a thorough review of the literature and methods used for counting bicycles and pedestrians [3]. There are numerous methods employed in counting bicycles, but there are only two fundamental time periods on which counts are made: short term counts and continuous counts. Short term counts can be as short as 15 minutes or as long as two weeks and can either be done manually or by automated technologies. Continuous counts typically span multiple months and are usually multi-year. Such counts are generally binned in time periods of 2 hours or less, sometimes with each bicycle time stamped individually. Since conducting manual counts (either in person or via video) 24-hours per day, 365 days per year would be an unreasonable task to ask of volunteers and prohibitively expensive for which to hire staff, continuous counts are gathered by automated counters.

The research suggests that both short-term counts and continuous counts are needed to gain an understanding of bicycle travel over the network [4]. Ideally, all count locations would be continuous counters, but since the establishment of such sites generally comes with an initial capital outlay of $2,000 to $10,000, it is not practical to place counters at all locations where counts are desired. For similar reasons, short-term motor vehicle counts are done at many locations and annualized based upon data from continuous counters on similar facilities in the vicinity of the short term count. We will use the same approach herein to annualize bicycle counts. An automated system of counters provides a means of updating bicycle use estimates more often as well as the potential to understand how bicycle travel is impacted by temporal and spatial variables. Table 1 summarizes common technologies available for short term and continuous counts on different bicycle facilities.

Table 1. Automated Bicycle and Pedestrian Count Technologies for Different Conditions.

	Short-Term	**Continuous**
BICYCLES		
Off-street separated path	Pneumatic tube Piezoelectric film Active Infrared	Inductive loops Piezoelectric film Active Infrared
On-street bike lane	Pneumatic tube	Microwave radar Inductive loop Video Detection
On-street mixed traffic	Pneumatic tube	Microwave radar Inductive loop Combo: Sonic, infrared, video
PEDESTRIANS		
Pedestrian only path or sidewalk	Passive and Active Infrared	Passive and Active Infrared Pressure pad
COMBINED BIKES AND PEDESTRIANS		
Multi-use path	Passive and Active Infrared	Passive and Active Infrared

The following provides more detailed information regarding the automated count techniques that have been used in Colorado.

Inductive Loop Detectors

Inductive loop detectors are commonly used to detect motor vehicles at traffic signals and are the most common vehicle sensor type in traffic management. The circuit is composed of loops of wire embedded in the pavement and the associated lead-in cables. The detector constantly senses the inductance in the circuit by measuring the resonant frequency of the circuit. When a metal vehicle passes above the loops, it induces eddy currents in the circuit, which changes the circuit's inductance [5]. Bicycle detection by inductive loops was studied in detail by Kidarsa [6], who modeled the extent of bicycle detection zones for typical traffic signal loop detector configurations. The exact configuration of the inductive loops can have a large impact on accuracy.

Inductive loop detectors are relatively low cost, well understood by transportation technicians, and easy to maintain. Loops can be installed by saw cutting the pavement and placing the loop in the cut slots. If the detector is installed prior to concrete placement, no saw cutting is needed as the loop can be placed in the base course below the concrete. However, such detectors cannot detect pedestrians. Inductive loop detectors can be sensitive to fluctuations in electric fields near the detectors and must be adjusted with the proper sensitivity settings to accurately detect bicyclists.

Passive and Active Infrared Sensors

Both passive and active infrared sensors operate by detecting objects, which break the infrared beam. In the case of passive sensors, only the number of beam breaking events is counted. In the case of active infrared sensors, the speed of the object that breaks the beam can also be observed. This allows the detector to differentiate cyclists from pedestrians, but since some cyclists may pass the detector at slower speeds and some runners may travel at faster speeds, the criteria for differentiation are imperfect. Neither type of infrared sensor detects traveler direction. This technology relies on aboveground infrared beam equipment located near the path, approximately at chest height. Due to the location of the infrared unit, vandalism and misalignment can be problems [7].

Automated Video Detection

Signal detection cameras can also be used for vehicle counts, though since this is a secondary function, there may be tradeoffs in device accuracy.

Seasonal Factors

The Traffic Monitoring Guide provides detailed guidance on how to create seasonal factors for motor vehicle traffic, but it does not address bicycle and pedestrian traffic estimation [8]. One hypothesis was that the methods used for creation of seasonal factors for motorists could be applied to bicycle and pedestrian traffic, and the National Bicycle and Pedestrian Documentation Project has attempted this by creating factors for mixed bicycle and pedestrian paths and for higher density pedestrian traffic areas [1]. Their documentation states: *"Once you have* *calculated your total daily, monthly, or annual volume, you can simply multiple the total by the percent breakdown between bikes and pedestrians based on your original count information."* Since the percent pedestrians vary substantially with weather (based on continuous counts from Arlington, VA, where bicyclists and pedestrians were broken out as shown in the appendix of [9]), such a simplification may lead to inaccurate estimates of either bicyclists or pedestrians.

Bicycle Volumes

Several studies have examined bicycle and pedestrian volumes by time of day and day of week, and sometimes season [10-13]. The purpose of some of these studies is often for planning, design, or safety studies. These studies typically consider the percent of counts during each time period to provide a simple way of scaling up short term counts.

While no established factors exist to estimate variation in bicycle use by season and weather, some work has been done in this area.

- Nankervis examined the impact of weather on bicycle volumes in a university area in Melbourne, Australia, and found that weather in the morning was probably more important than later in the day and that rain was more critical than wind and darkness [14].

- Researchers in Sweden studied winter cycling and found a 47% decrease in winter bicycling trips from summer trips and that cycling volumes were negatively affected below 41°F [15].

- In 2005, Lewin wrote her University of Colorado Denver Master's thesis using Boulder inductive loop detectors at two locations to study bicycle flow with temperature, precipitation, time of day, and day of week [16]. She created linear models of how bicycle flow at each location varied with relevant factors and found that for temperatures above 90°F, bicycle use seems to decrease. Figure 1 depicts this relationship.

- A macro level study of 100 large North American cities found that days over 90°F was negatively correlated with both the mode share of bicycle commuters in the city and the number of bicycle commuters per population [17].

- A study of bicycle ridership using continuous count data at five locations in Montreal, Canada, used a negative binomial model to find that temperature, humidity, and precipitation were all significant predictors of bicycle volumes [18]. The researchers found that: the month with highest ridership was September, probably due to students; Wednesdays had the highest ridership; and the peak hours were 7 to 9 AM and 4 to 6 PM. They also investigated the impact of weather prior to the weather currently being experienced and the impact of deviations from normal. They found that precipitation does have a lagging effect, such that precipitation in the past three hours or morning influenced ridership later in the day.

- In Minneapolis, a study of bicyclist and pedestrian volumes was conducted on urban roads and paths [11]. While this study focused on spatial variables, temporal and weather variables were also examined. The counts were collected manually in the fall on weekdays with no or low precipitation. They found that bicycle volumes were significantly lower when precipitation occurred and when there was a large deviation from average temperatures. They were significantly higher when temperatures were higher. They found that 5 to 6 PM was the peak hour for cyclists, and that the morning peak was from 8 to 9 AM, but with fewer cyclists.

- In Portland, Oregon, researchers found that peak traffic on the Hawthorne Bridge is highest on Mondays, while in Melbourne, Australia, Tuesdays represented the highest volumes [19]. Temperature and precipitation were found to be significant factors in both cities for predicting cyclist volumes, but the results suggested that rain is less of a factor in Portland than Melbourne. This is hypothesized to be due to the type of rain, since rain in Portland is more of a constant drizzle while rain in Melbourne can be heavy. Wind and humidity were not studied.

- A study of bicycle commuters in Vermont found that precipitation, temperature, wind, and snow were significant predictors of the probability that a person would choose to commute to work by bicycle. The study used survey responses instead of count data [20].

Additional studies of variation in bicycle use by weather in Europe include Brandenburg et al.'s study of cyclists in Vienna and Thomas et al.'s study of cyclists in the Netherlands, [21, 22].

Pedestrian Volumes

- A study of pedestrian activity at intersections in downtown Montreal, Canada, found that pedestrian activity was directly related to distance from downtown and that pedestrian activity decreased 22% for very warm weather (over 30° C = 86° F) [23].

- In Minneapolis, a study of bicyclist and pedestrian volumes was conducted on urban roads and paths. While the study focused on spatial variables, temporal and weather variables were also examined. The counts were collected manually in the fall on weekdays with no or low precipitation. They found that pedestrian volumes were significantly higher when temperatures were higher and lower when there was a large deviation from average temperatures, but found no significant difference with precipitation. They found that 5 to 6 PM was the peak hour for pedestrian traffic and did not observe a morning peak in pedestrian traffic, though there was a peak from noon to 1 PM [11].

- In order to study pedestrian safety at 81 intersections in Alameda County, California, Schneider used automated counters at 11 locations to create temporal factors to estimate pedestrian volumes and developed a statistical model to estimate pedestrian volumes at urban intersections based on land uses, weather, and season [13, 24].

Combined Pedestrian and Bicyclist Volumes

Two studies of combined non-motorized user volumes on urban networks in the US are of interest:

- In Indianapolis, analysis of combined bicyclist and pedestrian trail use counted using automated infrared counters suggested that August pedestrian and bicycle traffic is 8.7 times January trail use [25]. Additionally, they found that spatial socio-demographic conditions surrounding the trails had a significant impact on trail use.

- The Seamless Travel Project studied pedestrian and bicycle traffic on paths and sidewalks in San Diego using volumes from both active and passive infrared counters, some of which were capable of differentiating between bicyclists and pedestrians by speed [12]. This study focused on how facility type, land use, and other factors impacted non-motorized traffic volumes, but also considered time of day and day of week. As the weather in San Diego is relatively mild, weather was not a large factor in the study. They found that bicyclists and pedestrians had nearly identical patterns of use on paths and identified peak use periods that:
    - Bicyclists traveled more for recreation than pedestrians;
    - There were no sharp commute patterns for pedestrians and bicyclists;
    - The percent of commute trips, shopping/utilitarian trips, and recreational trips by non-motorized modes mirrored those of national all mode trips;
    - Locations with more recreational use had more daily fluctuations in use;
    - While nationally pedestrians outnumber bicyclists on trails 75% to 20%, there were more cyclists than pedestrians on the San Diego trails;
    - Weekends had higher volumes than weekdays;
    - 95% of travel on the trails was between 6 AM and 9 PM while 11 AM to 1 PM is the peak time period overall; and
    - July had the highest volumes and March the second highest.

Not surprisingly, the results from the San Diego study portray a very different picture of bicycle and pedestrian use than what we found on many of the trails and roads studied in Colorado.

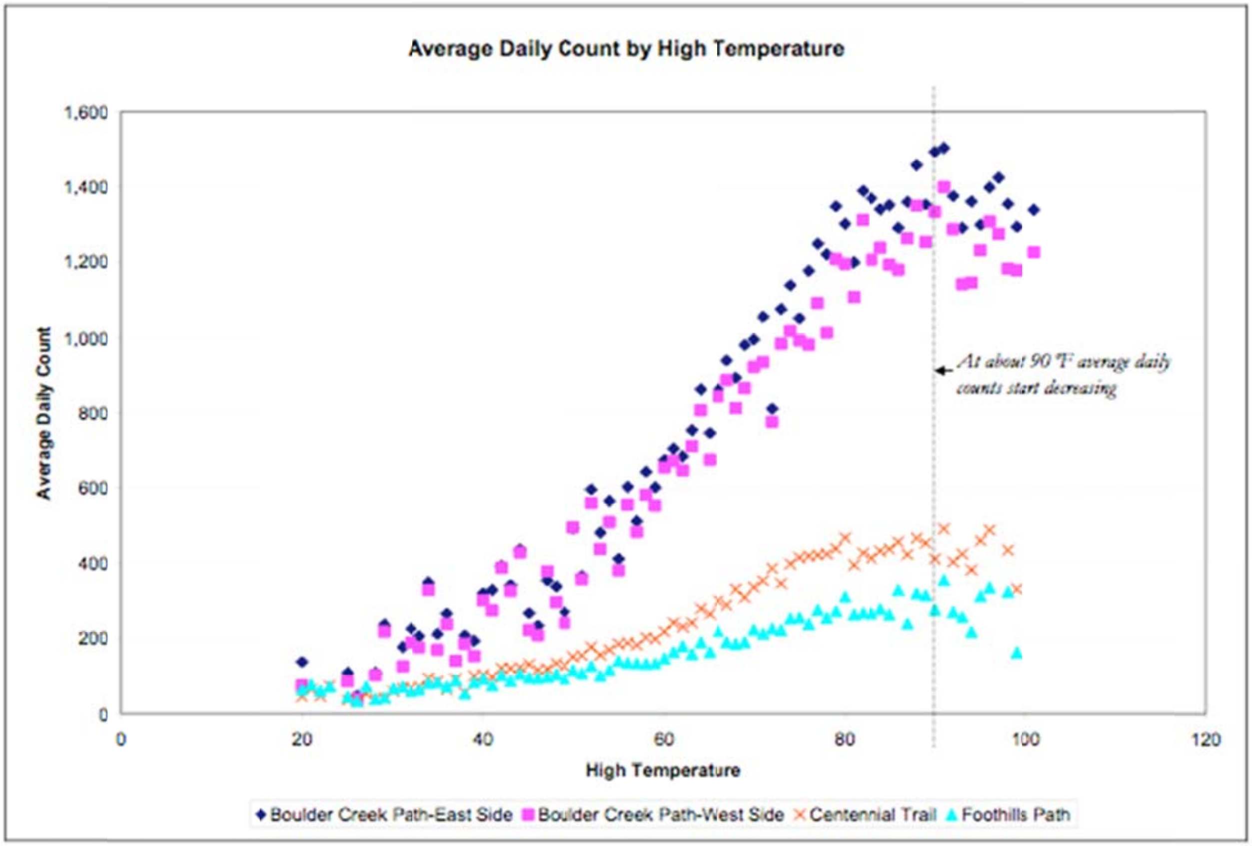

Figure 1. Average Daily Counts from Automated Detectors in Boulder on 3 Multi-use Paths from Lewin's Master's Thesis [16].

Estimating Bicycle and Pedestrian Volumes from Spatial Variables

Efforts to estimate demand for bicycle and pedestrian use based on spatial and design variables might also be used to estimate volumes of non-motorized users at locations where counts are not collected. Much study has focused on this area, but it is somewhat tangential to the temporal variation focus of this report. However, it is worth a brief discussion of this line of research, since this may be a topic that CDOT decides to further explore in the future.

Some of the studies discussed above and many other studies include spatial variation in bicycle and pedestrian counts. Studies of bicyclist and pedestrian volumes in Alameda County, Montreal, Minneapolis, and Indianapolis have already been discussed [13, 24], [23], [11, 25]. Additional studies of spatial variation in pedestrian volumes primarily, but also in bicycle volumes, have been conducted in Santa Monica, Charlotte, and Seattle [26, 27]. To support the creation of exposure metrics for safety studies, estimates of pedestrian crossing volumes and bicyclist on-street and crossing volumes have been done based on land use and road type as well as other spatial and temporal variables [10]. Additionally, much work on estimating bicycle and pedestrian travel demand has been conducted and is summarized in various reports [28-30].

Based on these studies, spatial variables of importance to bicyclists include:

- Socio-demographic variables such as age, ethnicity, education, and income;
- Land use variables include population density, land use mix, percent parking lots, percent commercial, and distance to downtown, shopping, ocean, or university; and
- Infrastructure related variables such as distance to a multi-use trail or bus line, bicycle facility type, terrain, speed limit, network connectivity and network street length within a half mile radius.

Table 2. Bicycle and Pedestrian Count Studies by Variable.

Study (Author, year)	**Location**	**Modes (Bike or Ped?)**	**Primary Temporal Variables**
Estimating urban trail traffic: Methods for existing and proposed trails [25]	Indian-apolis, IN	Bike and Ped combined on paths at 30 infrared count locations	Weather: daily deviation from average temperature, precipitation, snow, and sunshine Time: Weekend, month Special Event: State Fair
Forecasting Use of Non-Motorized Infrastructure: Models of Bicycle and Pedestrian Traffic in Minneapolis, Minnesota [11]	Minne-apolis, MN	Bike and Peds separately, volunteer counted on street segments and intersections in the fall, no rain. 43 12-hr counts. Total 240 locations	Weather: daily high temperature, daily deviation from average high temperature, and daily precipitation Time: Hour (5-6 PM peak) Weekend, month

Study (Author, year)	**Location**	**Modes (Bike or Ped?)**	**Primary Temporal Variables**
Methodology for Counting Pedestrians at Intersections: Use of Automated Counters to Extrapolate Weekly Volumes from Short Manual Counts [24]	Alameda County, CA	Pedestrians, 50 intersections manually counted with video, 11 approaches counted automatically with infrared EcoCounter. 11 counters averaged, factors computed	Weather (dummy variables) Cloudy, cool temp, hot temp Time hours to weekly
Pedestrian activity modeling at signalized intersections: land use, urban form, weather and spatio-temporal patterns. [23]	Montreal, Quebec, Canada	Pedestrians, Intersections manually counted	Weather (>86°F decreases counts)
Whether or not to cycle; whether or not cyclist ridership has grown: a look at weather's impact on cycling facilities and temporal trends in an urban environment [18]	Montreal, Quebec, Canada	Bicyclists from continuous counts at five inductive loop locations (EcoCounter) 2008 to 2010, April through November only (bike routes closed in winter. Negative binomial model	Weather: Hourly temperature, humidity, precipitation (dummy), lag effects of weather, deviation % of rain, precipitation, wind, and temperature from normal Time: Year, month, day of week, hour
Weather and cycling – a first approach to the effects of weather conditions on cycling [22]	Vienna, Austria Park	Bicyclists from one permanent video location, manual counts dawn to dusk in 2002	Weather: Temperature, precipitation and physiologically equivalent temperature (PET) Time: Hours
Quantifying and comparing the effects of weather on bicycle demand in Melbourne (Australia) and Portland (USA) [19]	Portland, OR, and Melbourne, Australia	Bicycle only from inductive loop detectors in paths (6 months of data) Log linear model	Weather: Temperature, precipitation (in mm) Time: Day of week, holidays

Task 1A: ii) Contacting Other State Agencies

On Tuesday, December 20, 2011, an email was sent to a list of 51 state agency contacts that were previously part of a travel monitoring survey of state agencies [31]. The list included one contact for each state and the District of Columbia. The text of the email was as follows:

> *Hello! The University of Colorado Denver is conducting a study on behalf of the Colorado Department of Transportation (CDOT) to create a method for estimating annual bicycle and pedestrian volumes in Colorado. As part of this, CDOT has asked us to contact other state agencies to find out what information and methods are used for non-motorized modes in other states. Below are a few specific questions, but please feel free to just tell us what you already know off the top of your head.*
>
> 1. *Does your state collect continuous (24-hour or longer) bicycle and pedestrian counts?*
> 2. *If so, what do you use them for?*
>   a. *Planning purposes?*
>   b. *Design of new facilities?*
>   c. *Creating seasonal factors to estimate annual bicycle and pedestrian volumes based on short term counts?*
>   d. *Safety evaluations?*
>   e. *Other?*
>   f. *None of the above.*
> 3. *Off the top of your head, do you know of any MPO's or other agencies in your state that are also collecting continuous bicycle and pedestrian counts and/or using such counts?*
>
> *We appreciate any information you would like to share before January 6. Thanks for your help!*

Seven email addresses were undeliverable, including California. A follow up email was sent to the following addresses with a Feb. 6, 2012 deadline:

- Vermont: jon.kaplan@state.vt.us;
- California: penny gray@dot.ca.gov;

- Florida: dennis.scott@dot.state.fl.us;
- Virginia: cindy.engelhart@vdot.virginia.gov;
- Delaware: anthony.aglio@state.de.us;
- Washington: rosenj@wsdot.wa.gov, macekI@wsdot.wa.gov;
- Wisconsin: jill.mrotekglenzinski@dot.wi.gov, susie.forde@dot.wi.gov;
- Alaska: maryann.dierckman@alaska.gov, bob.laurie@alaska.gov;
- Utah: nvirgen@utah.gov;
- Iowa: ronald.bunting@dot.iowa.gov, milly.ortiz@dot.iowa.gov;
- Nevada: rtravis@dot.state.nv.us; and
- Idaho: glenda.fuller@itd.idaho.gov.

Responses are summarized in Table 3, and a complete set of responses are presented in Appendix A. Responses were received from 19 states, seven of which said they had collected continuous bicycle and pedestrian counts at least at some time in the past, and only Vermont is using the data to compute factors.

Table 3. Responses from State Contacts.

State	Contact	Continuous Bike/Ped Data Collected?	Bike/Ped Data annualized?
Arkansas	Elizabeth Mayfield-Hart	No	No
Connecticut	Kerry Ross, Katherine Rattan	No	No
Florida	Dwight Kingsbury	Yes	No
Idaho	Glenda Fuller, Maureen Gresham	No	No
Illinois	Rob Robinson, Mike Miller	No	No
Minnesota	Gene Hicks, Lisa Austin	No	No
New York	Kurt Matias, Eric Ophardt	No	No
Nevada	Randy Travis	No	No
Oklahoma	John R. Bowman	No	No
Oregon	Don R. Crownover	Yes	No
Pennsylvania	Laine Heltebridle, Jeremy M. Freeland	No	No
Rhode Island	David A. Doyle, Jr.	Yes	No
South Dakota	Kenneth E. Marks	No	No
Tennessee	Steve Allen, Jessica L. Wilson	No	No
Vermont	Jon Kaplan	Yes	Yes
Virginia	Cindy Engelhart	Yes	No
Washington	Ian Macek	Yes	No
Wisconsin	Jill Mrotek Glenzinski	Yes	No
Wyoming	Sherman Wiseman	No	No

Task 1A: iii) Stakeholder Involvement

An email was sent out to the CDOT Traffic Data Committee requesting continuous non-motorized traffic data on December 20, 2011. A specific request for stakeholder input to the process was not made, but several committee members expressed interest in the process. These members were invited to a meeting in January to provide input to help define the Colorado specific methodologies for factoring. The names of the three individuals that may have interest in further involvement in the project are: Jay Pierce, Aurora; Janet Hruby, Steamboat Springs; and Mike McVaugh, Durango.

TASK 1B: DATA COLLECTION AND EVALUATION

Task 1B first describes the research team's efforts in gathering as much existing, Colorado-based, long-term bicycle and pedestrian count data as possible. The resultant dataset includes CDOT's **eight permanent count stations** as well as data from two cities (**Boulder and Denver) and four counties (Boulder, Douglas, Pitkin, and Summit)**. The next component of Task 1B focuses on the work that went into assessing the quality of the data from the various sources in order to best understand how the data can be used in the project. The data quality assessment discussion is divided into subsections based on the various issues we encountered. The last portion of Task 1B overviews the weather data collected and the rationale for variable selection.

Task 1B: i) Available Data in Colorado

While quantification of motor-vehicle traffic has been well studied in the U.S., little data are collected on bicycle use nationally other than the through the Census and voluntarily through ITE and the National Bicycle and Pedestrian Documentation Project by Alta Planning [1]. However, smaller local efforts to quantify bicycle use abound.

CDOT has collected bicycle and pedestrian count data since 2009, while counties and municipalities around the state have collected bicycle and pedestrian counts for as long or longer. An email was sent out to members of CDOT's Traffic Data Committee to gather this local data. Responses to the email are detailed in Appendix B.

In addition to the eight permanent count stations owned by CDOT, two cities (Boulder and Denver) and four counties (Boulder, Douglas, Pitkin, and Summit) contributed bicycle and pedestrian count data. Additional bicycle and pedestrian count data have been collected by other agencies, such as the city of Longmont, but were not available in time to be used in this study. Table 4 documents the bicycle and pedestrian count data available at approximately 70 count stations throughout the state. These stations are permanent or semi-permanent, so future data should also be available at these sites. Contact names for the agencies that provided the data listed in Table 4 are listed in the Appendix B. Tables 5 and 6 document the short-term count data collected by CDOT as of January 2012.

Table 4. Summary of Continuous Count Data Available in Colorado.

Location	Owner	Technology (Manufacturer)	Dates Available	Path or Road	Mode
Boulder	City of Boulder	Inductive Loops	1998 to present	12 locations on paths around the network at 25 stations	Bike
Boulder	City of Boulder	Inductive Loops (Eco-counter)	June 2010 to present	Folsom Ave. Bike Lanes north and southbound and 13th St. north and southbound	Bike
Boulder	CDOT	Inductive Loops (Eco-counter)	October 3, 2010 to present	US36 north of city of Boulder	Bike
Boulder County	Boulder County	Passive Infrared (JAMAR)	February 2, 2010 to June 29, 2011; February 2, 2010 to June 23, 2010; July 31, 2008 to July 2009	Rock Creek Trail Bridge at Dillon Rd.; LOBO Trail; and Hwy 119 northeast bound near Niwot	Bike/ Ped; Ped; Bike
Downtown Denver	City of Denver	Video detection (Iteris)	July 2011 to present	16th St eastbound at Grant	Bike
Denver	CDOT	Infrared (Eco-counter)	After September 9, 2009	Cherry Creek Path at Holly, 200 S. of Holly	Bike/ Ped
Littleton	CDOT	Infrared (Eco-counter)	After September 9, 2009 except June 5-25, 2010; 356 complete days in 2010	C470 Path South of Ken Caryl Ave.	Bike/ Ped
Aurora	CDOT	Inductive Loops (Eco-counter)	After October 2, 2010	Vaughn St. (local road) just south of 6th Ave.	Bike
Arvada	CDOT	Inductive Loops (Eco-counter)	October 1, 2010 to present for Westbound, to October 19, 2011 for Eastbound	W. 72nd Ave. between Wadsworth Blvd. (SH121) and Carr in east and westbound bike lanes	Bike
Broomfield	CDOT	Combo: Infrared and Inductive Loop (Eco-Counter)	Sept. 27, 2010 to Aug. 9, 2011 for Bike/Ped counts and October 1, 2010 to April 12, 2011 for separate Ped and Bike counts	Path under 287 between Interlocken and Flatirons Crossing Mall; west of 287, north of Deport Hill Rd.	Ped; Bike
Douglas County	Douglas County	Infrared (TRAFx) non-directional	6/11/2011 to present	8 locations on open space trails	Bike/ Ped
Steamboat Springs	CDOT	Inductive Loops (Eco-counter)	9/28/10 to present	US 40 at the intersection of RCR129, AKA Elk river Road	Bike
Durango	CDOT	Inductive Loops (Eco-counter)	9/28/10 to present	US550 (Milepost 22.97 south of 27th street)	Bike
Pitkin County	Pitkin County	Infrared (TRAFx) non-directional	September 2010 to present	17 paved and unpaved trail locations	Bike/ Ped
Summit County	Summit County	Infrared (TRAFx) non-directional	Summer 2010 (April 17 to Oct 15); Summer 2011 to present	5 Locations on Paths	Bike/ Ped

Note: "Bike" indicates a bicycle only count; "Bike/Ped" means bicycle and pedestrian counts are combined; "Bike and Ped" indicates that bicycles and pedestrians are counted separately. "Ped" indicates pedestrians only.

Table 5. Summary of Short Term Counts in the Denver Metro Area.

City	Location	Dates Available
Wheat Ridge	Clear Creek Path at Wadsworth	June 9-28, 2010; May 11 to July 31, 2011
Arvada	Ralston Trail – Brooks Dr. east of Garrison St.	8/17/10 to 8/31/10 and 9/21 to 9/24/10
Aurora	6th Ave. Pedestrian Bridge, Vaughn St. south of 6th Ave.	10/1/10 - 10/12/10
Denver	Platte River Trail at REI	June 1 - Aug 28, 2010, 12/10/10 to 3/31/11, 6/2/11 to 7/31/11
Denver	6th Ave. Frontage Rd at Knox	5/11/11 to 5/30/11
Denver	Cherry Creek Trail West of Cook Park	6/1/10 - 6/28/10, 1/4/11 - 1/19/11, 5/22/11 to 7/31/11
Denver	Cherry Creek Trail East of Colorado Blvd.	8/1/11 to 9/22/11
Denver	Cherry Creek Trail West of Cherry Street	8/1/11 to 9/22/11
Denver	Highland Pedestrian Bridge – 16th St. /Central St. West of I-25	3/30/11 to 4/20/11
Denver	Cherry Creek/Holly site on dirt trail north of concrete trail	11/2/10 – 11/4/10
Denver	8th Ave./ Valleje St. Pedestrian Bridge	5/11/11 to 5/30/11
Lone Tree	C470 Path at Quebec	June 1 to July 21, 2010; July 29 to Aug. 18, 2010
Highlands Ranch	C470 Path at Santa Fe	June 9-28, 2010, May 31 to July 31,2011
Aurora	Highline Canal Trail – Exposition Ave. west of Havana St.	8/17/10 – 9/10/10; 1/4/11 to 1/18/11
Lakewood	C-470 Trail South of 285	6/9/10 – 6/17/10
Castle Rock	Festival Park Trail – southwest of 2nd St. & Wilcox St.	1/20/11 – 4/20/11; 4/23/11 to 5/10/11
Castle Rock	East Plum Creek Trail – Meadows Parkway Southwest of SH85	2/16/11 to 4/30/11
Sheridan	Bear Creek Trail Pedestrian Bridge, Irving St. north of Bear Creek Dr.	2/16/11 to 2/22/11; 10/21/11 to 1/3/12
Sheridan	Irving St. south of Quincy St.	10/21/11 to 1/4/12

Table 6. Summary of Short Term Counts in Colorado Outside of the Denver Metro Area.

City	Location	Dates Available
Grand Junction	Pedestrian Bridge north of Colorado River – 27 3/8 Rd North of Cheyenne Dr.	June 29 – Aug 10, 2010
Glenwood Springs	Rio Grand Trail North of 23RD	June 29 – Aug 10, 2010
Glenwood Springs	Rio Grand Trail South of 23RD	7/13/10 to 7/27/10
Glenwood Springs	Bike Entry on South Grand	7/28/10 to 8/10/10
Fort Collins	Spring Creek Trail EB WB – Redwing Rd south of Bay Rd	11/5/10 – 12/9/10
Fort Collins	Spring Creek Trail NB/SB – Redwing Rd south of Bay Rd	11/5/10 to 11/17/10
Fort Collins	Spring Creek Trail EB/WB – Redwing Rd. south of Bay Rd.	11/5/10 to 12/9/10
Manitou Springs	The Incline Trail West of Manitou Springs (South of Vermont Ave. says map)	9/10/10 – 9/27/10
Colorado Springs	Rock Island Trail – Constitution Ave east of north Circle Dr.	2/15/11 – 4/30/11
Colorado Springs	Sand Creek Trail – S. Chelton Rd. east of S. Murray Blvd.	2/17/11 to 5/10/11
Loveland	US 34 Underpass – Between Boise Ave & Denver Ave.	10/12/10 to 11/5/10
Durango	Animas River Trail – east of SH550; Swinging Bridge N/O 15th	4/14/09 to 7/5/09; 6/28/10 – 8/18/10
Durango	Schneider Park Bridge	5/27/09 to 6/11/09; 6/28/10 to 8/18/10
Steamboat Springs	Yampa River Core Trail – south of 10th St./Yampa St. intersection next to ambulance barn.	8/11/11 to 10/1/11
Pueblo	Arkansas River Trail southeast of SH96/Chapa Pl	10/16/11 to 3/7/12
Pueblo	Fountain Creek Trail west of 8th/Erin St	9/26/11 to 4/2/12

Task 1B: ii) Assess Data Quality

The task of assessing the quality of bicycle and pedestrian count data presents multiple challenges, particularly due to: i) little data of this type is available, and ii) bicycle and pedestrian count volumes are significantly lower than motor vehicle counts, ranging from 10 to 2,000 per day. For instance, some count stations exhibited unusual travel patterns, but with little other data available about the locations, it was not always possible to assess the validity of these patterns. Also, locations with extremely low counts can lead to order of magnitude difficulties in analysis or could be indicative of malfunctioning count equipment.

This section describes the data available in detail and explains the issues encountered with each dataset. This process began with a graphical inspection of each dataset. Time periods with excessively high counts or a surprising number of zero counts were flagged. If local contacts were able to justify the high or low counts, the data were kept; if not, the data were deleted so as not to negatively and disproportionately impact analysis.

While validating counts was not part of the scope of work, we did conduct and document some count validation for the city of Boulder locations. Validation and adjustment factors were computed for two of these locations. Other count locations may have validated by city or county staff, but we were not able to find any such documentation. Thus, there is not clear evidence that the majority of count locations are accurately counting non-motorized users. However, since this project is more interested in identifying patterns than in determining absolute traffic volumes, most of the data was used despite lacking validation and accuracy adjustment factors. In some cases, unusual patterns may be the result of motorized traffic being inadvertently counted as non-motorized traffic. For example, such problems were documented at the older Folsom bicycle lane location in Boulder, but this count station was since moved so as to avoid the problem (the older Folsom data were not included in the study). Additional locations where significant motor vehicle counting is suspected include: Vaughn at 6th Ave in Denver; and the Keystone location in Summit County. For this reason, these locations were removed from the analysis. The details of the data are given below.

Colorado Department of Transportation Counters

Since 2009, the Colorado Department of Transportation has installed and maintained a set of EcoCounter automated bicycle counting equipment on paths and streets around the state. Below is a summary of these counters:

- Two permanent infrared counters were installed in 2009: one on the C-470 Path and the other on the Cherry Creek Path at Holly Street in Denver. These counters combine bicycles and pedestrians counts but separate counts by direction of path user. Data are available through the present.
- Six portable infrared counters were purchased in 2010 and have been in use around the state, except for one that was stolen within a month of its first use.
- Six locations around the state were chosen for permanent bicycle counters thanks to funds from a Kaiser Foundation grant. Inductive loops were then installed:
  - In the shoulders of US 36 immediately north of Boulder,
  - In the shoulders of US40 in Steamboat Springs,
  - In the shoulders of US550 in Durango,
  - In the shoulders of W. 72nd Ave. in Arvada,
  - In the roadway of Vaughn St. in Denver, one block south of 6th Ave, and
  - In a path in Broomfield adjacent to a bicycle/pedestrian underpass below HW287.

  The first five locations listed count bicycles by direction of travel. The counter in Broomfield is a combined infrared and inductive loop counter, which counts bicyclists and pedestrians separately. Again, these counters have not yet been validated.

Details of two permanent infrared counters installed in 2009:

- *Cherry Creek Path*. This location shows a clear recreational pattern with high volumes on Saturdays and Sundays and highest volumes at midday, though morning and evening peaks show some evidence of commute traffic. Since bicycle and pedestrian traffic is combined in these counts, it is not possible to distinguish pedestrian from bicycle volumes. Typically, pedestrian volumes are higher than bicycle volumes, so cyclist patterns may be hidden by the pedestrian patterns. Seasonal variation with highest volumes in the summer (June and July) and lowest volumes in winter (December through February) is clear. Monthly daily averages vary from 400 to 2,100 per day in both directions and the annual daily average is around 1,200 per day. Bike to Work Day volumes are substantially higher than normal Wednesday counts in both 2010 and 2011, further confirming the presence of commuters.

  - This location divides users by direction and shows generally higher volumes in the "OUT" direction, especially in the morning, and lower volumes in the "IN" direction, which are highest in the afternoon. This indicates the presence of some commuters who travel "OUT" in the morning and "IN" in the evening, though not as many return, at least by this route. As always with directional data, especially since these counters have not been validated, it is best to refrain from trusting atypical results too much.

- *C470 Path*. This location shows lower total counts than the Cherry Creek Path but still shows clear seasonal variation with highest volumes in summer (June and July) and lowest volumes in winter (December through February). As with many other combined counters, the recreational pattern is clear with the highest counts in the noon peak and on Saturdays and Sundays. Total number of users in the summer varies from 600 to 2,000 per day in both directions with peaks as high as 3,000 per day.

  - This location divides users by direction and shows volumes three to five times higher in the "IN" direction than the "OUT" direction. Again with directional data, it is best not to put too much stock in the results, especially since these counters have not been validated,
  - We found highly questionable data from June 5th to 25th, 2010 (either zeros or substantially higher than normal), so it was deleted.

Details of six Kaiser-funded permanent counters installed in 2010:

- *Durango*. This counter is located on the shoulders and outside edge of a main road and counts cyclists. Counts are not divided by direction. The highest counts were observed in May and July and the lowest in January in 2011. This indicates strong seasonal variation and a relationship with the school calendar, which may be especially important in Durango, home of Fort Lewis College. Peak hours are in the late morning (10 to 11

AM) and early afternoon (3 to 4 PM), indicating a college oriented commuter schedule. However, volumes are highest on Saturdays overall. In the summer, volumes are highest during the week except for Mondays. Volumes range from 20 to 75 counts per day in the summer. Bike to Work Day does not have abnormally high counts. Occasional days with zero counts in summer may be due to construction, but this has not been confirmed. Occasional days with zero counts in the winter may be due to severe weather events. Saturday, May 28, 2011 showed record high counts, possibly due to graduation.

- *Steamboat Springs*. This counter is located on the shoulders and outside edge of lane of a main road and counts cyclists. Counts are not broken up by direction. Seasonal variation is clear with the highest counts observed in the summer months (June through August) and the lowest in February in 2011. Peak hours are 8 to 9 AM and 5 to 6 PM, and highest volumes are on weekdays, indicating a clear commuter pattern. Daily summer volumes are generally in the range of 80 to 260 cyclists with a peak on Wednesday, June 15, 2011, when Ride the Rockies passed over the counters. Bike to Work Day, one week later, shows typical Wednesday volumes.

- *Boulder*. US 36 counters north of Boulder had erroneous data in the northbound direction from August 5 to October 11, 2011, so these counts were removed from the analysis. Low or zero counts on September 6, 7, and 23 as well as October 3, 2011 in the southbound direction, possibly due to construction, were also removed from the analysis.
    - This counter shows a clear recreational pattern with much higher volumes on weekends than weekdays, and although weekdays have peaks in morning and evening, directional data shows rides originating in Boulder during both peaks. Most riders appear to be riding for training or recreational purposes, though occasional utilitarian riders do use the highway. If the directional data is accurate, northbound volumes are markedly higher than southbound volumes. However without further verification of the data, such a directional split may not be accurate.

- *Arvada.* The counts on the bike lanes on West 72nd Avenue are so low that it is difficult to know if the counter is working correctly, though observations during installation support the low counts. The total counts for this roadway are usually less than 20 per day with high volumes of around 30 per day in the summer. They appear to follow a recreational trend with higher volumes on weekends, though the low counts prevent clear patterns during the day from being evident. Increased volumes on Bike to Work Day are evident and clear seasonal variation with highest monthly counts in June and July is also evident. There appears to be higher volumes in the eastbound direction, but this may be due to inaccuracies in the detection as the counters have not been checked for accuracy.

- *Aurora.* The counts on Vaughn Street, a local road near a school and within two blocks of 6th Ave., a busy arterial, are also low with highs around 50 per day in the summer. This location appears to have more of a commuter pattern with high volumes during weekdays and higher volumes in the "IN" direction in the morning from 7 to 9 AM and the "OUT" direction in the afternoon from 4 to 6 PM. There seems to be generally higher volumes in the "IN" direction, but this may be due to inaccuracies in the detection, as the counters have not been checked for accuracy. Increased volumes on Bike to Work Day are evident and clear seasonal variation with highest monthly counts in June, July, and August is evident in the "OUT" direction but not in the "IN" direction. The "IN" direction seems more dependent on the school year, with low volumes in June and July. This may indicate that school children are using the road, or that school buses that park nearby, are being erroneously counted.

- *Broomfield*. Because this location uses both infrared and inductive loop technologies, it has separate bicycle and pedestrian counts for October through April, 2010, though unfortunately only the combined counts from the infrared counter seem to be available after that.
    - The pedestrian only counts show generally lower counts on weekends with lowest counts on Sundays and highest counts on Tuesdays with some evidence of lower counts in the winter, though this is hard to observe as the summer months are not included in the dataset. The pedestrian counts appear to have a recreational

pattern with higher volumes at midday than during morning or evening peaks, as is typical for pedestrian counts in urban areas. Volumes at this location are generally in the range of 50 to 200 pedestrians per day (fall and spring).

- The bicycle only counts also show lower counts on weekends with the lowest counts on Sundays and the highest on Thursdays. The daily pattern appears to be more of a commuter pattern with peaks in the morning, from 8 to 10 AM, and evening with the highest peak from 3 to 6 PM. Volumes at this location are generally in the range of 30 to 100 riders per day (fall and spring) and are generally less than half of the pedestrian count. The counts are not broken up by direction.
- The combined counts are naturally dominated by the pedestrian recreational pattern with one large peak in the midday to afternoon, though volumes are highest during the week and lowest on Sundays.

Video Counting in Denver

Such counting instruments have been installed in Denver with the specific purpose of counting bicycles in a bicycle lane. The accuracy of such counts is dependent on vehicles not driving in the bicycle lane, pedestrians not walking in the bicycle lane, and bicycles riding single file inside the lane. The device, depicted in Figure 2, counts bicycles approaching the signal and is aimed directly at the bicycle lane. The city of Denver reports high accuracy (over 95%) for this detector. Detection using this device began in the summer of 2011 after experiments with other video detection devices failed to yield accurate results.

Figure 2. Denver Video Counting using Iteris Camera.

Boulder Continuous Count Data

Since 1998, continuous bicycle counts have been recorded in Boulder using inductive loops with automated detectors. Currently there are: 12 Canoga brand detectors at 12 locations on the city's network of multi-use paths; and 4 EcoCounter brand detectors at two on-street locations. Directionality of the bicyclists is recorded at most, but not all, locations. The validity of almost all of these detectors were tested in 2009 and 2010 [32, 33]. The 12 detector stations are listed in the Table 7 with their tested accuracies. Some of the inaccurate detectors have since been adjusted. While many of under or over counting detectors were not used, the remaining data should be appropriate for this study. Figure 3 shows the approximate locations of all but the southern-most detector.

The counts are detected by the Global Traffic Technologies (GTT) Canoga C922, C923, or C924 hardware card in a signal control box. The model number varies depending on the number of channels. Each station is one detector card. Some detectors may still be the older 3M C824T cards originally installed in the late 1990s, but most have been switched over to the Canoga C900 series. The counts are usually collected in one or two-hour time intervals and saved in the volatile memory on the card until they can be uploaded onto a laptop by a field technician.

Detectors that record cyclist direction use a set of two inductive loops. Figure 4 shows an example of such a formation, often referred to as a “double chevron.” These detectors count cyclists by noting when there is a change in inductance in both loops, one after the other, but only if the second change occurred within a predetermined time period. In this way the detector can record the direction of the cyclists by which loop changed in inductance first. However, if the detector observes a change in inductance in one loop, but not the other within a given time period, the detector would not record a count. This should prevent counting slow moving objects, such as strollers. Two channels are required to record cyclist direction for a given double chevron. The chevrons are angled in order to better count cyclists riding side by side.

Table 7. Inductive Loop Automated Counters in Boulder.

Station No.	Location	Facility	Detector Brand	First Year Counts Collected	Channel	Percent Different from Accurate	Accurate? (within ±15%)
4 & 6	Arapahoe & 13th	Boulder Creek Multi-use Path	Canoga	1998	1	< -19%	Under-count
					2	< -16%	Under-count
					3	< -36%	Under-count
					4	< -23%	Under-count
5 & 7	Arapahoe & 13th	Broadway Multi-use Path	Canoga	1998	1	7%	Yes
					2	-25%	Under-count
					3	5%	Yes
8 & 11	4000 Arapahoe	Boulder Creek Multi-use Path	Canoga	1998	1	-5%	Yes
					2	-4%	Yes
					3	-5%	Yes
					4	-6%	Yes
9 & 10	4000 Arapahoe	Skunk Creek Multi-use Path	Canoga	1998	1	7%	Yes
					2	0%	Yes
					3	25%	Not enough data
					4	-33%	Not enough data
23	Broadway & Baseline	Broadway Multi-use Path	Canoga	1998	1	-58%	Under-count
					2	-67%	Under-count
12	Arapahoe & 38th	Arapahoe Multi-use Path	Canoga	1999	1	-18%	Under-count
					2	-22%	Under-count
13 & 14	Foothills & Arapahoe	Foothills & Arapahoe Multi-use Paths	Canoga	1998	1	-30%	Under-count
					2	-45%	Under-count
					3	-78%	Under-count
					4	-18%	Under-count
22	Broadway & Table Mesa	Broadway Multi-use Path	Canoga	1998	1		Not tested
					2		Not tested
16 & 18	Foothills & Pearl	Pearl Parkway Multi-use Path	Canoga	1998	1		Not enough data
					2		Not enough data
					3	0%	Yes
					4	114%	Over-count
17 & 19	Foothills & Pearl	Foothills Multi-use Path	Canoga	1998	1	-32%	Under-count
					2	0%	Yes
					3	20%	Over-count
11	Foothills & Colorado	Foothills & Centennial Multi-use Path	Canoga	1998	1	0%	Yes
					2	-35%	Under-count
					3	-5%	Yes
					4	-6%	Yes
12	55th & Pearl Parkway	Pearl Parkway Multi-use Path	Canoga	2000	1	0%	Yes
					2	0%	Yes
1	13th St. at Walnut	NB shared roadway & SB contra flow bike lane	Eco Counter	2010	NB	4%	Yes
					SB	-3%	Yes
2	Folsom St.	Bicycle lanes	Eco Counter	2010	NB	6%	Yes
					SB	11%	Yes
				2011	NB2	-7%	Yes
					SB2	-17%	Under-count

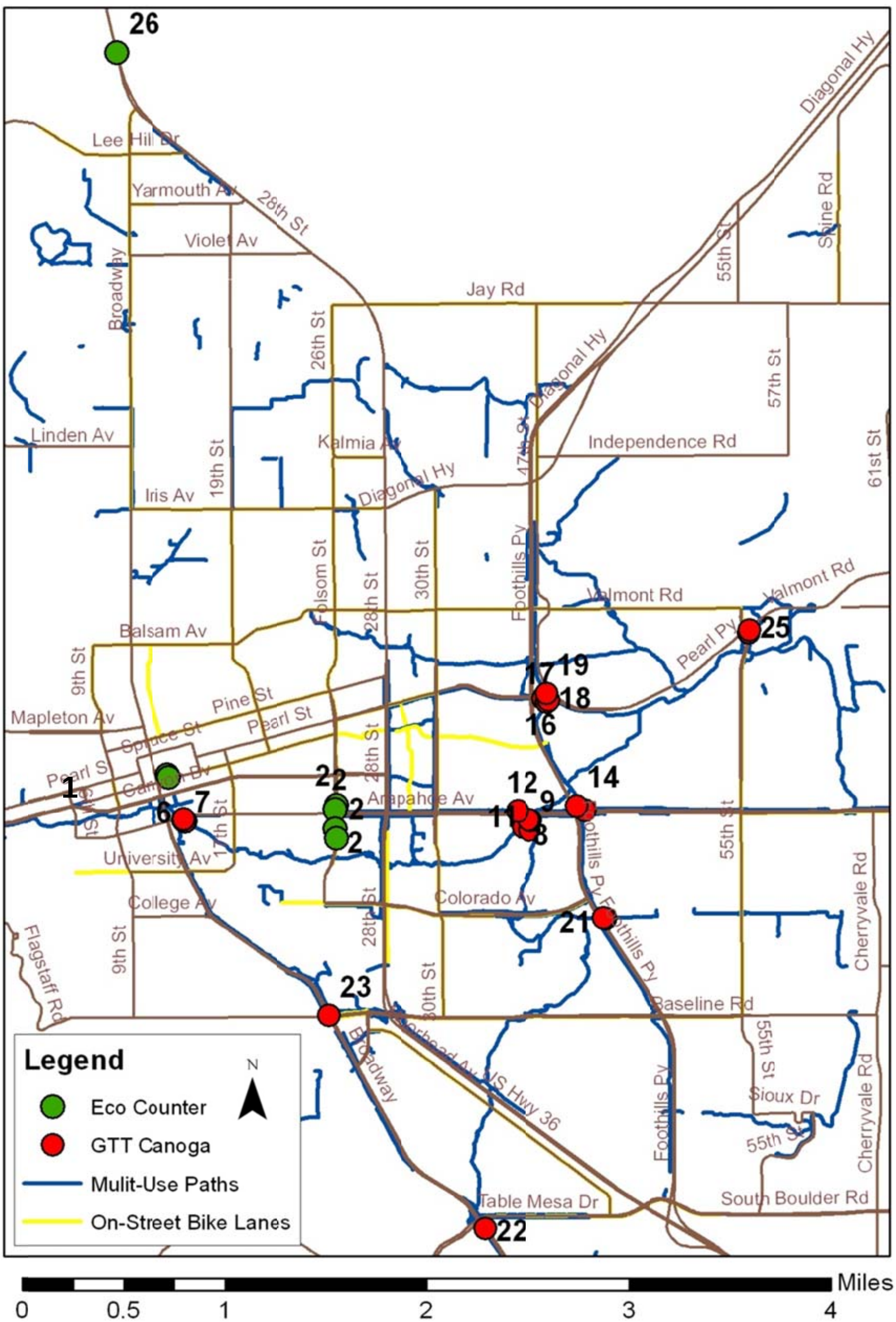

Figure 3. Boulder Automated Bicycle Count Locations.

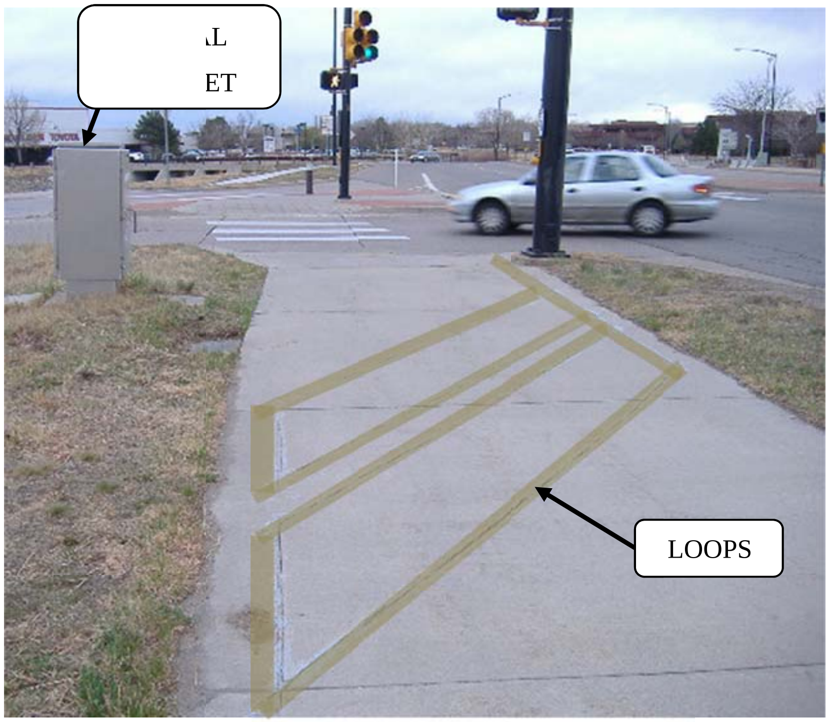

Figure 4. Directional inductive loops with associated signal box at northwest corner of the northbound ramp of Foothills Parkway and Pearl Parkway.

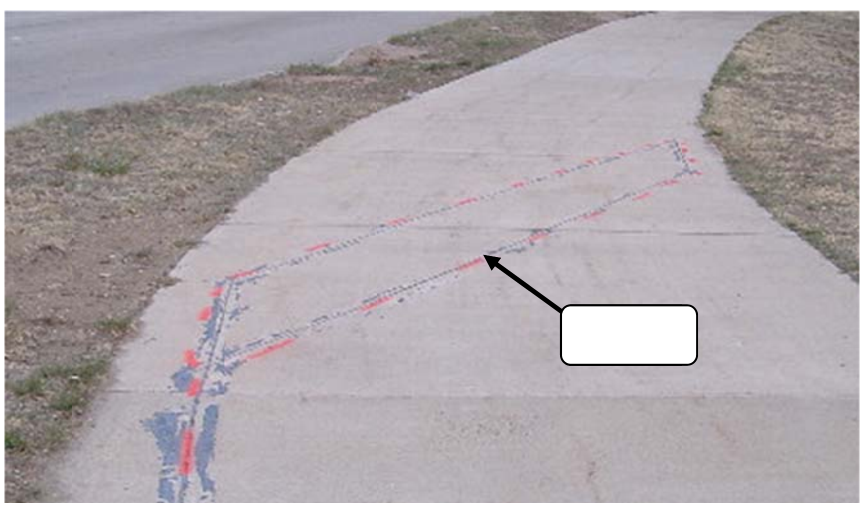

Figure 5. Single chevron inductive loop at 55th & Pearl, Channel 1.

Single inductive loops were also used in some locations as shown in Figure 5. With a single loop, the detector can only count the number of cyclists passing the loop, not the direction of travel. For both single and double chevrons, the loops are usually placed about 12 inches from the edge of the concrete.

Data Problems in Canoga Detectors

Some of the data have been lost when the counts exceed the storage capacity of the detector, due to the lack of availability of field personnel to upload the data regularly. With one-hour bin sizes, which are currently being used in most of the detectors, downloading must be done about once per month to avoid data loss.

Another problem has been power losses, which can delete the data at locations where backup power is not available. Though the city is currently working toward providing backup power for the stations, this process is not complete. These difficulties in data retrieval have created substantial gaps in the continuity of the data at many of the count locations. Available data varies by location from 15 percent to 70 percent of the time period from August 2000 to July 2008. A few weeks of count data from 1998 and 1999 are also available for most of the detector locations.

Another problem in data collection has been differences in time stamps. For example, the same data could be downloaded twice, each time with different times attached to the same data. It is likely that this is caused when the time on the laptop differs from the actual time. Time stamps are established when the data are downloaded based on the time on the laptop. Technicians often reset the time on the laptop they use for downloads so that the bins will be time stamped on the hour - 12:00 instead of 12:47, for example. As the same laptop was used to collect multiple locations on the same day, the laptop time could sometime be displaced by several hours, creating a discrepancy. One way to avoid this problem is to download the data on the hour instead of changing the clock, which has been done since 2009.

Data Problems in Eco Counter Detectors

The Eco Counter inductive loop detectors were installed during the summer of 2010. The detectors on 13th St. were checked for accuracy and found to be accurate, although the detector in the northbound direction on the shared path may under or over count any individual cyclist, but very rarely counted motor vehicles as bicycles [34].

The detectors on Folsom Ave. were found to be undercounting originally. After learning this, the sensitivity on the Folsom detectors was set to 0 (instead of -2), which resulted in over-counting with accuracies as shown in Table 7. Eco Counter felt that such accuracies were poor due to electrical interference. The loops were moved to locations in the bike lanes on the south side of Arapahoe in September 2011, after which initial accuracies are as shown in Table 7 with -2 sensitivity.

Boulder County Counters

Boulder County also owns three passive JAMAR infrared bicycle and pedestrian scanners, which record counts and supposedly direction, but the directionality has been found to be unreliable by Boulder County staff. One, installed in July 2008, is located on a bridge where the shoulder of a divided highway (119) crosses a creek and is thus usually only used by northeast bound bicyclists. The others two were installed in February 20120 and are located on paths: one on the Rock Creek Trail near Dillon Rd., and the other on the Longmont-Boulder (LOBO) Trail near SH52. The one on the LOBO trail was found to only count pedestrians because the beam was set too low (cyclists spinning feet were apparently not warm enough to be detected), but it was moved to a new location on the trail in the summer of 2011. We do not have data for this new location. According to Boulder County staff, the counter on 119 and the counter on the LOBO Trail have been checked with manual counts, but the counter on the Rock Creek Trail has not been validated [35]. The SH119 counter had a clear commuter pattern (morning and evening peaks and high volumes during the work week), while the Rock Creek Trail has a clear recreational pattern, with on peak during midday and high volumes on weekends. The LOBO Trail was more of a combination of commuter and recreational patterns. Counters in Boulder County are summarized in Table 8.

Table 8. Continuous Bicycle and Pedestrian Counters in Boulder County.

Owner-ship	Station	Type	Mode	Peak Month	Peak Day	Peak Summer Workday Hour	AADB	Volume	Year
County	Rock Creek	Path	Combo	Sept	Sun	1:00 AM	43	Low	2010
County	SH119NEBound	Road	Bike	June	Wed	9:00 AM	31	Low	2009
County	SH52overLOBO	Path	Peds	*	Fri	9:00 AM	*		
CDOT	US36	Road	Bike	*	Sat	12:00 PM	*		2011
City	13thSt	Road	Bike	*	Tues	5:00 PM	609	High	2010
City	Arap38th	Path	Bike	*	Wed	4:00 PM	164	Low	2010
City	Arapahoe2	Path	Bike	Aug	Wed	5:00 PM	126	Low	2010
City	BdwyNside	Path	Bike	*	Wed	8:00 AM	433	Medium	2010
City	BdwySside	Path	Bike	*	Wed	4:00 PM	635	High	2010
City	BldrCrkEside	Path	Bike	*	Wed	2:00 PM	823	High	2010
City	BldrCrkEside2	Path	Bike	July	Wed	4:00 PM	659	High	2010
City	BldrCrkWside	Path	Bike	June	Tues	4:00 PM	678	High	2010
City	BldrCrkWside2	Path	Bike	July	Tues	4:00 PM	722	High	2010
City	Brdwy	Path	Bike	*	Tues	5:00 PM	689	High	2010
City	BwyTmesa	Path	Bike	*		7:00 AM	*		2010
City	Centennial	Path	Bike	Sept	Tues	8:00 AM	368	Medium	2010
City	Folsom2	Road	Bike	*			*		
City	Foothills	Path	Bike	June	Tues	8:00 AM	360	Medium	2010
City	Foothills1	Path	Bike	June			*		
City	Foothills2	Path	Bike	July	Wed	8:00 AM	383	Medium	2010
City	FthlsNECor	Path	Bike	June		8:00 AM	*		2010
City	FthlsSECor	Path	Bike	June		8:00 AM	*		2010
City	Prl55thN	Path	Bike	*		8:00 AM	*		2010
City	Prl55thS	Path	Bike	*		8:00 AM	*		2010
City	PrlPkwySECor	Path	Bike	July		1:00 PM	*		2010
City	PrlPkwySWCor	Path	Bike	July		1:00 PM	*		2010
City	Skunk	Path	Bike	July	Tues	5:00 PM	341	Medium	2010
City	ToArap	Path	Bike	June	Tues	9:00 AM	74	Low	2010

City of Longmont Counters

The city of Longmont, located in Boulder County, has been counting trail users on their St. Vrain and Macintosh Lake Paths since approximately 2007 using three active infrared beam detectors made by Ivan Technologies. The detectors are moved at least once per year and are distributed to six locations. The detectors count all moving objects that break the beam and do not distinguish direction of travel. These data were not available for this study.

Douglas County Counters

Douglas County Open Space Department owns eight TRAFx brand infrared counters, which they have used to count pedestrians, bicyclists, and equestrians on trails since June 2011. Two are located on pedestrian only trails. Data from these trails are summarized in Table 9.

Summit County Counters

Summit County Parks and Recreation has been counting bicyclists and pedestrians at five locations on their path network since summer 2010 using TRAFx brand infrared counters. Due to the harsh winters, they stopped counting in the winter of 2010-2011; however, they attempted to count during winter 2011-2012. Vandals destroyed one of their counters during the summer of 2010, which resulted in data loss at another site. To our knowledge, these counters have not been validated. Data from these trails are summarized in Table 10.

Pitkin County Counters

Pitkin County has been counting trail users on their paved and unpaved trail systems since September 2010, adding additional counters added in the passing years. As of summer 2012, counts from 17 count stations were available including winter data. The counters are TRAFx brand infrared counters, which count all passing trail users (including equestrians, snowmobilers, skiers, and snowshoe users in addition to pedestrians and bicyclists). Data from these trails are summarized in Table 10.

Table 9. Other Denver Metro Continuous Bicycle and Pedestrian Counters.

Location	Station	Type	Mode	Peak Month	Peak Day	Peak Summer Workday Hour	AADB	Volume	Year
Arvada	Arvada-W72ndAve	Road	Bike	June, July	Sun	7:00 AM	9	Low	2011
Aurora	Aurora-VaughnSt	Road	Bike	Aug	Wed	6:00 PM	27	Low	2011
Broomfield	Broomfield-Combo	Path	Combo	*	Tues	11:00 AM	*		2011
Broomfield	Broomfield-Cycle	Path	Bike	*	Tues	5:00 PM	*		2012
Broomfield	Broomfield-Peds	Path	Peds	*	Tues	11:00 AM	*		2012
City and County of Denver	16th &Grant	Road	Bike	Aug	Tues	5:00 PM	778	High	2011 to 2012
Denver	CCHolly	Path	Combo	Aug	Sun		1195	High	2010
Denver	CCHolly	Path	Combo	Aug	Sat	6:00 PM	1185	High	2011
Douglas County	County Rd5	Road	Combo	*		1:00 PM	*		
Douglas County	Dawson Butte	Path	Combo	Aug	Sun	11:00 AM	67	Low	2012
Douglas County	Glendale	Path	Combo	April	Sun	8:00 AM	255	Medium	2012
Douglas County	Glendale-Trail	Path	Combo	*		8:00 AM	*		
Douglas County	Greenland	Path	Combo	May	Sat	10:00 AM	55	Low	2012
Douglas County	Greenland Dog Park	Path	Combo	*		9:00 AM	*		
Douglas County	Greenland-South	Path	Combo	*		8:00 AM	*		
Douglas County	Hidden Mesa	Path	Combo	April	Sun	11:00 AM	91	Low	2012
Douglas County	Hidden Mesa-Pleasant	Path	Combo	*		9:00 AM	*		
Douglas County	Sharptail	Path	Combo	June	Sun	6:00 PM	9	Low	2012
Douglas County	Spruce Meadows	Path	Combo	Sept	Sun	10:00 AM	25	Low	2012
Douglas County	Spruce Mt	Path	Combo	July	Sun	11:00 AM	149	Low	2012
Ken Caryl	KC470	Path	Combo	July	Sat	4:00 PM	218	Medium	2011

* Insufficient data available

Table 10. Other Colorado Continuous Bicycle and Pedestrian Counters Outside of the Denver Metropolitan Area.

Location	Station	Type	Mode	Peak Month	Peak Day	Peak Summer Workday Hour	AADB	Volume	Year
Durango	Durango	Road	Bike	May	Sat	1:00 PM	25	Low	2010
Pitkin County	Arbaney Kittle	Path	Combo	June	Sun	10:00 AM	85	Low	2011
Pitkin County	BasaltMass	Path	Combo	July	Sat	12:00 PM	*	Low	
Pitkin County	BrushCreek	Path	Combo	July	Sat	9:00 AM	*	Low	
Pitkin County	CrystalTrail	Path	Combo	July	Sun	10:00 AM	*	Low	
Pitkin County	DartRGT	Path	Combo	Aug	Sat	11:00 AM	*	Low	
Pitkin County	Emma Trail	Path	Combo	*	Sat	11:00 AM	*	Low	
Pitkin County	EmmaRGT	Path	Combo	June	Sun	10:00 AM	61	Low	2011
Pitkin County	EofAspen	Path	Combo	July	Sun	10:00 AM	66	Low	2011
Pitkin County	HunterCrk	Path	Combo	Aug	Sun	11:00 AM	75	Low	
Pitkin County	OwlCreek	Path	Combo	July	Sat	11:00 AM	4	Low	2011
Pitkin County	RadarRd	Path	Combo	June	Fri	12:00 PM	*		
Pitkin County	RGT-RFC	Path	Combo	July	Sun	8:00 AM	*		
Pitkin County	Smuggler	Path	Combo	July	Sat	11:00 AM	*		
Pitkin County	SteinPark	Path	Combo	July	Sun	11:00 AM	*		
Pitkin County	UpperRGT	Path	Combo	July	Sun	10:00 AM	*		
Pitkin County	Viewline	Path	Combo	*	Sun	11:00 AM	*		
Pitkin County	WoodyCrk	Path	Combo	July	Sat	12:00 PM	120	Low	
Steamboat Springs	Steamboat	Road	Bike	Aug	Tues	5:00 PM	112	Low	2011
Summit County	Dillon Dam Path	Path	Combo	July	Sat	8:00 AM	95	Low	2012
Summit County	Farmers Korner	Path	Combo	*		11:00 AM	*		2012
Summit County	Four Mile	Path	Combo	July	Sat	11:00 AM	69	Low	2012
Summit County	Keystone	Path	Combo	March	Tues	11:00 AM	103	Low	2012
Summit County	Officers Gulch	Path	Combo	June	Sat	12:00 PM	125	Low	2012
Summit County	Swan Mt	Path	Combo	June	Sat	11:00 AM	78	Low	2011 to 2012

Data Summary by Volume

To better categorize bicyclist and pedestrian volumes, we considered using the categories proposed by the CalTrans Seamless Travel report to categorize locations by peak hour counts [12]:

<u>*Bicycle Volumes*</u>	
Low	*0-20 per hour*
Moderate	*21-60*
High	*over 60*
<u>*Pedestrian Volumes*</u>	
Low	*0-40 per hour*
Moderate	*41-100*
High	*over 100*

However, since we felt that the average daily counts were more indicative of the traffic at the site, we categorized the sites in the following manner corresponding to roughly one standard deviation from the mean annual average daily bicyclists (AADB) at the Boulder sites.

Bicycle Volumes (AADB)

Low	less than 200
Moderate	200 to 600
High	over 600

Of the 69 counters: 42% were in the in the “Low” bicycle volume category; 9% were in the “Moderate” volume category; and 14% were in the “High” volume category. 26% did not have enough data to compute AADB or AADBP, so no volume category was assigned to them.
Of the 48 (of the total 69) count sites with enough data to compute AADB in the years of interest, 65% are in the "Low" category, 15% are in the "Moderate" category, and the remaining 20% are in the "High" category.

Of the 45 stations around the state that have sufficient data to compute the annual average daily bicyclists or combined bicyclist and pedestrian counts, most are on off-street paths in urban areas without mountain climate. 21 of the stations record only bicyclists, and 24 record combined bicycle and pedestrian counts.

While one would expect that bicycle only count locations would have, on average, fewer counts than combined locations, the opposite is true, with bicycle only count stations averaging approximately 400 counts per day over the year and combined bicycle and pedestrian count stations averaging approximately 180 counts per day over the year. This is likely due to most of the bicycle count stations being in urban areas while most combined count stations are in rural areas. On average, counts at stations in urban areas are four times higher than those in rural areas, which makes sense given that higher population densities often lead to higher bicyclist traffic volumes.

Path vs. Roads

A common question for those who would plan, design, or advocate for bicycle and pedestrian facilities is "*do off-street paths generate higher volumes than on-street facilities?*" A recent study in San Diego finds that paths do have higher volumes. The difficulty with answering this question based on the Colorado data is that none of the locations were chosen randomly, and thus the selection is biased because they cannot statistically represent the group they belong to. However, with the data available, the Colorado locations included in this dataset show that for cyclists, the on-street facilities have on average approximately 280 users per day, while off-street path facilities have approximately 460 users per day. This seems to confirm the San Diego finding, but unfortunately, due to the low number of on-street count stations (only seven included in this study), the difference was not significant.

For combined pedestrian and bicycle counts, only path locations were counted, so no data was available to compare path to off-street locations.

Climate

For the 24 combined bicycle and pedestrian counts, the 12 locations at lower elevations had 3.5 times as many path users per day on average as the 12 locations in mountain climates. However, since all but one of the stations in mountain climates were considered to be in rural locations, the difference in average annual daily traffic between the climatic regions may just be due to counts in urban areas being higher than those in rural areas as mentioned previously. In this dataset the correlation between rural and mountain climate variables is approximately 0.6.

General observations

On average, annual average daily urban bicycle use is five times higher than rural multi-use path use. Off-street bicycle facilities have, on average, higher volumes than on-street facilities, but this was not significant due to too few on-street facilities in the dataset.

Task 1B: iii) Weather Data

As shown by previous researchers, weather can have a significant impact on bicycle and pedestrian volumes. For this reason, weather data was gathered for each counter location by day, and where possible, by hour.

Previous studies have found that temperature and precipitation are significant factors in predicting pedestrian and bicycle volumes. Wind speed was not found to be a significant factor in some previous studies, but this may be due to the climate and context of the areas studied. Colorado has significantly higher gusts than many of the previous locations studied and for this reason, we have included wind in our study. Humidity was often not investigated in other studies.

Perceived Temperature

There are two standard indices of perceived temperature used in the US: heat index (for temps over 80^{o} F) and wind chill. Heat index is a function of temperature and relative humidity. Wind chill is a function of temperature and wind speed. In Canada, humidex, a function of dew point and temperature, is used in place of heat index [36]. The Germans developed one perceived temperature metric, which combines both concepts and includes radiation from the sun, clothing, and other human variables. Instead of using a computed perceived temperature, this study preserves simplicity by using the raw data: dry bulb temperature, wind speed, and where available, humidity.

Boulder Weather

Hourly and daily weather data was obtained from the National Oceanic and Atmospheric Administration (NOAA). Hourly data was obtained from the weather station located near the Boulder municipal building at the corner of Canyon Boulevard and Broadway in Boulder and was only available from 2003 through 2010. Daily data was obtained from the weather station located at the National Institute of Standards Building located near the intersection of Broadway and 27th Way in Boulder and was available for the entire time period of the study.

TASK 2: ANALYSIS, MODELS, AND METHODOLOGIES

Task 2A: Data Analysis

Task 2A first compiles motorized traffic volumes on roads near existing continuous bicycle and pedestrian counters and compares variations in bicycle and pedestrian volumes (hourly, daily, and monthly) to the variations for motorized traffic volumes. Task 2A then investigates whether and how hourly, daily, and monthly adjustment factors for bicycle and pedestrian volumes are similar or different from adjustment factors for motorized traffic. This type of comparison was completed at four sites around Colorado and will help bring bicycle and pedestrian volumes into context with the other modes in preparation for the factor estimation.

Task 2A: i) Compare Motorized to Non-motorized Traffic Patterns

Summary

Are motor vehicle traffic patterns similar to non-motorized traffic patterns at the same location? To investigate this question, motor vehicle traffic patterns were compared to non-motorized traffic patterns occurring along the same roadway corridor, or in the vicinity of each other, for four test cases, as listed in Table 11. This analysis found that motorized and non-motorized traffic are sometimes, but not always, correlated. The highest correlation is with monthly patterns, but motorized traffic varies much less with the seasons than non-motorized traffic. Even though some of the motorized and non-motorized count stations were on the same corridor, they did not necessarily share the same travel patterns, indicating that bicyclists and pedestrians may be using the corridor for different trip purposes than motorized users.

Analysis

To compare non-motorized and motorized traffic counts, which are of different magnitudes, both were normalized by dividing the hourly, daily, or monthly traffic counts by the published AADT for motorized counts and by the computed annual average daily bicycle and/or pedestrian (AADB or AADBP) traffic for non-motorized counts. The AADB and AADBP were computed from the continuous count data using the AASHTO 1992 method [37].

Table 11. Four Comparison Cases of Motorized and Non-motorized Traffic Patterns.

Location	Non-motorized Station Description	AADB[1] or AADBP	ATR Station ID	ATR Location Description	2011 AADT	Factor Group
Durango	US550 (Milepost 22.97 south of 27th street)	25	104809	ON SH 160 SE/O SH 550 N JCT, CAMINO DEL RIO, DURANGO	30,000	6
Central Denver	Cherry Creek Path at Holly, 200 S. of Holly	1,170	000510	ON I-70 E/O SH 95, SHERIDAN BLVD, DENVER	96,000	5
C-470	C470 Path South of Ken Caryl Ave.	216	000512	ON SH 470 NW/O SH 8, MORRISON RD, MORRISON	73,000	6
			105548	ON SH 470 E/O QUEBEC ST, LONE TREE	103,000	6
			000003	ON SH 470 NW/O SH 85, SANTA FE DR, LITTLETON	73,000	6
Steamboat Springs	US 40 at the intersection of RCR129, AKA Elk river Road	106	000231	ON SH 40 N/O SH 131	7,800	4

[1]Note that AADB and AADBP listed here may not be identical to that listed in other tables because these values were computed for slightly different time periods.

Durango

While it was not possible to compare motorized and non-motorized counts at the same location in Durango, counts from two state highways that pass through the city were compared: motor vehicle counts on SH160 and bicycle counts on SH550. Published AADT for 2011 is 30,000 vehicles [38].

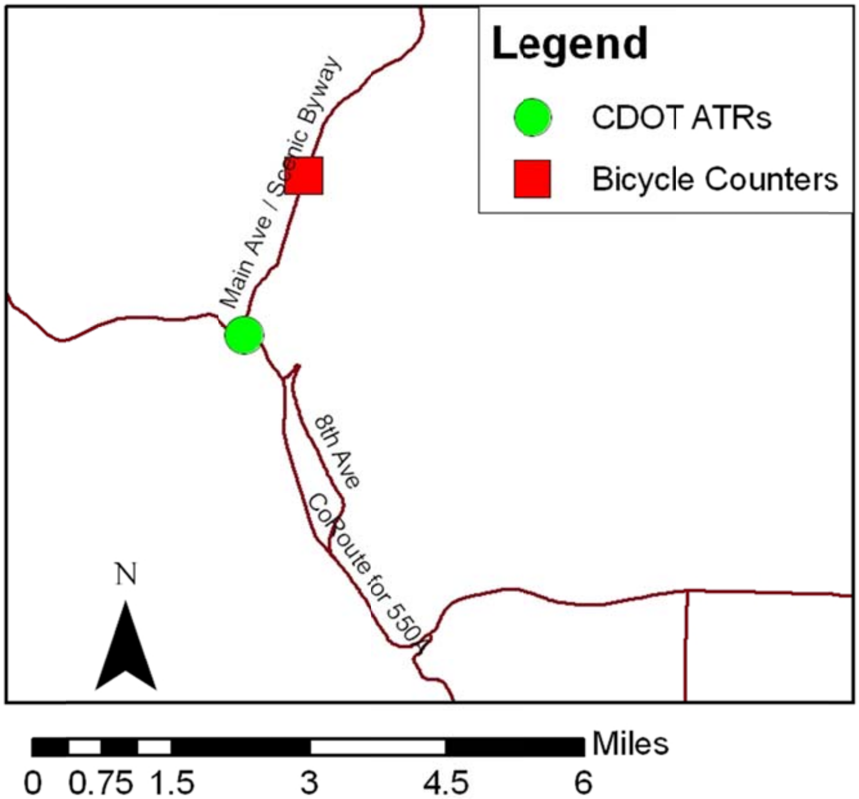

Figure 6. Map of Durango Counters Used in Comparison Study.

In order to calculate AADB at the bike counting station, a year of data – available from September 28, 2010 to September, 26, 2011 – was used. During this time period, 21 days of counts were missing or partially missing. Data from these days were removed from the estimate of AADB, and AADB was calculated to be 25 bicyclists per day.

The average hourly traffic counts, as a percent of annualized daily traffic, were plotted for both modes to compare patterns for workdays and weekends (Figures 7 and 8). Since motor vehicle counts were not available for 36 days and bicycle counts for 23 days during the study period from September 28, 2010 to September 26, 2011, these days were removed from the analysis. The plots show the difference between patterns for summer and winter. For motor vehicles, there is little difference between these patterns, but for cyclists there is a noticeable difference, with winter peak hours generally later in the day than summer peak hours. The figures show that peak hours for motorized and bicycle traffic do not coincide for any of the time periods studied.

Unfortunately since bicyclist counts are low at this location, there is great variability in the counts. Though, it seems clear that there is not a traditional commute pattern in the bicycle count data at this location. The hourly pattern may instead represent a recreational or university student traffic pattern.

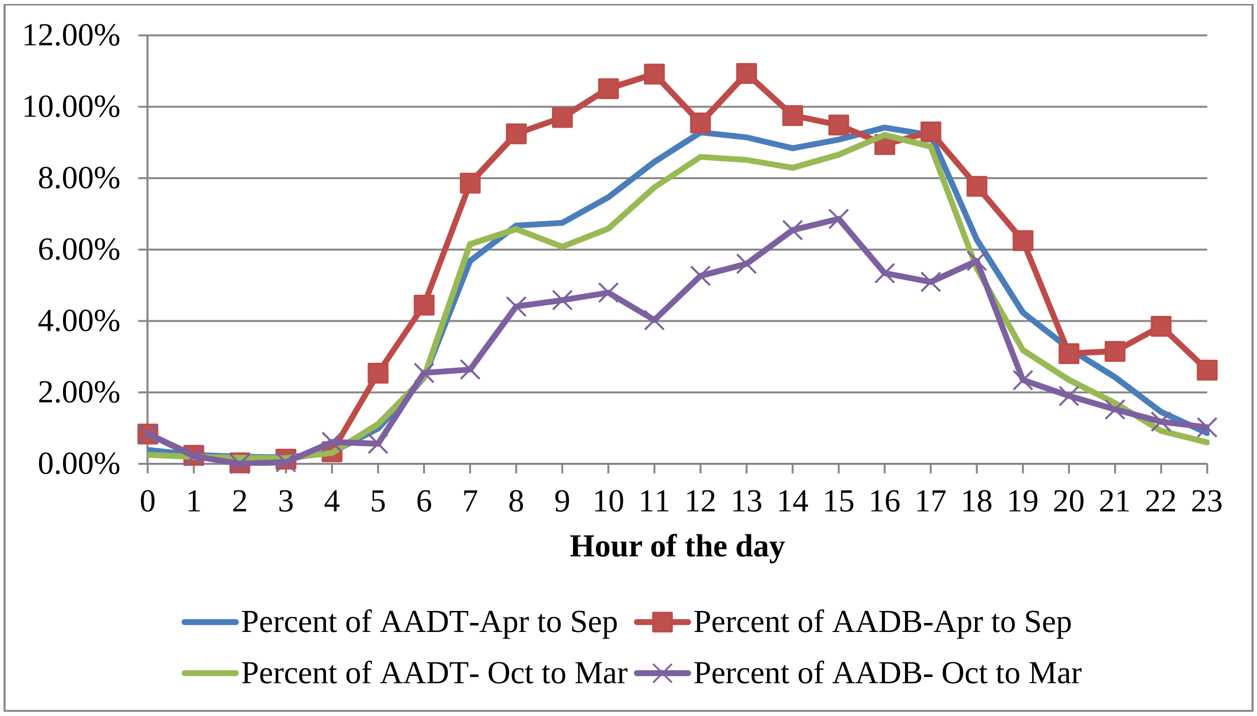

Figure 7. Durango Hourly Factor Comparison for Workdays.

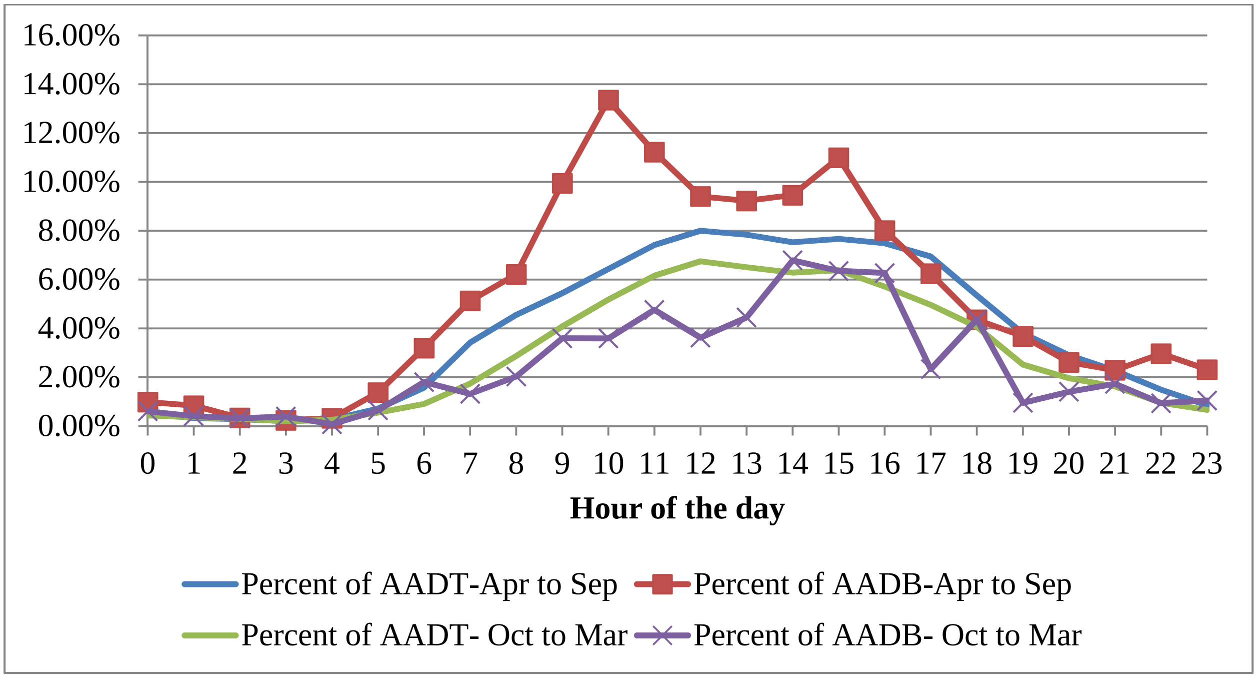

Figure 8. Durango Hourly Factor Comparison for Weekends.

In addition to examining hourly patterns, daily and monthly (seasonal) patterns were compared in Figures 9 and 10. The figures show the inverse of the CDOT average daily and seasonal factors for 2011 Factor Group 6 compared to the inverse of the average daily and monthly factors for bicycle traffic during the period from October 2010 to September 2011.

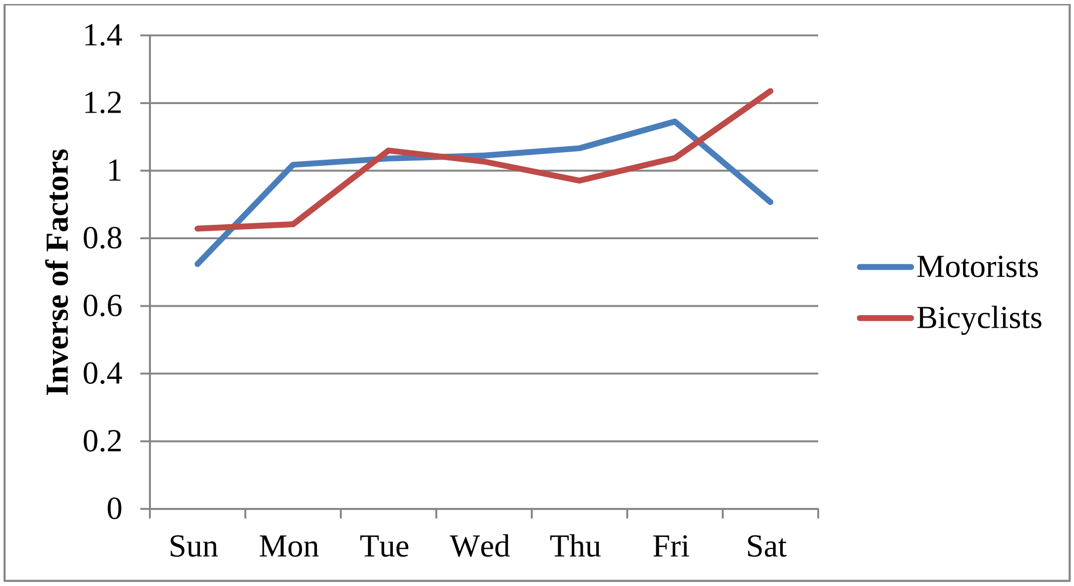

Figure 9. Durango Daily Factor Comparison.

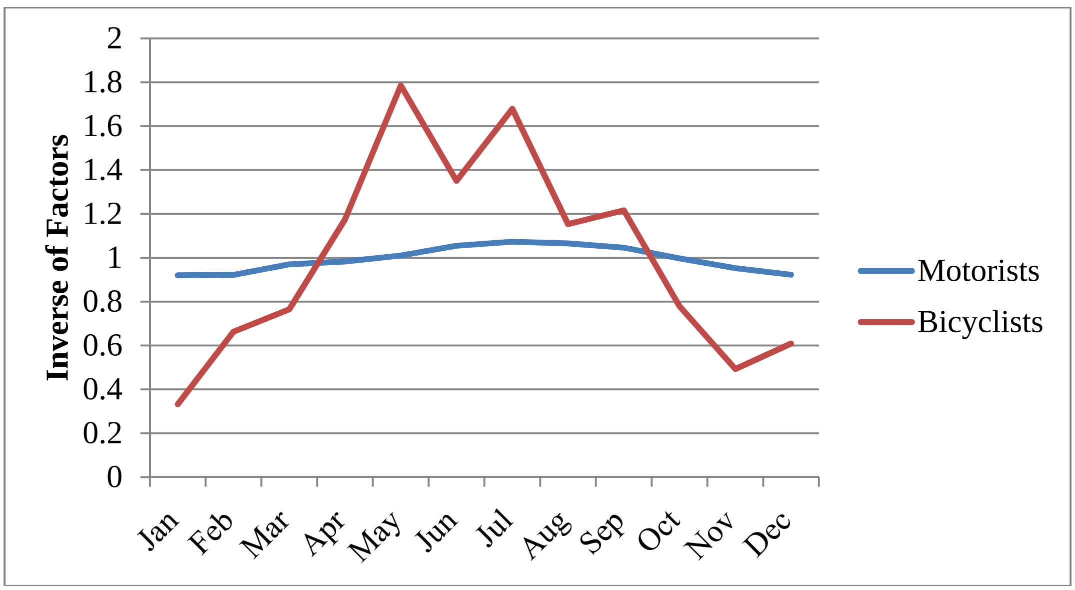

Figure 10. Durango Monthly Factor Comparison.

The previous figures show that the daily bicycle traffic patterns do not correlate well with motor vehicle counts, and even on the monthly scale, the bicycle traffic varies much more with the seasons than motor vehicle traffic.

To compare the hourly, daily, and monthly traffic patterns between modes, the correlation between normalized hourly traffic counts and between factors was computed. The results for Durango are reported in Table 12. The correlation coefficient between the motorized and non-motorized normalized hourly counts is 0.496, indicating some relationship between the two traffic volumes, but not a strong one. For these reasons, using motor vehicle factors to estimate AADB for this location would not likely result in high accuracy.

Central Denver

As for the other locations, Denver motor vehicle and bicycle/pedestrian counters were not co-located (Figure11). For this reason, counts from two main facilities that pass through the city were compared: motor vehicle counts on I-70 and bicycle and pedestrian counts on the Cherry Creek Path at Holly.

In order to calculate AADBP at the non-motorized path user counting station, the available data – from October 1, 2010 to October 31, 2011 – was used. Data from days with missing or partially missing counts were removed from the estimate of AADB.

The average hourly traffic counts, as a percent of annualized daily traffic, were plotted for both modes to compare patterns for workdays and weekends (Figures 12 and 13). The plots show the difference between patterns for summer and winter. For motor vehicles, there is little difference between these patterns; for cyclists, summer counts are much higher than winter peak hours. Non-motorized traffic on the Cherry Creek Path shows a commute pattern on weekdays, but the peak hours are not the same as those for the motor vehicle traffic.

In addition to examining hourly patterns, daily and monthly patterns were also compared (Figures 14 and 15). These graphs show the inverse of the CDOT average daily and seasonal factors for 2011 Factor Group 5 compared to the inverse of the average daily and monthly factors calculated for bicycle traffic during the period from October 2010 to September 2011. These plots show that the non-motorized traffic peaks on the weekends and in August, while the motorized traffic peaks on Fridays and June through August. Motorized traffic has much less variation with month.

While there is very low correlation between the hourly counts for motorized and non-motorized users compared (correlation coefficient = 0.5), there is some evidence that daily factors are somewhat inversely correlated and monthly factors are somewhat correlated, as shown in Table 12. However inverse correlation is not a good basis for using motor vehicle factors to estimate AADBP. For these reasons, using motor vehicle factors to estimate AADB for this location is not expected to result in high accuracy.

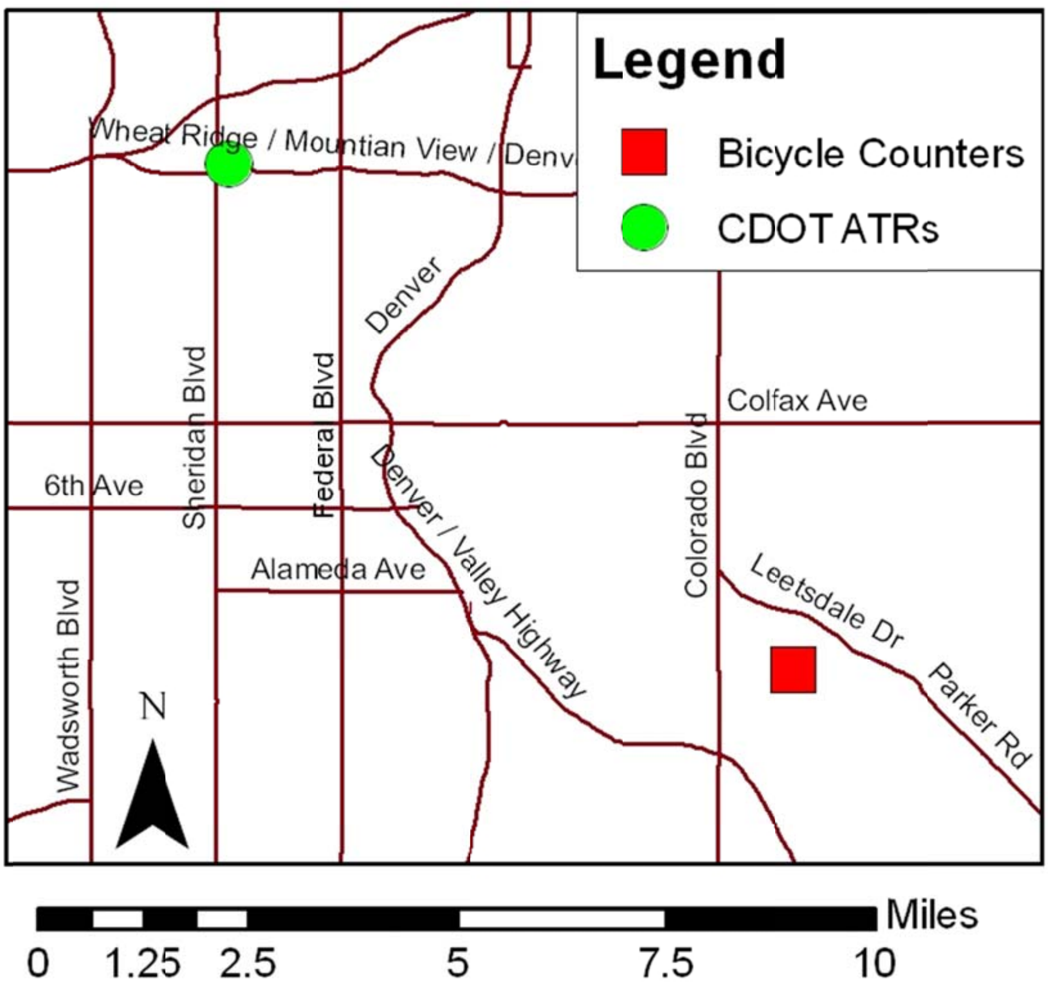

Figure 11. Map of Central Denver Counters Used in Comparison Study.

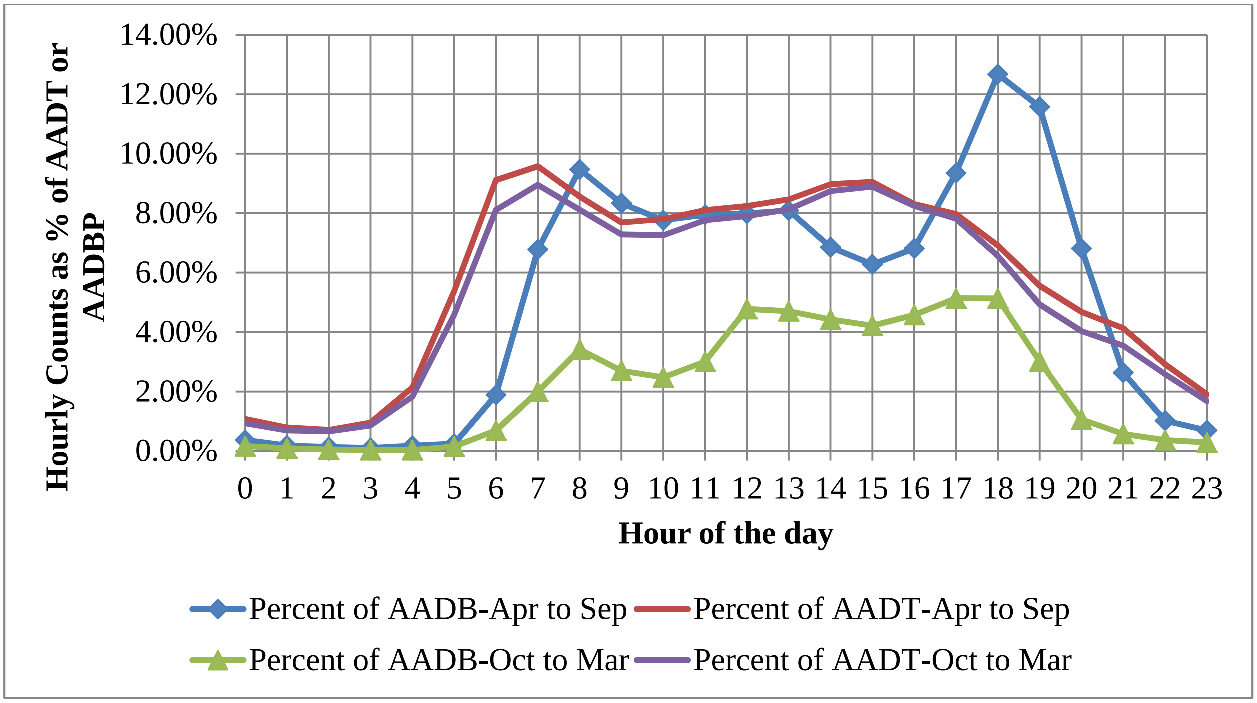

Figure 12. C-470 Hourly Factor Comparison for Workdays for Cherry Creek Path and Station 000510.

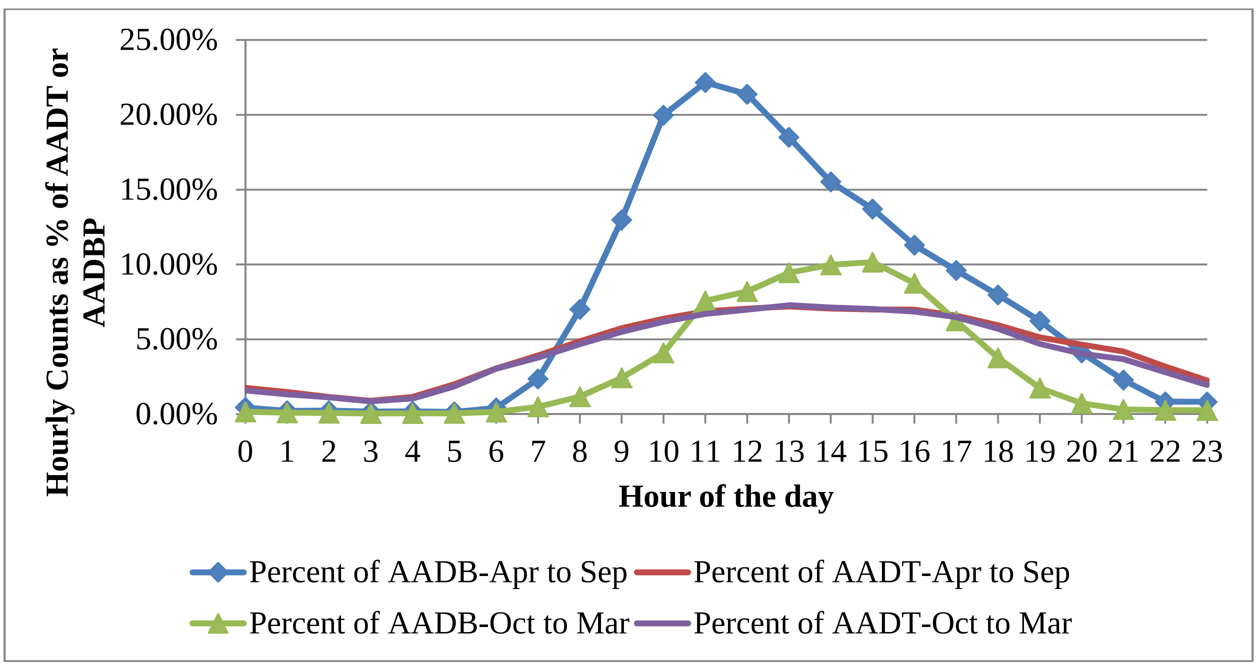

Figure 13. C-470 Hourly Factor Comparison for Weekends for Cherry Creek Path and Station 000510.

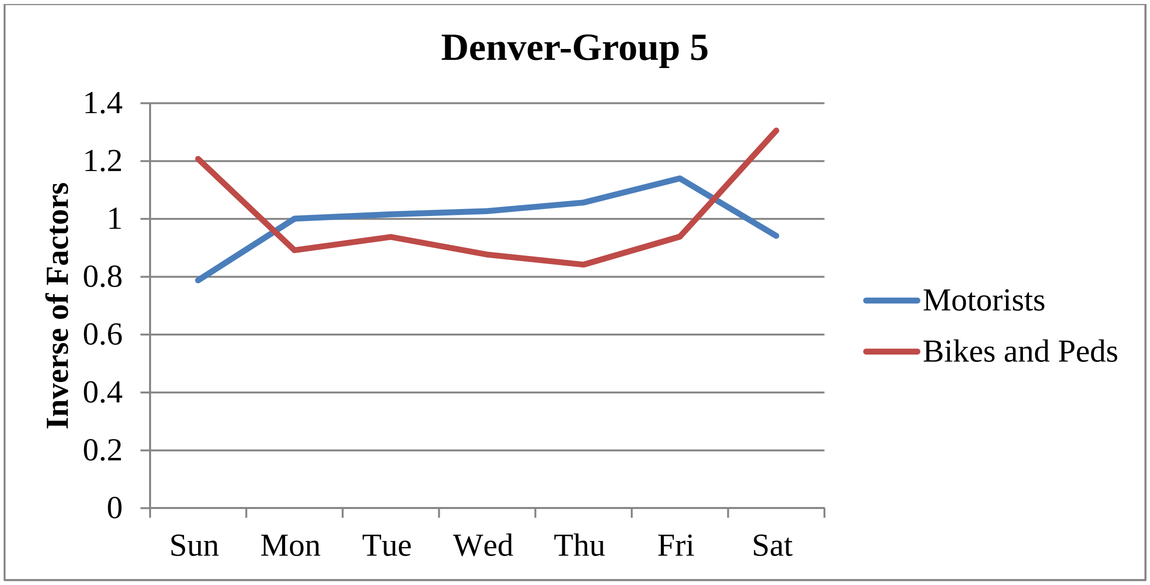

Figure 14. Central Denver Daily Factor Comparison.

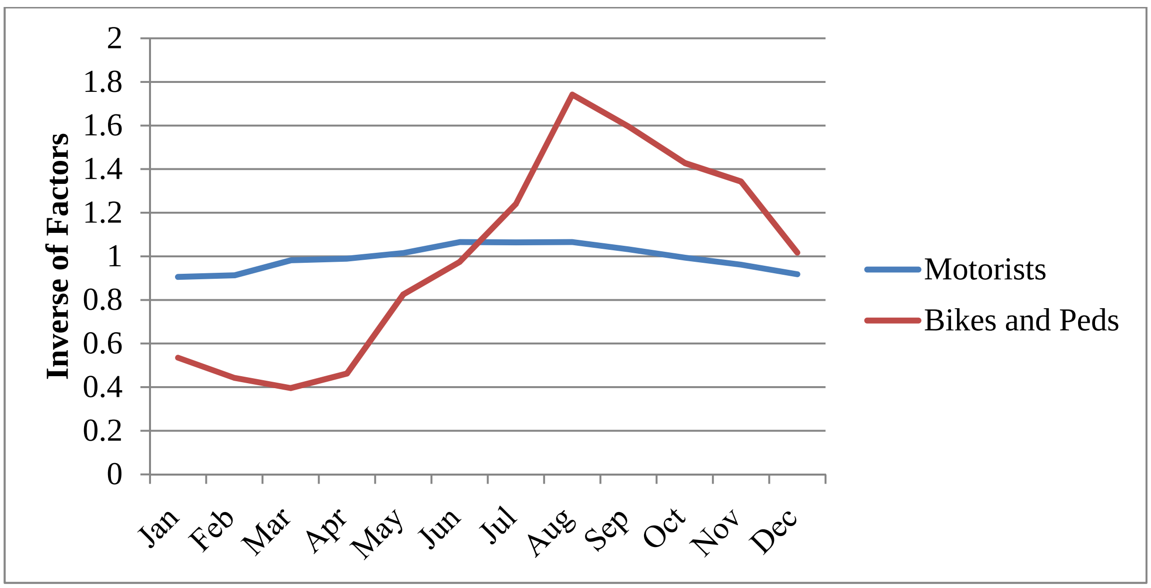

Figure 15. Central Denver Monthly Factor Comparison.

C-470

Unlike the other locations, non-motorized and motorized counters, while not co-located, are found along the same corridor. Multiple ATRs are located along the C-470 corridor along, which also runs a parallel multiuse path. As show in Figure 16, Station 000003 near Santa Fe Boulevard is the closest to the non-motorized count station and is the primary station used for comparison. The count stations to be compared include: three motor vehicle counts stations along C-470 at Morrison Rd., Santa Fe Blvd., and Quebec St.; and one bicycle and pedestrian counts station on the C-470 Path south of Ken Caryl Avenue.

In order to calculate AADBP at the non-motorized path user counting station, the available data from September 1, 2010 to October 20, 2011 was used. Data from days with missing or partially missing counts were removed from the estimate of AADB.

The average hourly traffic counts as a percent of annualized daily traffic were plotted for both modes to compare patterns for workdays and weekends (Figures 17 and 18) for ATR Station 000003. Plots of bicycle and pedestrian traffic volumes for the other locations are not shown because they appear identical. For motor vehicles, there is little difference between summer and winter traffic; for cyclists, summer counts are much higher than winter peak hours. Non-motorized traffic on the C-470 Path depicts a peak evening hour that somewhat corresponds to the peak evening hour for motor vehicle traffic. However, the non-motorized traffic also peaks in midday with no morning peak, while motor vehicle traffic has a morning and evening commute pattern.

In addition to examining hourly patterns, daily and monthly patterns were also compared. Both are compared in Figures 19 and 20, which show the inverse of the CDOT average daily and seasonal factors for 2011 Factor Group 6 compared to the inverse of the average daily and monthly factors calculated for bicycle traffic during the period from September 2010 to October 2011. These plots show that the non-motorized traffic peaks on the weekends and in July, while the motorized traffic peaks on Fridays. Motorized traffic is less dependent on seasonality, with highest counts shown June through August.

As for the central Denver case, while there is very low correlation between the hourly counts for motorized and non-motorized users compared (correlation coefficient = 0.2 on average for all three motorized traffic comparison stations), there is some evidence that daily factors are somewhat inversely correlated and monthly factors somewhat correlated, as shown in Table 12. However, inverse correlation is not a good basis for using motor vehicle factors to estimate

AADB. For these reasons, using motor vehicle factors to estimate AADB for this location is not expected to result in high accuracy.

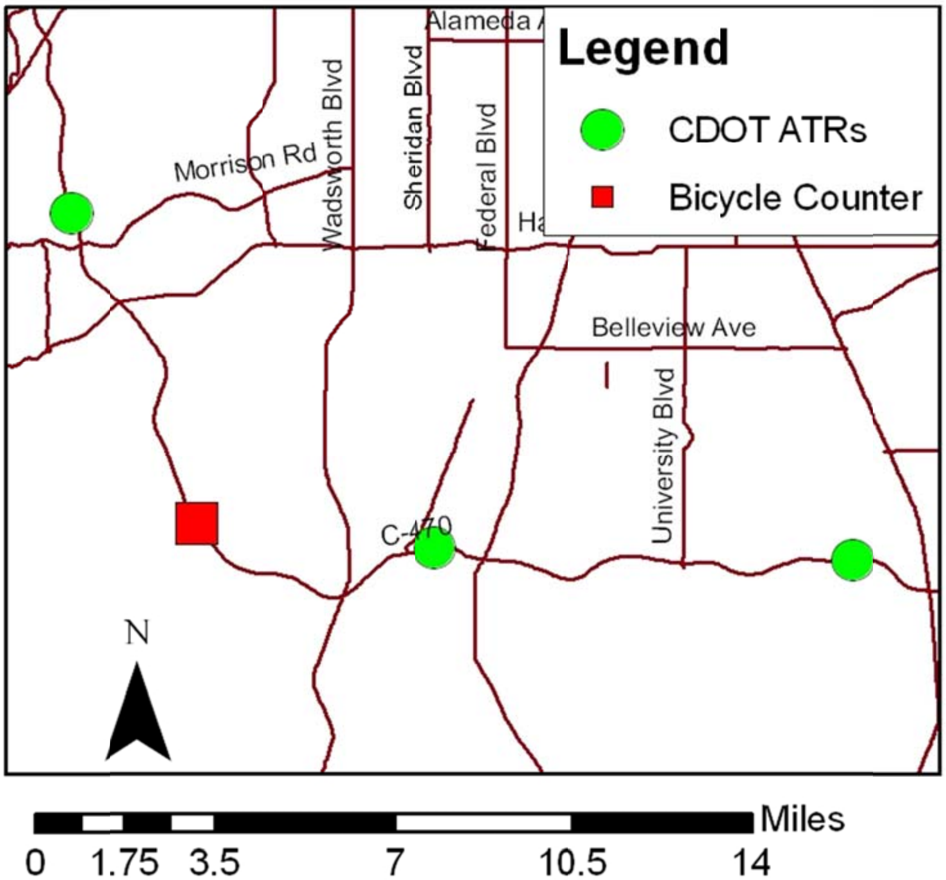

Figure 16. Map of C-470 Counters Used in Comparison Study.

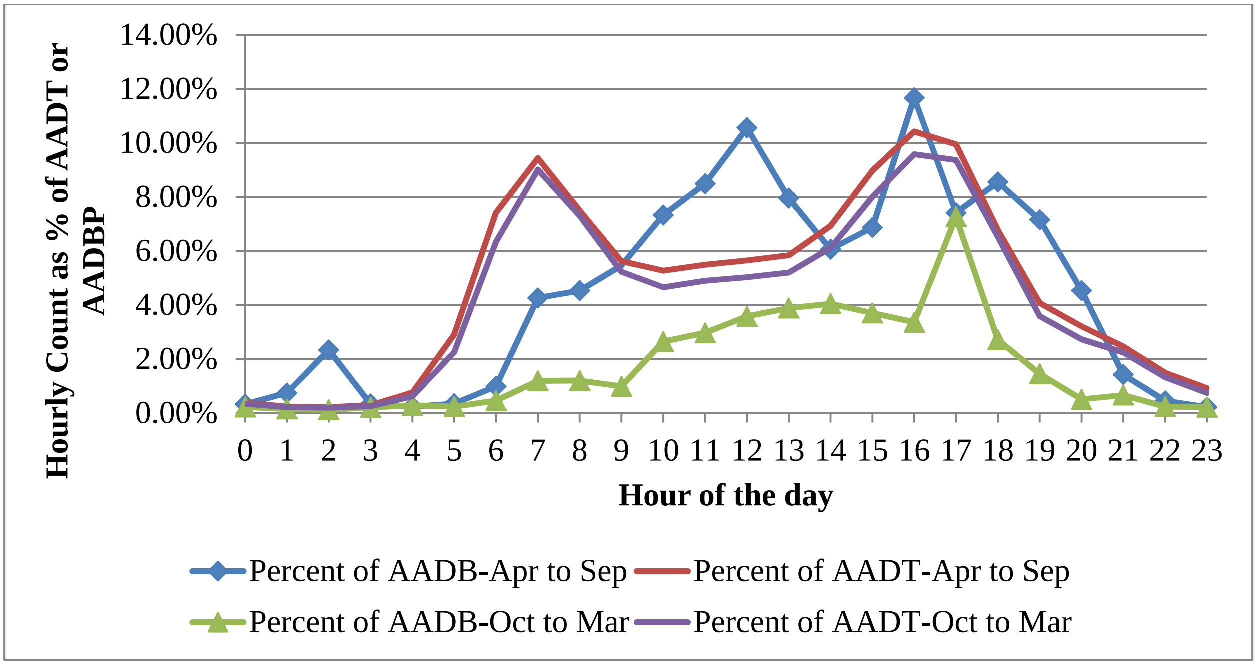

Figure 17. C-470 Hourly Factor Comparison for Workdays for Station 000003.

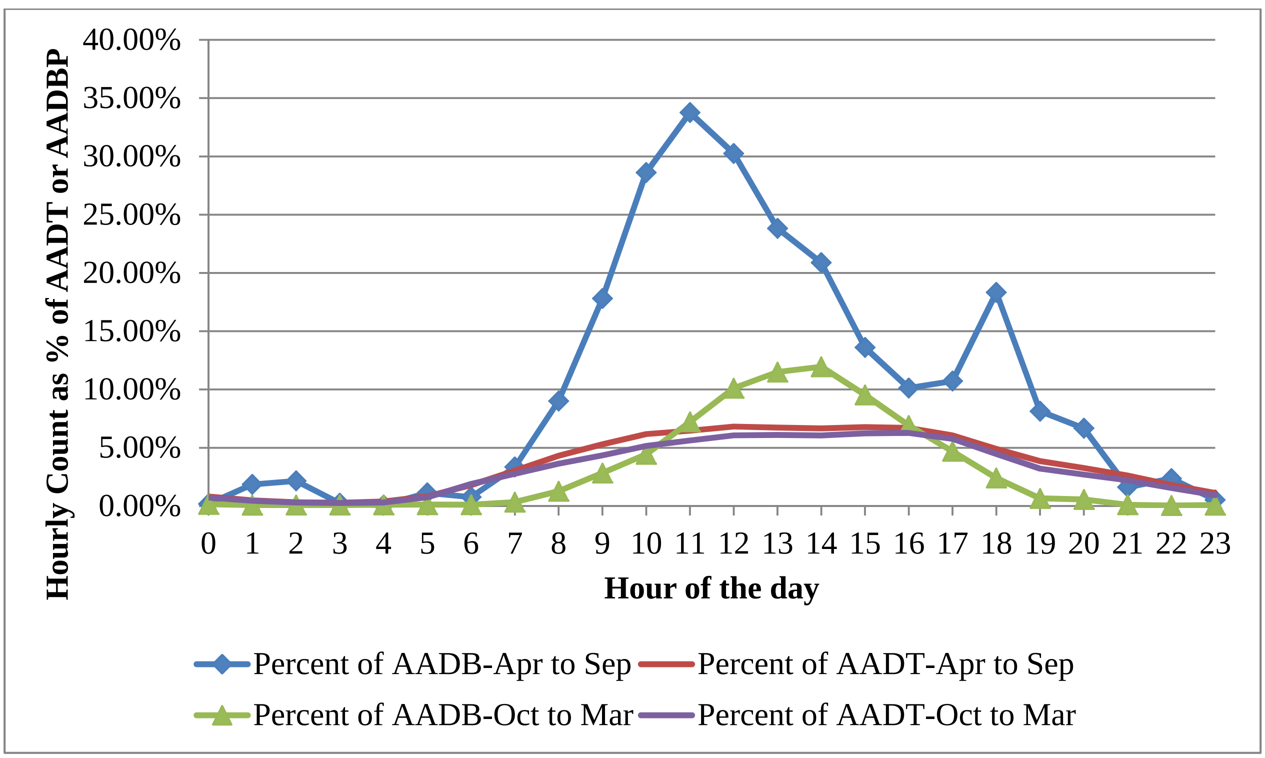

Figure 18. C-470 Hourly Factor Comparison for Weekends for Station 000003.

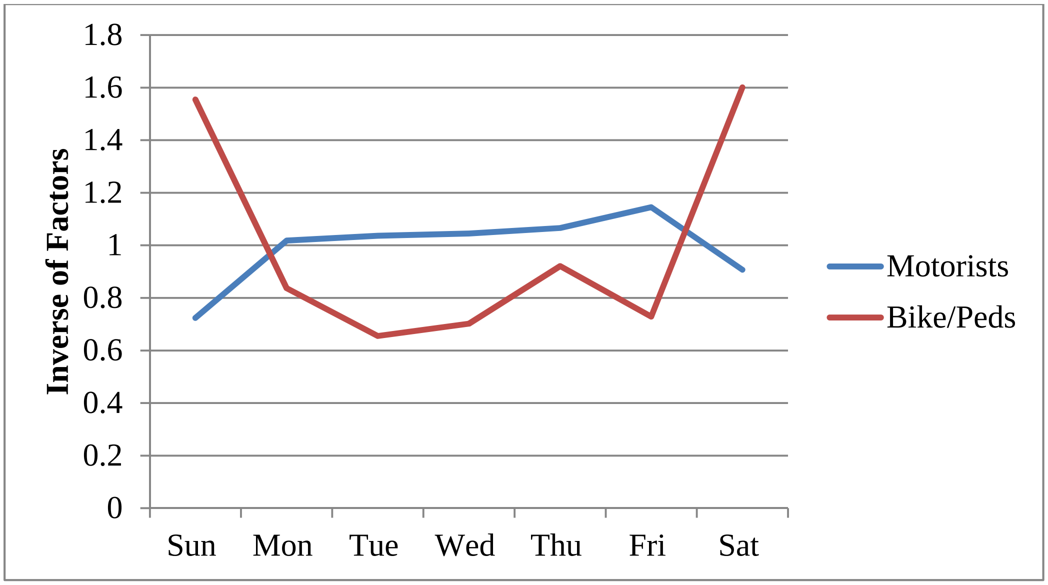

Figure 19. C-470 Daily Factor Comparison.

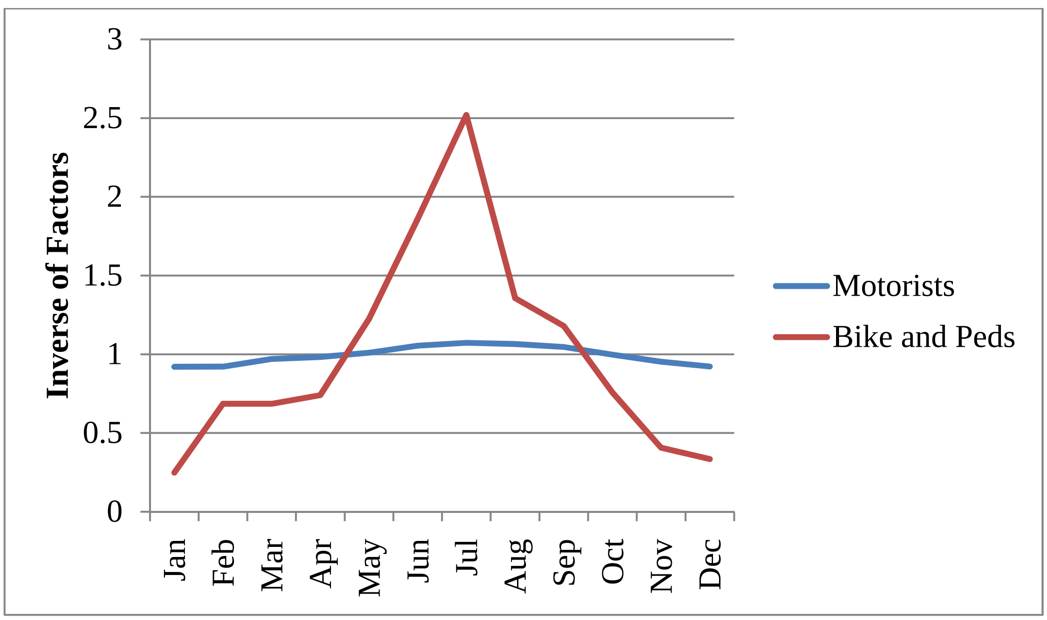

Figure 20. C-470 Monthly Factor Comparison.

Steamboat Springs

While non-motorized and motorized counters were not co-located, they are both on the same roadway, US40, which is the main thoroughfare through the city of Steamboat Springs. As shown in Figure 21, the bicycle counter is located north of town, while the motor vehicle counter is located on the southern end of town. Both counters are on the highway itself.

In order to calculate AADB, the available data from September 29, 2010 to December 30, 2011 was used. Data from days with missing or partially missing counts were removed from the estimate of AADB.

The average hourly traffic counts as a percent of annualized daily traffic were plotted for both modes to compare patterns for workdays and weekends (Figures 22 and 23), in summer and winter. For motor vehicles, there is little difference between summer and winter traffic; for cyclists, summer counts are much higher than winter counts, as expected. Bicycle traffic also shows a clearer commute pattern than motorized traffic. Bicyclist peak morning and evening hours are one hour later than the motor vehicle peak hours, except for winter mornings when the morning cyclist peak is two hours later than the motor vehicle peak hour. This could be due to the need for cyclists to wait for warming to melt ice and snow on the roadway. Bicycle traffic also peaks in midday with clear peaks around noon in summer and 1 PM in winter, while motor vehicle traffic has a midday peak earlier in the day.

In addition to examining hourly patterns, daily and monthly patterns were also compared (Figures 24 and 25). Bicycle traffic is highest on weekdays, while motorist traffic is higher on weekends, which is the opposite of the patterns observed in Denver. Motorized traffic is less dependent on seasonality, with highest counts in summer and also peaking in March. Bicycle traffic shows much higher peaks in summer.

The correlation coefficient of the hourly percent AADT and AADB data is 0.727. This indicates that there is some correlation between hourly patterns for motorized and non-motorized traffic. Comparing the Steamboat Springs counts to those from Denver, the daily patterns are inversely correlated (Table 12), though not as strongly as seen in the Denver case. The monthly patterns are only slightly correlated with the least correlation for any of the cases studied. This may be due to higher motor vehicle traffic in Steamboat for skiing in winter, while bicycle counts are more determined by local resident commute patterns.

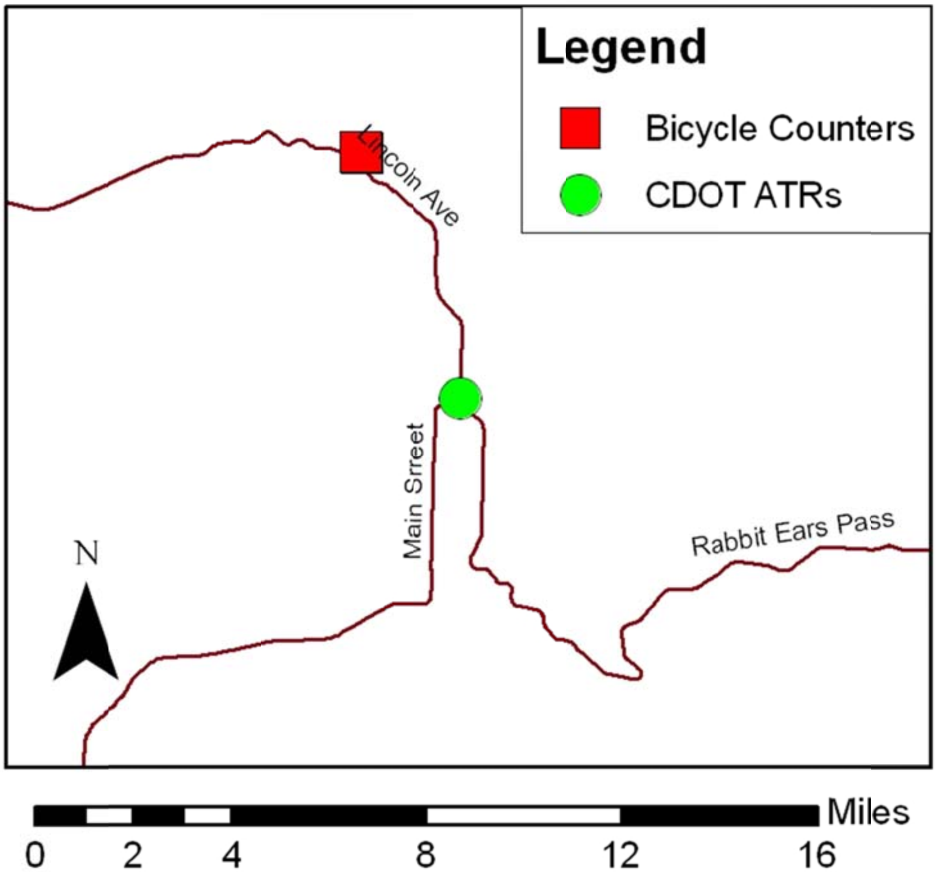

Figure 21. Map of Steamboat Springs Counters Used in Comparison Study.

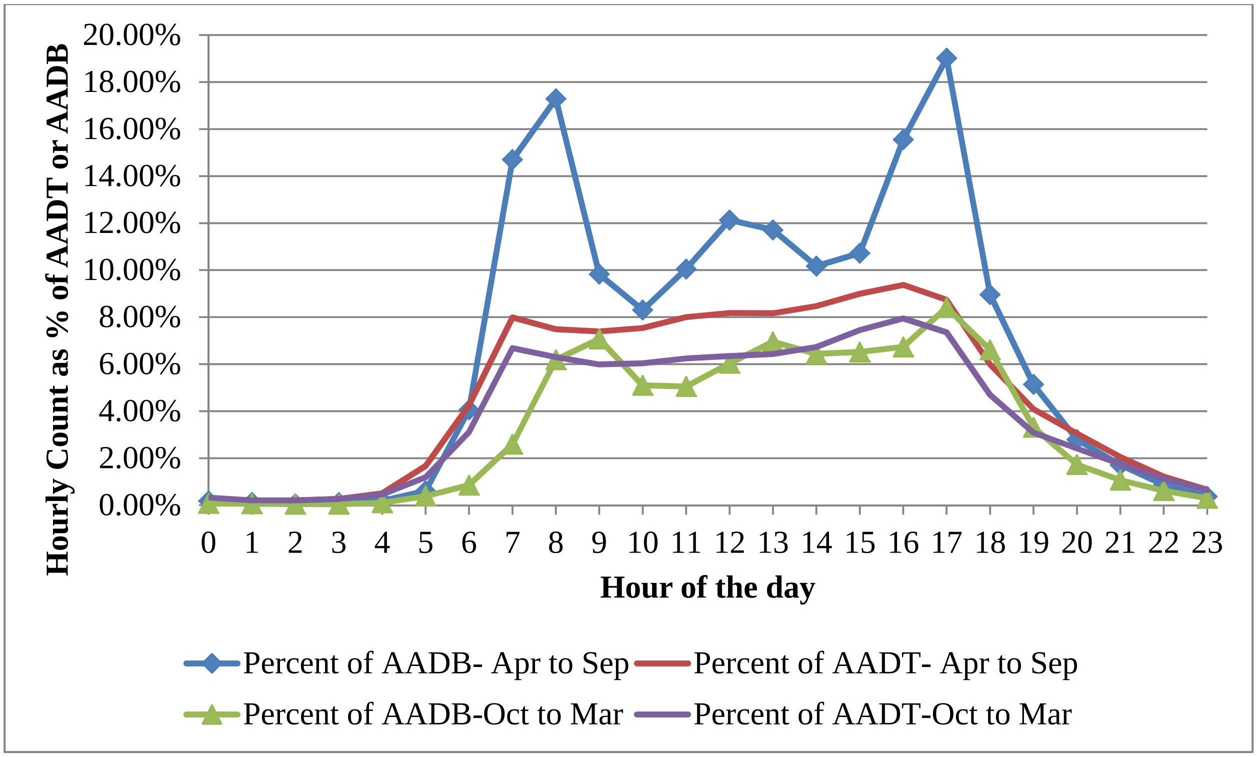

Figure 22. Steamboat Springs Hourly Factor Comparison for Workdays.

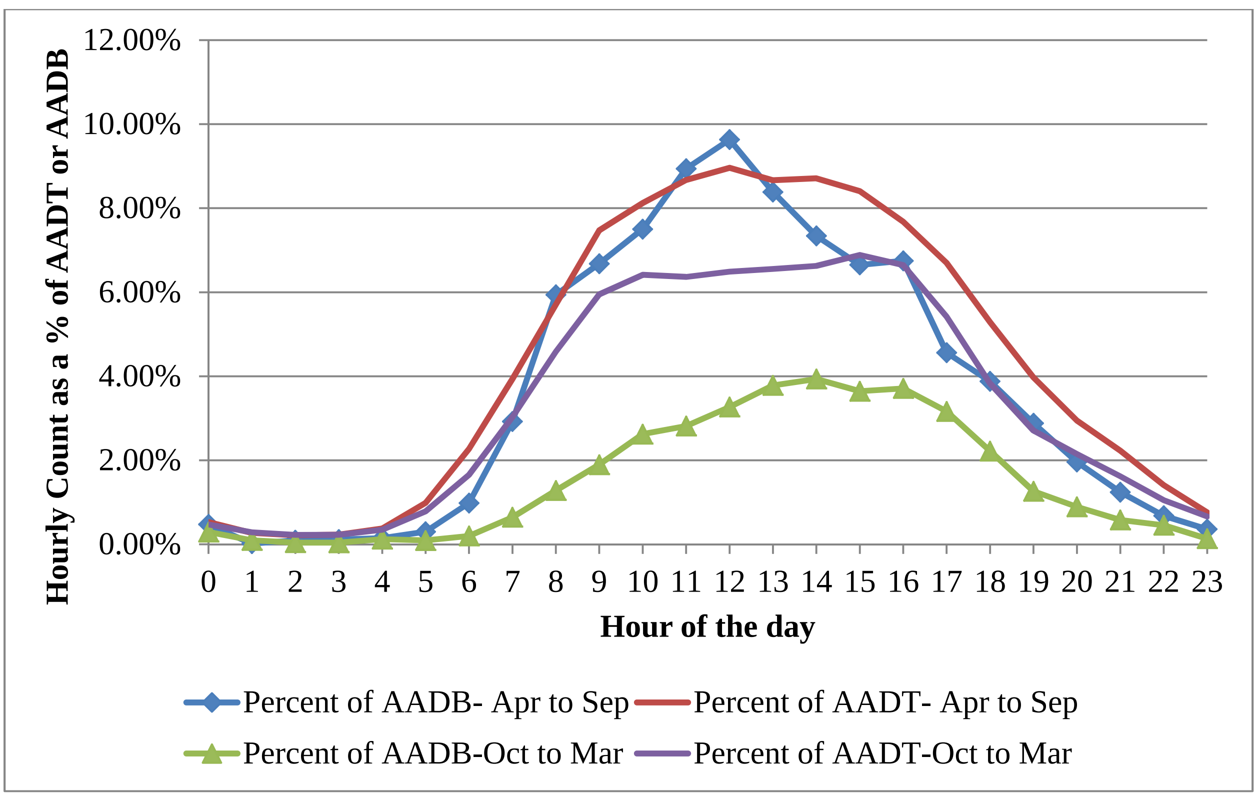

Figure 23. Steamboat Springs Hourly Factor Comparison for Weekends.

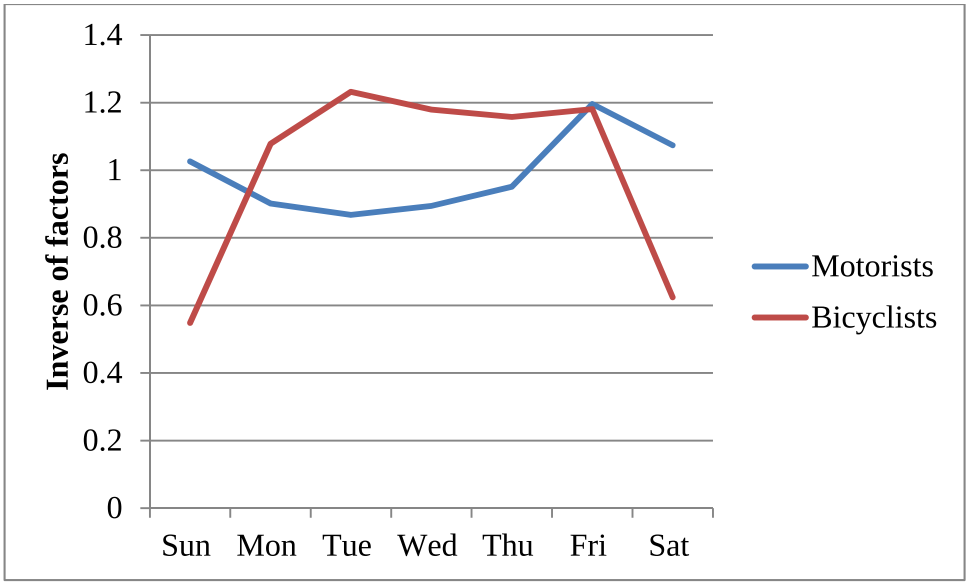

Figure 24. Steamboat Springs Daily Factor Comparison.

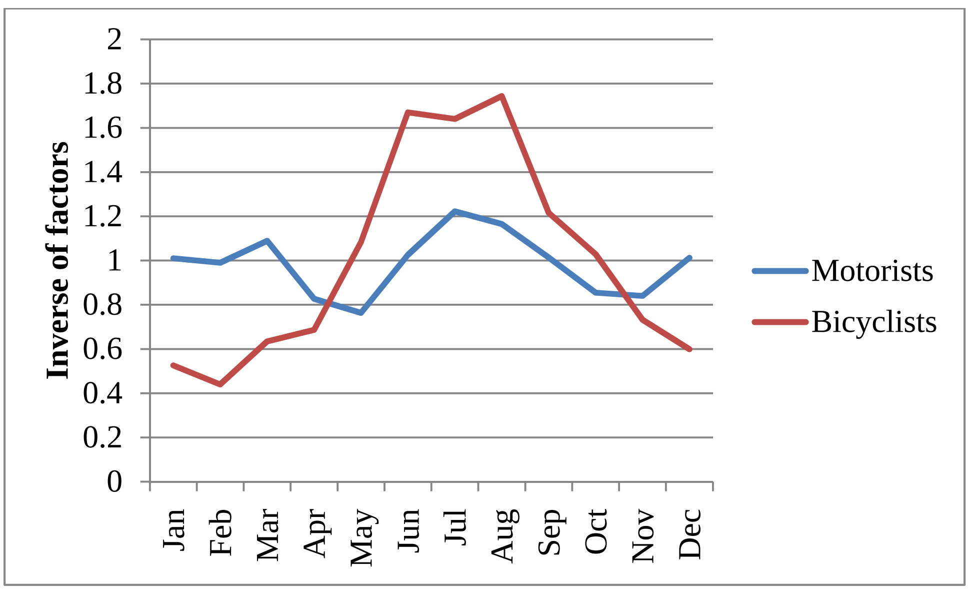

Figure 25. Steamboat Springs Monthly Factor Comparison.

General Comparison

Generally for the four cases examined, motorized and non-motorized traffic in the same geographic area or corridor did not share the same patterns. As shown in Table 12, the counts were not well correlated in general, with a few exceptions: Steamboat Springs hourly counts show some correlation between motorized and non-motorized patterns; both Denver locations show inverse correlation between motorized and non-motorized daily traffic patterns; and Durango and C-470 stations show strong correlation between monthly patterns.

Monthly patterns did generally coincide with peaks in the summer months for both modes, but the non-motorized modes showed much greater variation with the seasons.

The daily patterns were sometimes inversely correlated in cases where non-motorized traffic had high weekend counts while motorized traffic saw high weekday counts. However, even in cases where both experience higher weekday counts, Fridays were the highest count days for motorists, while mid-week days were typically higher for non-motorized traffic.

Hourly patterns were not well correlated between the two modes, except for Steamboat Springs, the only non-motorized location with a clear traditional commute pattern of the four studied.

Table 12. Correlation Coefficient between Motorized and Non-Motorized Traffic Factors.

Location	**Hourly**	**Daily**	**Monthly**
Durango	0.5	0.3	0.8
Central Denver	0.5	-0.7	0.6
C-470	0.2*	-0.8	0.9
Steamboat Springs	0.7	-0.3	0.4

Overall, this indicates that motor vehicle patterns are not good predictors of non-motorized patterns, and if they are used, neither proximity nor sharing the same corridor is a good reason to choose a factor group. If motor vehicle factors were applied to non-motorized traffic, they would dramatically under predict seasonal fluctuations, which would result in either under prediction of summer counts or over prediction of winter counts. In the case of daily factors, even if the appropriate factor group were known, motor vehicle factors may generally predict the correct pattern, but would tend to over-predict counts on Fridays, a common high count day for motorists, and under predict counts on Tuesdays, a common high count day for non-motorized users in the Colorado data. In the case of hourly counts, even if a non-motorized count location shares the same daily pattern with motorized traffic, the hourly non-motorized pattern may differ significantly from motorized patterns. And even when both modes show evidence of a commute or recreational pattern, the peak hours of those patterns may not coincide.

Even in the two cases where both motorized and non-motorized counters are located on the same roadway or corridor (C-470 and Steamboat Springs), patterns differed significantly between the modes. As has been found for motor vehicles, two roads close to each other can exhibit dramatically different traffic patterns. In none of the four cases studied were motorized traffic patterns found to be good predictors of non-motorized traffic for both daily and hourly traffic.

While traffic patterns of motorized and non-motorized users in proximity to one another or using the same corridor may not share the same patterns, are other motorized patterns useful for predicting non-motorized traffic patterns? This will be discussed in the next section.

Task 2A: ii) Factor Comparison

CDOT currently computes seasonal and daily factors for six factor groups representing six different motor vehicle traffic patterns, as plotted in Figures 26 and 27. It would be convenient if the same or similar patterns were present in non-motorized traffic so that the existing factor groups could be used for computing annual average daily non-motorized traffic. In the last section, motorized and non-motorized traffic in the same areas – or along the same corridors – were compared for four cases, but it was found that these patterns did not necessarily correlate and none correlated well for both daily and monthly patterns. However, it may be that non-motorized traffic correlates well with other motorized traffic patterns not studied in the four cases investigated in the previous section.

Looking at the seasonal factors in Figure 26, motor vehicle Factor Group 3 is the most likely candidate to match non-motorized patterns because it has a much higher seasonal variation than the others, with a peak in the summer and low counts in the winter. Looking at the daily factors in Figure 27, all of the motor vehicle factors show a strong peak on Fridays, which is rarely the case for non-motorized users. This was shown in Table 8, where Fridays were the least frequently listed peak day for non-motorized users. This makes it less likely that motorized factor groups would accurately predict non-motorized traffic, although the seasonal factors for motor vehicle Factor Group 3 may be a good fit.

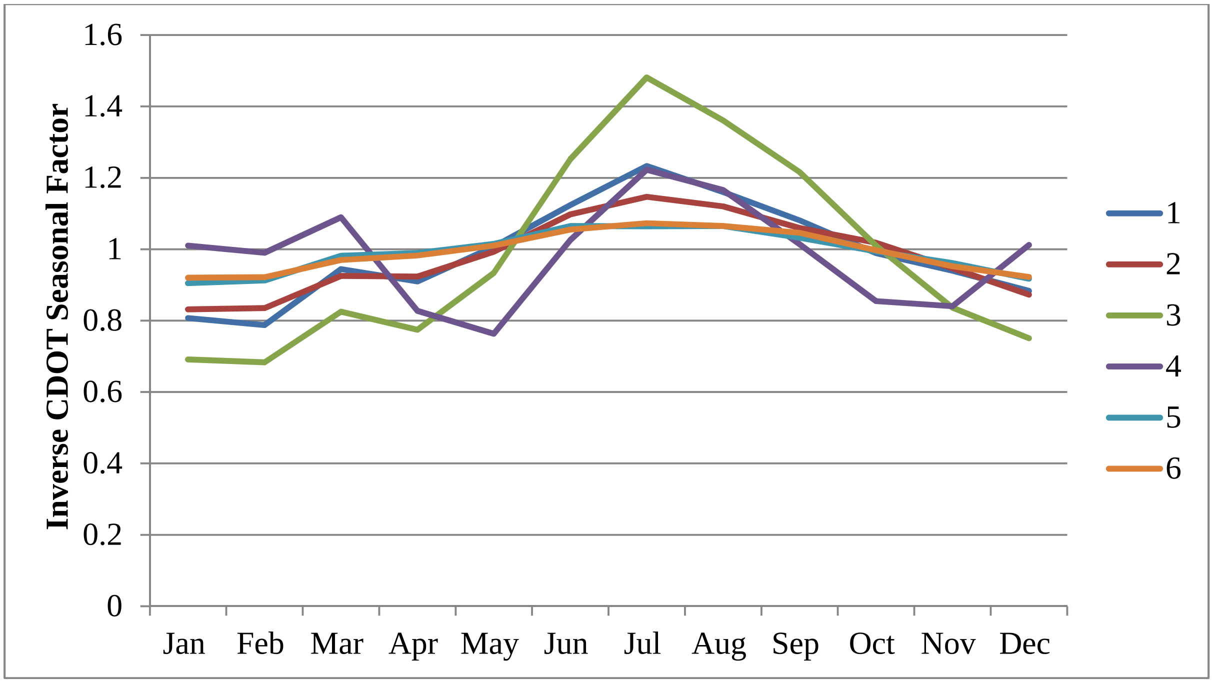

Figure 26. CDOT 2011 Seasonal Factors.

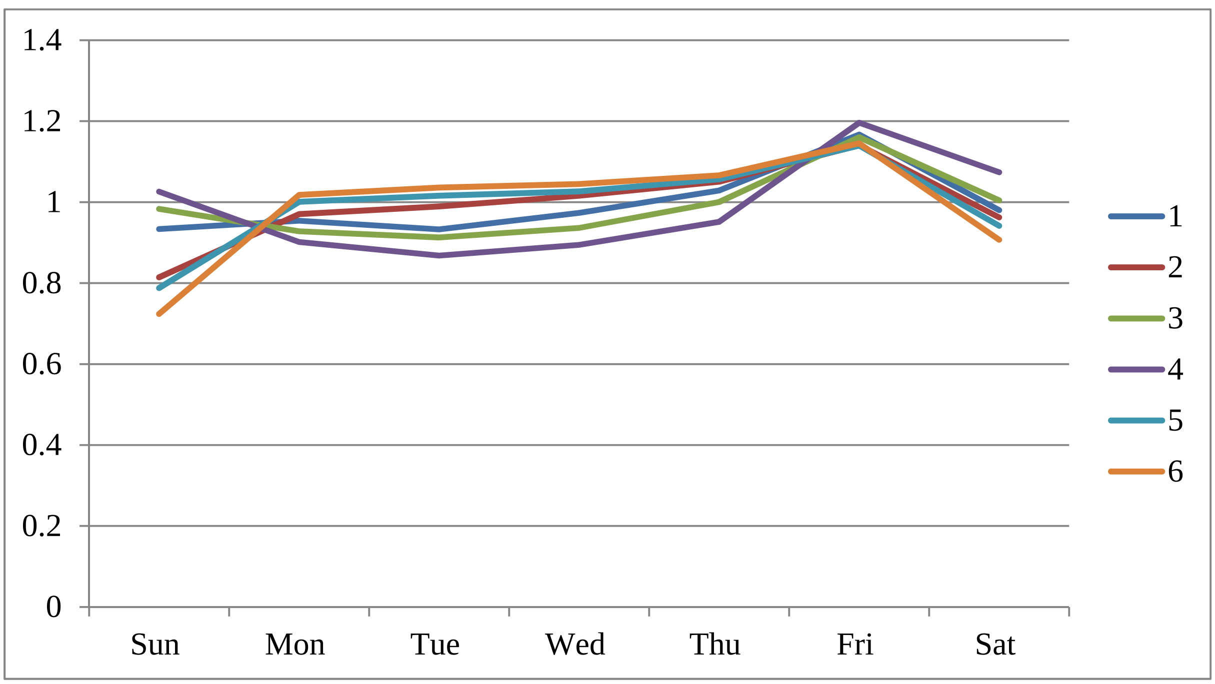

Figure 27. Average CDOT 2011 Daily Factors.

Task 2B: Bicycle / Pedestrian Models and Estimation Factors

Task 2B begins with bicycle count models for changes related to direction of travel, hourly peaking, seasonality, weather, and special events for Boulder (not enough data was available to conduct similar analyses for pedestrians). We then developed a Colorado-specific model for annual bicycle and pedestrian volumes with seasonal factors and other factors, such as weather and recreational vs. commuting bicycle and pedestrian use. The factors were then validated by using them to compute AADB for one location where a full year of count data was available, Steamboat Springs for 2011. The last section of Task 2B evaluates the feasibility of using existing CDOT motorized traffic data calculation and reporting tools for non-motorized bicycle and pedestrian volumes.

Task 2B: i) Models and Factors for Bicyclists

Several methods for estimating AADBP were investigated including: i) the factor method similar to that used for motor vehicles; and ii) multiple statistical models that incorporated hourly weather data. Since the city of Boulder has 25 stations of somewhat continuous bicycle count data from 1998 to the present, it was decided to focus on these stations for this part of the study. Since the Boulder data is less diverse than the complete set of Colorado count stations, only two factor groups were used: commute and non-commute.

After exhaustive analysis of the Boulder bicycle count data (see Nordback thesis [9]), it was found that while including weather data in a statistical model does increase the accuracy of the estimates, the additional work needed to incorporate such a method into CDOT's existing database software does not warrant the increase in accuracy at this time. Factoring methods are simpler, work well with CDOT's data management system, and require much less staff time to implement. A summary of the analysis performed to reach this conclusion is included below.

Annualization Methods

Several annualization methods were explored, including statistical models as well as traditional factoring approaches. The statistical models were able to incorporate temperature and other weather variables, while the factoring approach included only temporal variables and the classification variable used to determine the factor groups, the dummy variable “Commute.” The methods explored can be divided into three types: statistical models of hourly counts applied to estimate AADB; statistical models of AADB from hourly counts; and factoring methods.

In order to estimate AADB using statistical models that estimate hourly counts for a location where continuous counters are not present, the following two numbers were calculated: i) for the given year, knowing the hourly weather for all the hours of the year, the statistical model was used to estimate the counts for each hour of the year and the hourly counts were summed to give the unadjusted AADB calculated for the year [$(\sum^{year} c_{eh})/365$]; and ii) given a manual hourly count collected at a location where no continuous count data are available, the statistical model was used to estimate the count on that day and the ratio of the actual to estimated hourly count was called the adjustment factor. The adjustment factor (c_{kp}/c_{ep}) was then multiplied by the AADB estimated by the model to obtain the adjusted AADB:

$$AADB_e = (c_{kp}/c_{ep}) * (\sum^{year} c_{eh})/365$$

where:

$AADB_e$ = estimated annual average daily bicyclists

c_{kp} = known count for time period *p*

c_{ep} = estimated count from statistical model for time period *p*

c_{eh} = estimated hourly count from statistical model

In order to estimate AADB more directly, AADB estimates for the years studied at all locations were created. Treating AADB as the dependent variable with hourly counts and temporal and weather variables as the independent variables, statistical models were created to directly estimate AADB.

A modified version of the factoring method recommended in the TMG was also used to estimate AADB. For the purposes of the Boulder data, the locations were broken into two factor groups: those with clear commute patterns and those without. Two factoring approaches were used to calculate estimated AADB. One was a traditional factoring approach based directly on the methods proposed in the Traffic Monitoring Guide:

$$\text{AADB}_e = c_{kh} * H_{yf} * D_{yf} * M_{yf}$$

where:

AADB_e = estimated annual average daily bicyclists

c_{kh} = known count for one hour

H_{yf} = hourly factor for a given hour of the day in a given year y for a factor group f.

= (actual AADB for that year)/(average hourly traffic for that hour in that year)

D_{yf} = daily factor for a given day of the week in a given year y for a factor group f.

= (actual AADB for that year)/(avg. daily traffic for that day of the week in that year)

M_{yf} = monthly factor for a given month in a given year y for a factor group f.

= (actual AADB for that year)/(average daily traffic for that month of that year)

The second factoring approach calibrated factors specifically for the three peak hours, 8:00 to 9:00 AM, 12:00 to 1:00PM, and 5:00 to 6:00PM (8,12,5) on Tuesdays, Wednesdays, and Thursdays (TWR). This factor method was developed specifically for the turning movement count data available from the city of Boulder. The method is detailed below:

$$\text{AADB}_e = c_{kp} * D_{pyf} * M_{pyf}$$

where:

AADB_e= estimated annual average daily bicyclists

c_{kp} = known count for sum of three peak hours (8,12,5) on a TWorR

D_{pyf} = factor for a given month in a given year y for a factor group f for all TWR for the sum of the three peak hour counts

= (average daily count for TWR only for a given month in a given year)/(average three peak hour count per day for TWR only for a given month and year)

M_{pyf} = monthly factor for a given month in a given year y for a factor group f.

= (actual AADB for that year)/(average daily count for TWR only for a given month in a given year)

As described above, the factors were created to factor up the average of the three peak hours on TWR to AADB, instead of creating separate factors for each hour. Two factors were created: a daily factor that factored the average three peak hour counts up to an average workday daily count, and a monthly factor that factored an average workday for that month up to an average annual count. Thus, only daily and monthly factors were needed. Since it is not necessary at this time to calculate future years, growth factors were not applied, but instead factors for each year and month were computed.

While this method may appear crude, it has the advantage of creating many factors. For example, when the method was applied to the Boulder data, 245 daily and 245 monthly factors were created for the time period from 2000 to January 2012 in both factor groups. Thus, a total of 490 factors were used to estimate the AADB from the hourly counts.

Comparing Methods

To test the different methods, a sample year was selected that had nearly all of the data for one year at one location: the Boulder Creek Path, west side, at 13th and Arapahoe in 2007[1]. Ideally these test data would not have been included in the creation of the model, but unfortunately the 2011 data that had not been included in model formation did not consist of a complete year of continuous count data to test. Thus, a random sample of data removed from the count data used to calibrate the model would also not include a full continuous year of count data.

Both the statistical models as well as the factoring method were used to estimate AADB for the average of three peak hours (8 AM, 12 PM, 5 PM) for any Tuesday, Wednesday, or Thursday. The models were compared by computing the average, standard deviation, and 95% confidence intervals (assuming normal distribution of the differences) for both the differences and percent differences between the actual AADB and that predicted for each model.

Table 13 shows the average percent differences and standard deviations of the percent differences of the error in AADB estimation for each method. The percent differences were

[1] Hourly counts from 8 days, Tuesday, January 30, 2007 at 11 AM through Wednesday, February 7, 2007 at 11 AM are missing from the dataset. To fill the gap, data from Tuesday, January 25, 2005 at 11 AM to February 2, 2005 at 11 AM were inserted into the test dataset. While these data were used to estimate AADB for the location, model estimates for those dates were removed from the comparison of models.

computed as the estimated minus the actual AADB divided by the actual AADB as shown below.

$$Error\ as\ \%\ Difference = (AADB_e - AADB)/AADB$$

where:

Error as % Difference = the percent difference between estimated and actual AADB

$AADB_e$ = estimated AADB

AADB= actual AADB

Table 13. Abbreviated Comparison of AADB Estimates Using Multiple Approaches.

Model or Approach	**Error as % Difference**	
	Ave.	**St. Dev.**
Linear Model: HourlyCount= f(sin/cos Time, sin/cos Month, Commute, HrlyTemp, $HrlyTemp^3$)	7%	212%
Log-Linear Model: ln(HourlyCount)= f(sin/cos Time, sin/cos Month, Commute, Year, Workday2, HrlyTemp, $HrlyTemp^2$, $HrTemp^3$) R^2=0.46	11%	41%
Negative Binomial Model: ln(HourlyCount) = f(sin/cos Time, sin/cos Month, Commute, HrlyTemp, $HrlyTemp^2$, Time* HrlyTemp, Month* HrlyTemp)	21%	40%
Negative Binomial Model: ln(HourlyCount)= f(sin/cos Time, sin/cos Month, Commute, HrlyTemp, $HrlyTemp^3$)	22%	42%
Negative Binomial Model: ln(HourlyCount) = f(sin/cos Month, HrlyTemp, $HrlyTemp^2$, CompDat2)	-4%	35%
HYBRID MODEL (HM) Negative Binomial Model: ln(HourlyCount) = f(SchlDy, HrlySun, Month, HrlyTemp, $HrlyTemp^2$, CompDat2)	-6%	30%
Using two statistical models: one for the peak hours to create the adjustment factor and the other for predicting AADB.	8%	40%
Negative Binomial Model: ln(AADB) = f(HourlyCount)	-46%	10%
FACTOR METHOD (FM)	-13%	37%
Average of HM and FM	-10%	33%

Many approaches were used to model hourly counts and to estimate AADB. The methods were evaluated: primarily, by comparing standard deviation of the AADB estimation error; and secondarily, by comparing the average estimation error. Based on these evaluations, what we are calling the hybrid model, which includes both temperature and month, provided the best estimates of AADB because it had the lowest standard deviation for a model with reasonable average error. However, the factor method more accurately predicted AADB than all of the other statistical models, except the two models that included the hybrid variable "CompDat2." While only simple multiplication was used to compute the factor model, the sheer number of factors used helps explain why such a seemingly simple method out-performed most of the statistical models, which use only a few estimated parameters to describe the same data.

Understanding Error in AADB Estimation

From further investigation of the error in AADB estimation, the factor method was compared against the hybrid statistical model, which was the best of the statistical methods for estimating AADB. In the previous discussion, only one location was used to test the accuracy of the models. To better understand the error in the methods, three other count stations with one continuous year of bicycle count data were identified and used to compare the methods further. The test data used are listed in Table 14. Errors produced by these methods were analyzed under different circumstances: by length of short-term count collection period, by weather conditions, by month, and by location.

Table 14. Continuous Count Data Used to Compute Error in AADB Estimates.

Location	Side	Dates	Commute Pattern	Volume
Arapahoe & 13th St.	Boulder Creek Path West Side	January 2007 through December 2007	No	High
Arapahoe & 38th St.	Arapahoe Path	June 2004 through May 2005	No	Low
Arapahoe & Foothills Pkwy.	Arapahoe Path	June 2004 through May 2005	Yes	Medium
Arapahoe & Foothills Pkwy.	Foothills Path	June 2004 through May 2005	Yes	Medium

The hybrid model was recreated without the test data, and the AADB error was recomputed. The parameters only changed slightly. While the AADB estimation error did increase, the increase was 5% or less in all cases, and for twenty-four hours or more of hourly count data, the error did not increase at all.

Table 15 reports the mean of the error of both methods at the four locations where AADB is known. Figure 28 compares the error for the two methods for the four locations, and Figure 29 shows the same information using a log scale for the time period for which short-term counts are known, in order to better show the error for time periods less than 24-hours. For this table and for these figures, error is computed as the absolute percent difference between the estimated and actual AADB, as described in the following equation:

$$\textit{Error as Absolute \% Difference} = |AADB_e - AADB|/AADB$$

where:

Error as Absolute % Difference = the absolute percent difference between estimated AADB and actual AADB

$AADB_e$ = estimated AADB

AADB = actual AADB

The table and figures both show how the average AADB estimation error can range from over 60% to less than 10%, depending on the time period for which counts are known. Figure 28 shows that for time periods over one week, the additional accuracy gained is minimal. Figure 29 shows that for short time periods of less than twenty-four hours, accuracy fluctuates. In most cases, the Tuesdays, Wednesdays, and Thursdays (TWR) factors provide better estimates of AADB, but in other cases they provide worse estimates. In all cases, estimates based on twelve-hour counts on TWR are better than estimates based on twelve-hour counts on any day, including TWR. Thus, counting on TWR – and calibrating specific factors for those days – generally reduces error.

Table 15. Comparison of Error in AADB Estimates by Method and Location.

		Error as Average Absolute % Difference							
Location:		Arap13th		Arap38th		ArapFthls		ArapFthls	
Station:		West Side				Foothills1		Arapahoe	
Year:		2007		2004-2005		2004-2005		2004-2005	
Actual AADB:		778		86		431		311	
Short-term Count Period	**Hours**	FM	HM	FM	HM	FM	HM	FM	HM
1 hour: 7am-7pm any day	1	49%	45%	58%	58%	56%	48%	52%	48%
1 hour: 7am-7pm TWorR	1	41%	37%	47%	50%	41%	47%	39%	46%
1 peak hour: 8,12,5 TWorR	1	36%	31%	44%	45%	46%	57%	40%	54%
2 peak hours: 5 to 7pm TWorR	2	41%	40%	54%	39%	46%	42%	43%	42%
3 peak hours: 8,12,5 TWorR average/day*	3	30%	23%	36%	36%	47%	46%	46%	46%
3 peak hours 8,12,5 TWR*	9	25%	17%	31%	34%	41%	44%	40%	45%
7am-7pm any day	12	34%	26%	47%	44%	41%	34%	38%	34%
7am-7pm TWorR	12	25%	21%	38%	39%	28%	33%	28%	33%
24 hours any day	24	26%	25%	36%	38%	35%	29%	37%	30%
1 week	168	17%	13%	28%	31%	20%	19%	24%	21%
2 weeks	336	11%	9%	25%	30%	19%	17%	19%	20%
4 weeks	672	7%	5%	24%	30%	14%	17%	14%	21%

FM = Factor Method and HM = Hybrid Model

*Values computed using daily and monthly factors specifically calibrated for peak hours.

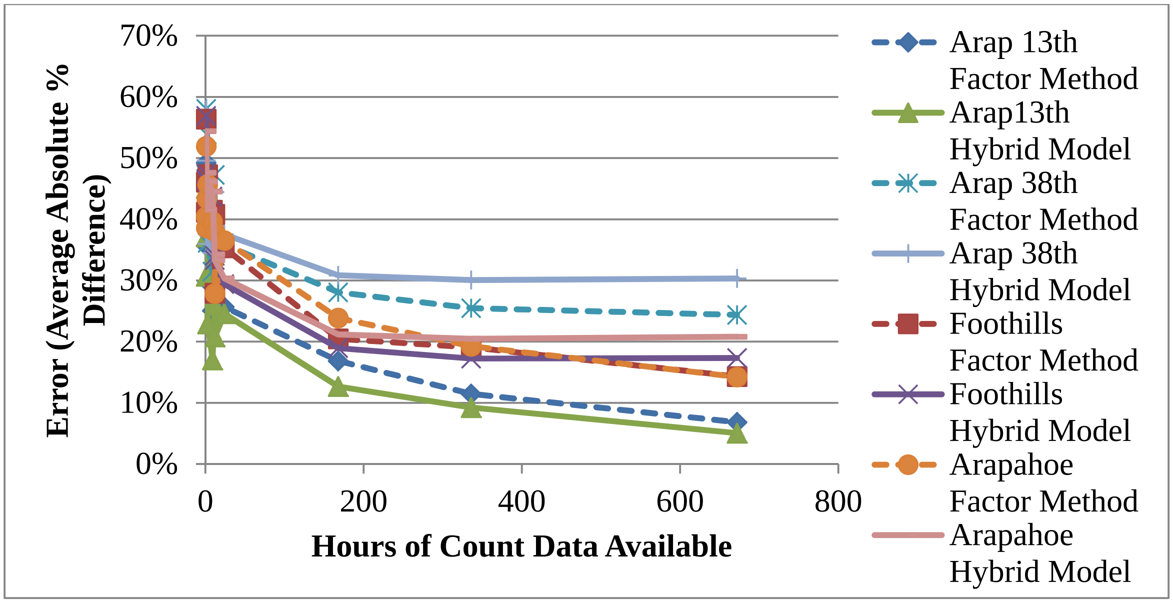

Figure 28. Error in Estimated AADB by Duration of Short-Term Count.

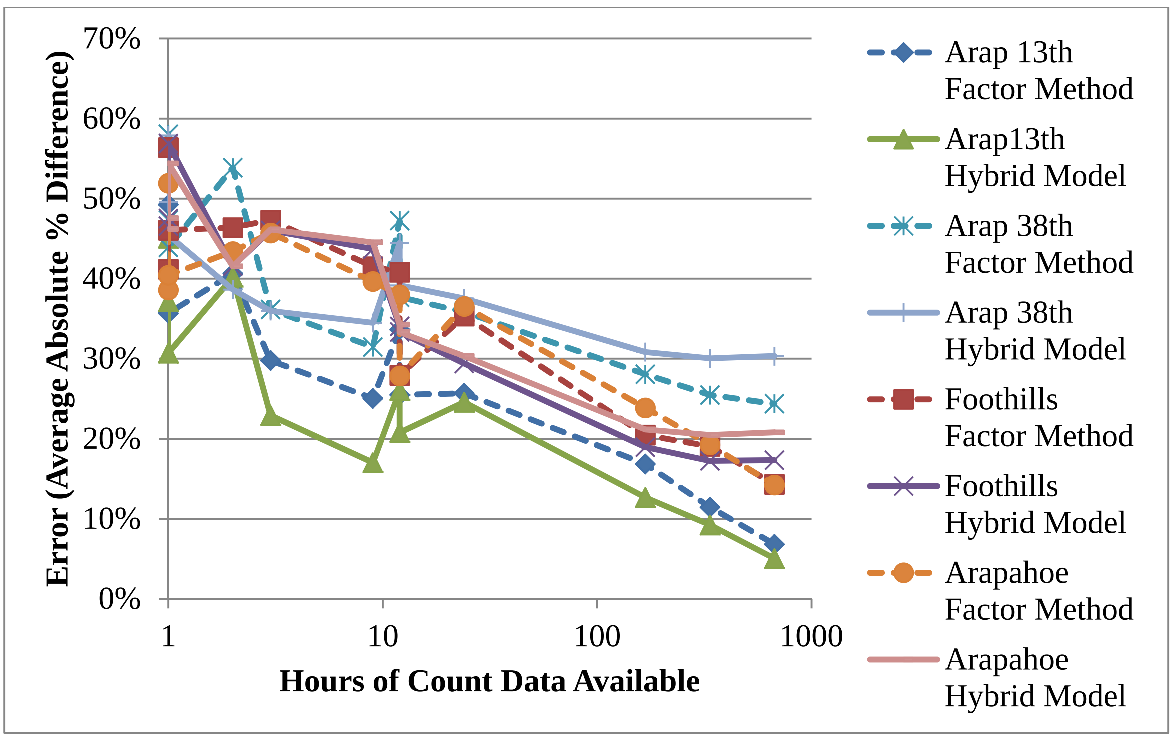

Figure 29. Error in Estimated AADB by Duration of Short-Term Count on a Log Scale.

Analyzing Error

In addition to errors related to the duration of short-term counts, volume of traffic, day of week, and factoring method, AADB estimation error is also impacted by elements such as seasonal variation, variation in hourly bicycle counts, and number of continuous count stations used to calibrate the factors. Since it was necessary to hold the count scenario constant in order to observe the effects of the other variables on AADB accuracy, one count scenario was chosen: counting on all three assumed peak hours (8, 12, 5) on any TWorR day.

Variations in AADB Error by Weather Conditions

One might expect that weather, especially those weather events not included in the model, may help explain some of the error in the AADB estimates. To investigate this, the percent error measured as the average percent difference – between the estimated and actual AADB for the four path locations where actual AADB is known from a continuous record of hourly count data – were plotted with the weather phenomena of interest as shown in Figures 30 through 34. These estimates were based on knowing all three peak hours (morning, noon, and evening) on one day, either TWorR.

Temperature is included in the hybrid model but not directly in the factor method. Based on a study of Figure 4-5, several conclusions can be made. The hybrid model appears better than the factor method at estimating AADB at temperatures above 50°F. However the hybrid model does not provide as good a fit in colder temperatures with AADB estimates scattered, both under and over estimating. At temperatures below 50°F, the factor method tends to underestimate AADB. For higher temperatures, the factor method may overestimate AADB, although the results are scattered both for over and under estimating. As would be expected, the hybrid model, which includes temperature, does seem to provide better AADB estimates with respect to temperature; however, the fit is not as good at lower temperatures. This may be due to weather events such as snow and ice.

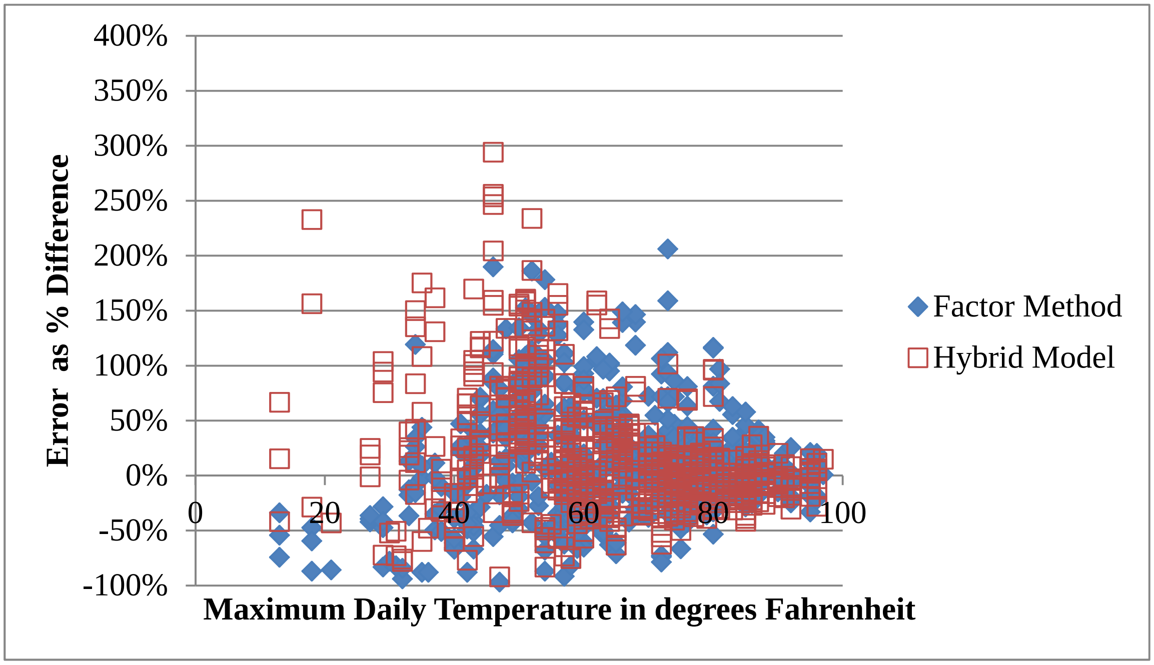

Figure 30. Daily High Temperature vs. Error in AADB Estimation.

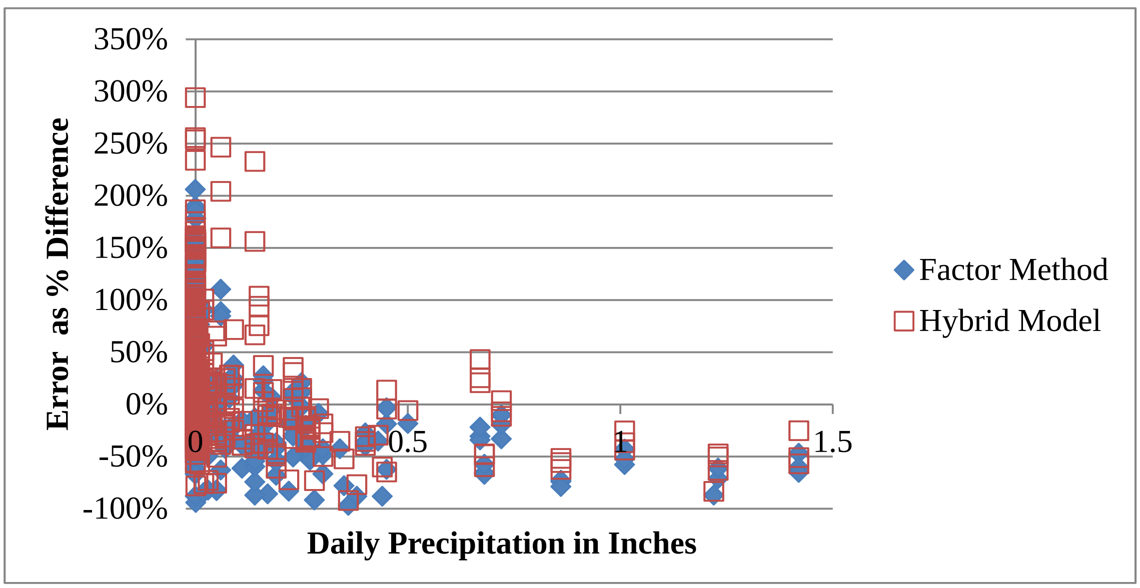

Figure 31. Daily Precipitation vs. Error in AADB Estimation.

Precipitation is not specifically included in either the hybrid or the factor method. Figures 31 through 33 show error in AADB estimation under various precipitation conditions. All three figures show that for higher precipitation, both models underestimate AADB. This is expected, as days with precipitation would have lower counts, and neither method has a mechanism to allow for increasing AADB when sufficient precipitation is present. Based on a study of these graphs, the threshold for underestimating AADB is 0.8 inches of precipitation for both methods, one inch of snowfall for the factor method, 4 inches of snowfall for the hybrid model, and five inches of accumulated snow on the ground for both methods. For precipitation above these thresholds, the methods underestimate AADB. Given this information, future models should include at least some precipitation metric such as a dummy variable with a value of one for precipitation above the threshold and zero for precipitation values below it. Including such a variable should help the estimates of AADB when precipitation is involved.

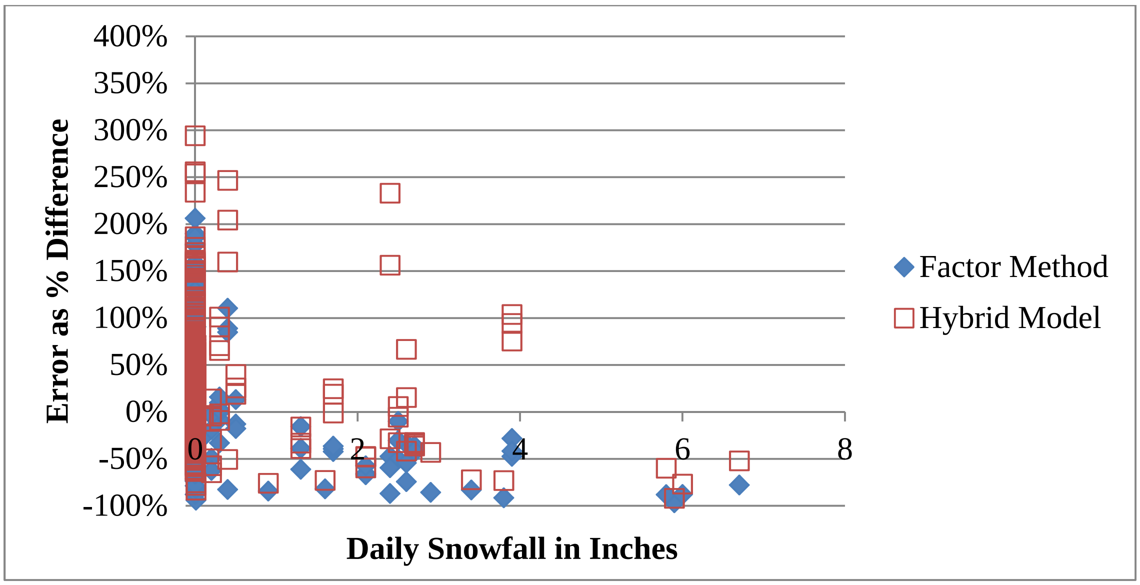

Figure 32. Daily Snowfall vs. Error in AADB Estimation.

Wind in Colorado can be fierce, especially in winter, with gusts above seventy miles per hour. Days with such gusts are noted by the National Oceanic & Atmospheric Administration (NOAA) ("Boulder wind info," 2012) and used to create a wind dummy variable for days with high winds. Figure 4-9 shows how error in AADB estimates varies on days with high winds. Based on this figure, wind does not seem to reduce the reliability of the AADB estimate nor cause a systematic under or over count. This may be because the wind events often happen at night and in the winter when bicycle counts are usually low. For this reason, including wind in the model is not expected to greatly increase the accuracy of AADB estimates.

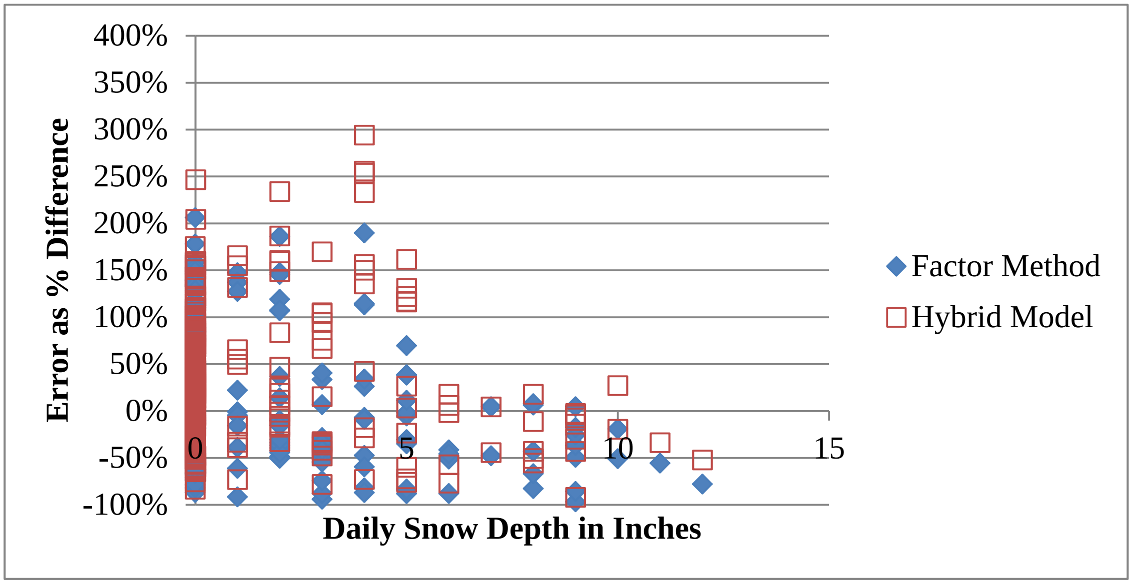

Figure 33. Snow Depth on the Ground Surface vs. Error in AADB Estimation.

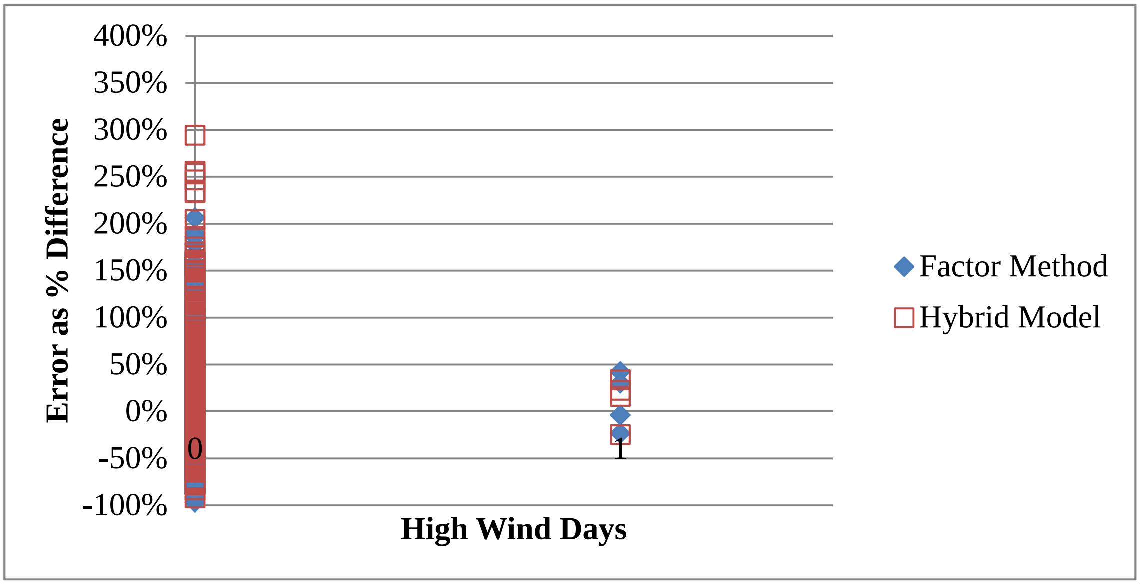

Figure 34. Days with Strong Wind vs. Error in AADB Estimation.

<u>Variations in AADB Error by Month</u>

The average AADB error with month is shown in Figure 35. When AADB estimates are based on counts in the months of July through October, the error in these estimates is substantially lower than in other months. This seems plausible since these months tend to have higher bicycle volumes and thus less variability. Figure 36 illustrates that variation in bicycle counts is lowest overall for the months of May through October.

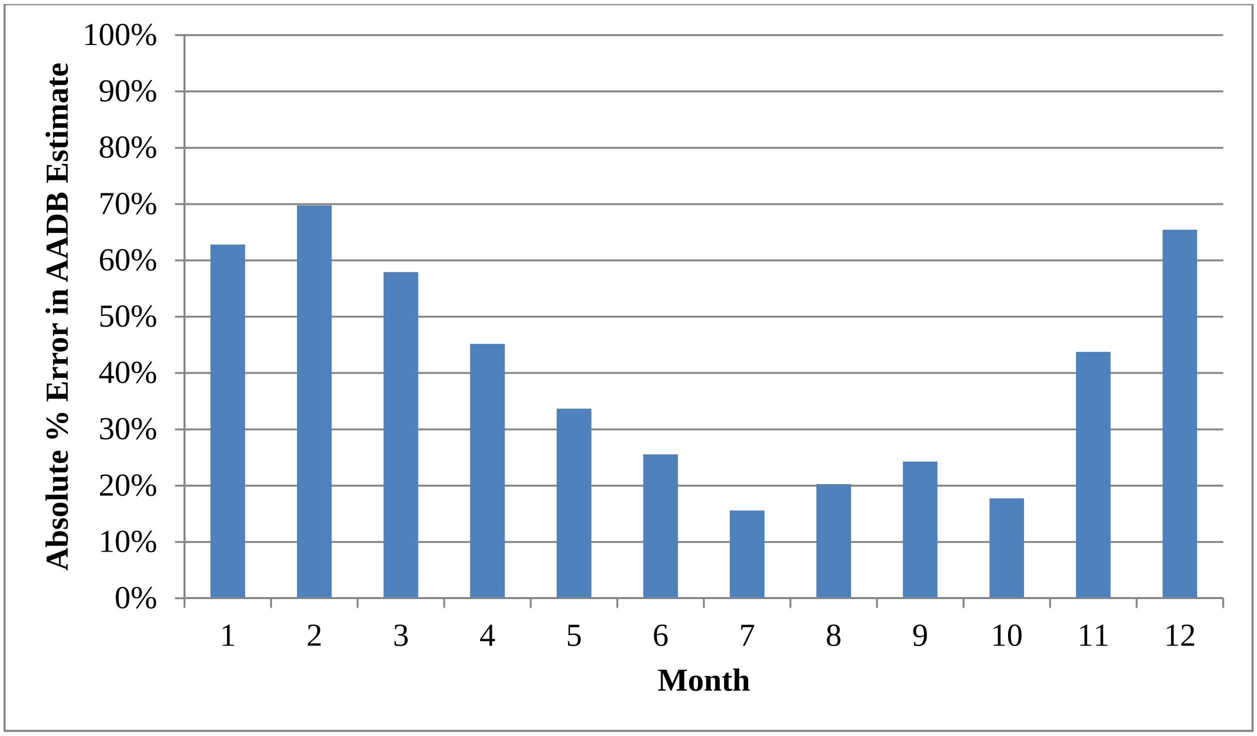

Figure 35. AADB Estimation Error by Month for Factor Method.

If this is the case, it begs the question as to why are AADB estimates for May through June relatively poor for the Boulder data. Looking at the total hours of counts available from the permanent count stations in Figure 37, July through October have more hours of counts than May and June. Thus, it is a combination of more continuous counts available for calibrating AADB estimation factors and lower variability in summer counts that result in lower error for the July through October AADB estimates than for the May through June estimates (Figure 35).

This finding also underscores the importance of operating permanent continuous count stations. Though Boulder has thirteen continous count stations for each of the two factor groups, less than half of that data was actually available for any given month due to incidents when data were not properly collected or counters were not accurate. In effect, the data available were the equivalent to having about approximately five or six permanent count stations per factor group, the minimum recommended by the TMG for motorized traffic. Had more continous count data been available, AADB error would likely have been lower. However, had the city only installed one or two permanent count stations, the error is likely to have been higher.

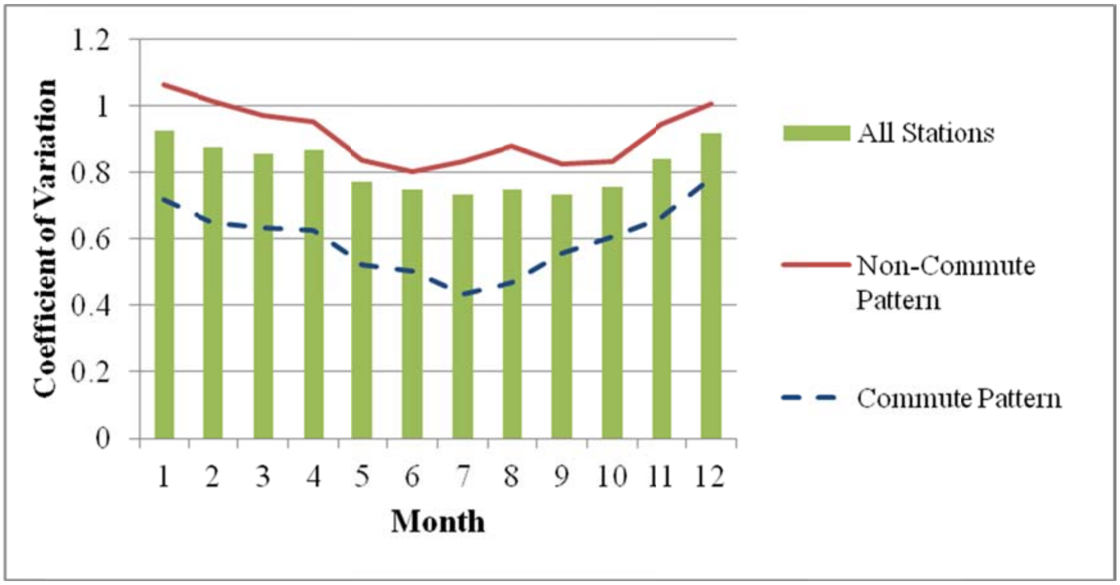

Figure 36. Variation in Daily Bicycle Counts by Month.

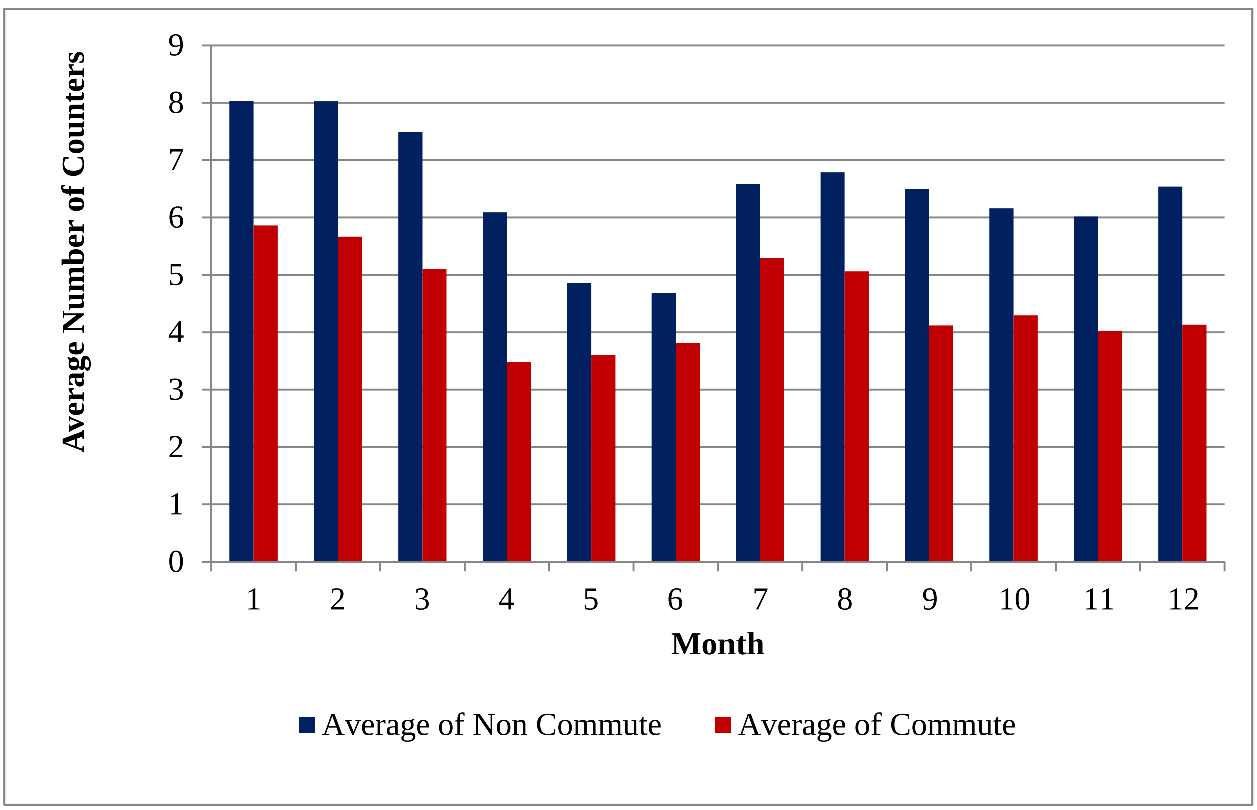

Figure 37. Number of Continuous Counter Datasets Available by Month.

Comparison to AADT

After discussing AADB error, one might wonder how it compares to error in motorized traffic volume estimates. According to an analysis of AADT estimates in Florida and Minnesota, average absolute percent differences in AADT estimates range from 5% to 83% per location and averaged 12% in Minnesota and 14% in Florida [39]. While this AADT analysis was based on hundreds of locations and the analysis described herein is based on four locations, it provides perspective for understanding the errors observed in AADB. When a week of counts is available, the average AADB absolute percent difference error ranges from 15% to 30%, which is near the range observed for AADT. If four weeks of bicycle counts are available for each location, the average error is 15%, which is very close to the average error reported for AADT from 24-hour counts.

Why might more bicycle counts be needed than motor vehicle counts to compute annualized daily volumes with the same level of accuracy? Bicyclist traffic volumes are lower and more variable due to weather and events than motor vehicle volumes; thus, the relatively smaller volume of bicycle counts means that the change in counts from day to day – whether due to random or other variation – is a higher percentage of the total count, which in turn increases the variability of the counts and makes it harder to estimate average annual volumes.

How Many Continuous Count Stations are Needed per Factor Group?

One question of great concern for those creating bicycle counting programs is how many continuous count stations are needed to produce accurate estimates of AADB? To answer this question, the following steps were taken:

1. Calibrate the statistical model and the factors using all the continuous counts for that factor group, except those involved in validating the model.
2. Estimate AADB at one location (Arap1) for one year for each day (24-hour) period during that year.
3. Calculate the error in the AADB estimate by comparing the AADB estimated for each 24-hr period (there were thus 365 estimates) to the actual, known AADB for that year.
4. Compute for each day how many continuous count stations in the factor group had data for that day.

5. Plot the number of count stations available for that day with the AADB estimation error for that day.
6. Fit a linear trend line so we could see what direction the data was trending.

This analysis shown in Figure 38 depicts how AADB estimation error varies with the available number of continuous counters and reveals that while error does decrease with increasing numbers of counters, the correlation is not as strong as expected. What is the optimal number of continuous counters and the optimal length of short-term counts for a city? While further research is needed to answer this question, the analysis conducted here shows that conducting short-term counts at times of year when variation in traffic is lowest has a higher impact on AADB accuracy than installing more than two continuous count station per factor group. In other words, **it is more important to collect short-term counts during the best count months than to install more continuous counters**, though both do tend to increase estimation accuracy.

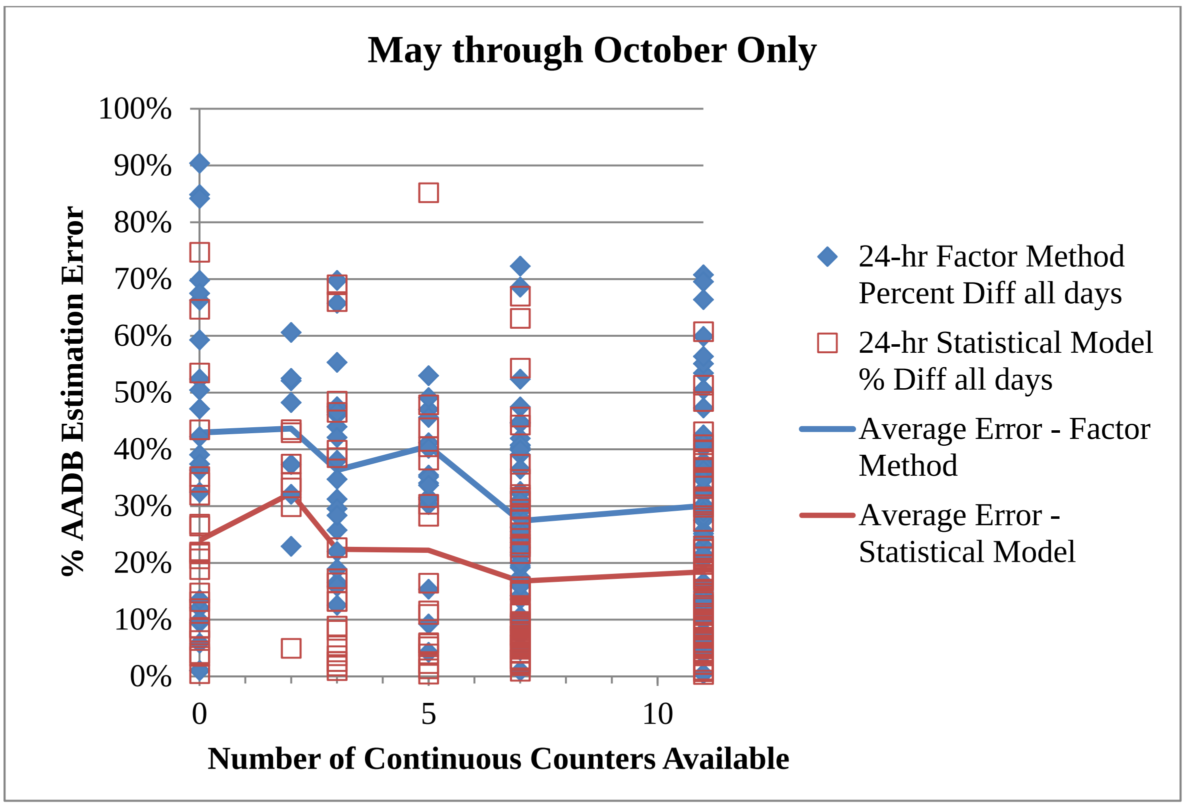

Figure 38. How the Number of Continuous Counters May Impact AADB Error.

The Traffic Monitoring Guide recommends a different approach to the question of how many counters are needed. Instead of looking at the accuracy of AADBP estimates resulting from various groupings, the guide recommends that the precision of the factors is a sufficient metric to judge the grouping of counters. The normalized precision interval, or confidence interval, is based on the coefficient of variation of the monthly factors of the group as shown in the equation below which is the same as Equation 3-5 in the 2001 TMG [8]. This approach assumes that the continuous count station locations were chosen randomly, which is not the case for any of the non-motorized count stations in this study but is commonly assumed in traffic studies, which also have purposefully chosen count station locations. Resulting normalized precision intervals are shown in Figure 39.

$$D = T_{1-d/2,n-1}\, C/\sqrt{n}$$

where

D = normalized precision interval = half confidence interval as a percent of the mean for each month from all the count stations in that factor group

T = value of the Student's T distribution with $1-d/2$ level of confidence and $n-1$ degrees for freedom

n = number of continuous count stations

d = significance level

C = the coefficient of variation of the factors for each month from all the count stations in that factor group

= standard deviation of the factors for each month for all count stations divided by the mean of the factors for each month for all count stations

Applying this metric, the following graph shows the normalized precision interval of the monthly factors for various numbers of counters. The smaller the normalized interal interval the tighter the precision. For motor vehicle traffic, the TMG reports five to eight continuous counters as the optimal number to meet the recommended 10% preceision with 95% confidence. For the Boulder bicycle count data, even with nine or more counters, the average precision is still above the recommended 10%. It makes sense that more continuous counters per factor group would be needed for bicycles as bicycle counts are more variable. However, the average line seems to bottom out around seven to nine continuous counters for the Boulder data, indicating little improvement in confidence of the factors for more than 9 counters in a group.

While the analysis discussed herein is not diffinitive, it seems to suggest that to achieve a reasonably accurate set of factors at **least seven countinuous counters per factor group** would be needed. The exact number of counters needed will vary with the dataset. The analysis presented here is from the Boulder bicycle counts only. Other sets of non-motorized continuous counters may be more or less variable.

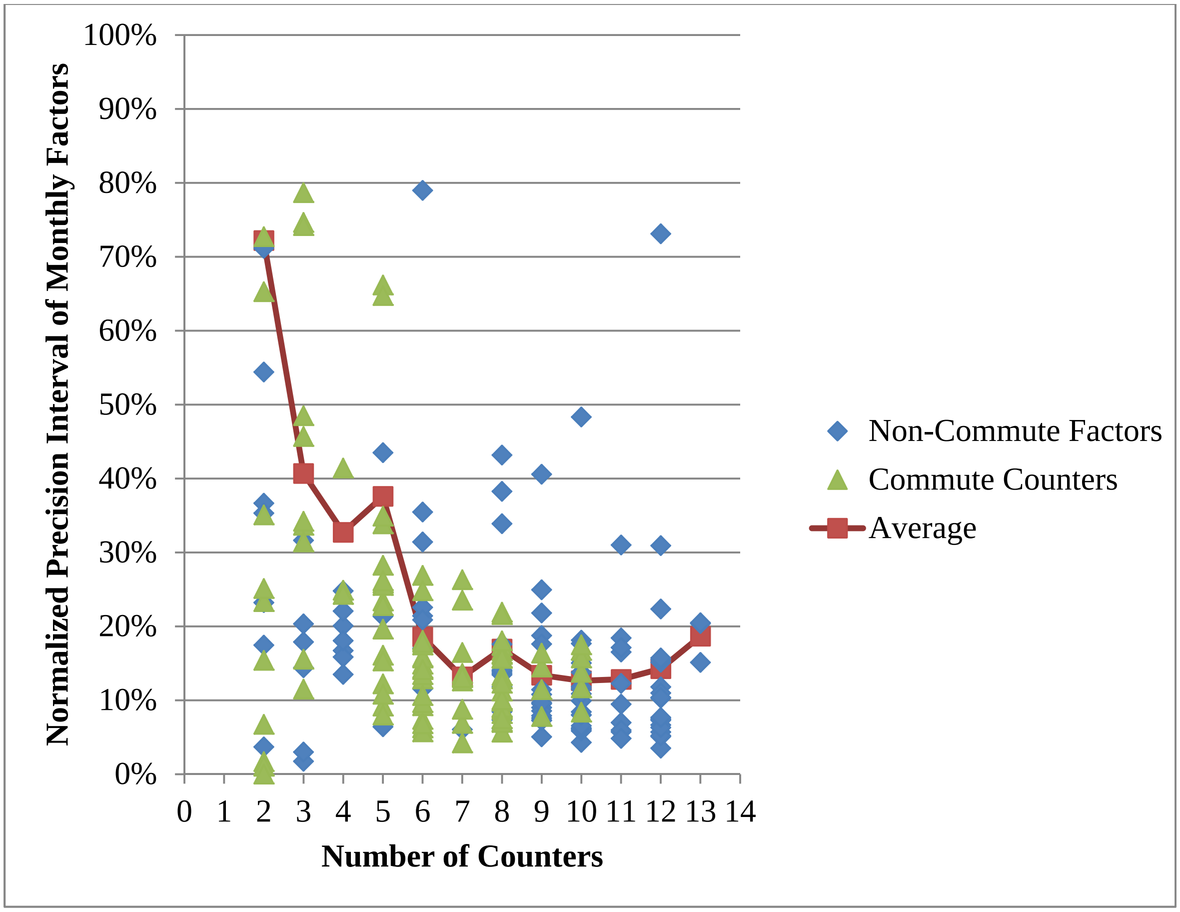

Figure 39. Normalized Precision Interval of Monthly Factors.

Daily Weather with Hourly Counts

Hourly weather data are not available for all locations, are more numerous and therefore more difficult to manage than daily weather, and can require more work to obtain than daily counts that are available from multiple government and private websites. For these reasons, an analysis of how using daily, instead of hourly, weather data would impact the accuracy of AADB estimates was performed. Two hybrid statistical models were calibrated using the complete count dataset except test data, and the accuracy of their AADB predictions was compared. The resulting errors in AADB estimation are reported in Table 16.

When the accuracy of the models was compared, the accuracy of the daily weather model in most cases had lower error than that of the hourly weather model. This is not what one would expect, as daily weather provides less fine grained information than hourly weather data. However, since in almost all the cases the daily weather model did not produce significantly higher error than the hourly weather model, it seems safe to conclude that the use of daily high temperature instead of hourly average temperature will not result in significantly worse results.

Table 16. Comparison of AADB Estimation Error using Daily vs. Hourly Weather Data.

	Absolute Average % Difference, Averaged for All Cases	
Location	**Using Hourly Weather Data**	**Using Daily Weather Data**
Arap13th	25%	27%
Arapahoe1	38%	32%
Foothills1	37%	30%
Arap38th	37%	35%
Average	**34%**	**31%**

Recommendations

Based on this work, we make the following recommendations:

- **One week of continuous hourly counts is optimal for reducing AADB error.** Such counts can be collected using portable tube counters specifically designed for bicycle counting or similar equipment. If this is not possible, 24-hour counts are the minimal information needed. While not ideal, they reduced average errors from 46% for a two-hour count to 38% in this study. Estimates based on one-, two-, or three-hour counts were found to have average error of as much as 58%. With less than twenty-four hours of data collected, actual peak hours cannot be identified, and the appropriate factor group (commute or non-commute) cannot be determined. If such counts are the only data collection methods available, collect data for at least the three peak hours on TWR at each location.
- Ideally **short-term counts should be conducted when variability in counts is lowest.** For Colorado, that time period occurs between May and October. Of course this varies based substantially with location and climate, with the season being shorter in the mountain regions. It may be even more important to the accuracy of the AADB estimates to conduct short-term counts in the best time period than to add continuous count stations to the factor group, though both are important for accuracy.
- At least 7 continuous counters should be used per factor group, according to analysis conducted using the Boulder data.
- Using daily weather data rather than hourly weather data is sufficient for the purposes of estimating AADB using a statistical model.

Task 2B: ii) Colorado Models and Factors

The first step in creating a method for estimating annual average daily non-motorized traffic is to understand the patterns occurring at each location. The following discussion will focus on daily and monthly patterns, since these are the factors that will need to be estimated. Hourly patterns are of importance too, but hourly factors will not be needed by CDOT because all of CDOT’s non-motorized bicycle and pedestrian short-term count stations collect at least one week of continuous hourly counts.

Of the 69 stations studied, 42% provided bicycle only counts, while 55% provided combined bicycle and pedestrian counts. Only one station in the study, Broomfield, provided bicycle and pedestrian counts separately. Comparisons of bicycle and pedestrian hourly, daily, and monthly patterns for Broomfield (Figures 40 to 42) illustrate that patterns can vary by mode, even at the same site. Since bicyclists and pedestrians patterns can differ, monthly and daily traffic patterns for cyclist-only count stations are discussed separately from combined bicyclists and pedestrian count stations.

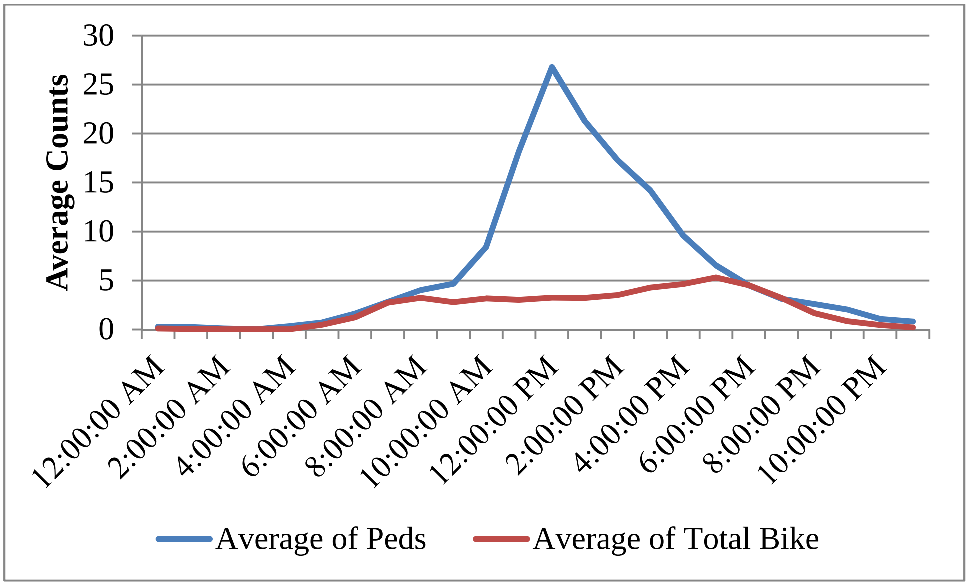

Figure 40. Comparison of Hourly Patterns in Broomfield for Pedestrians Only and Bicyclists Only.

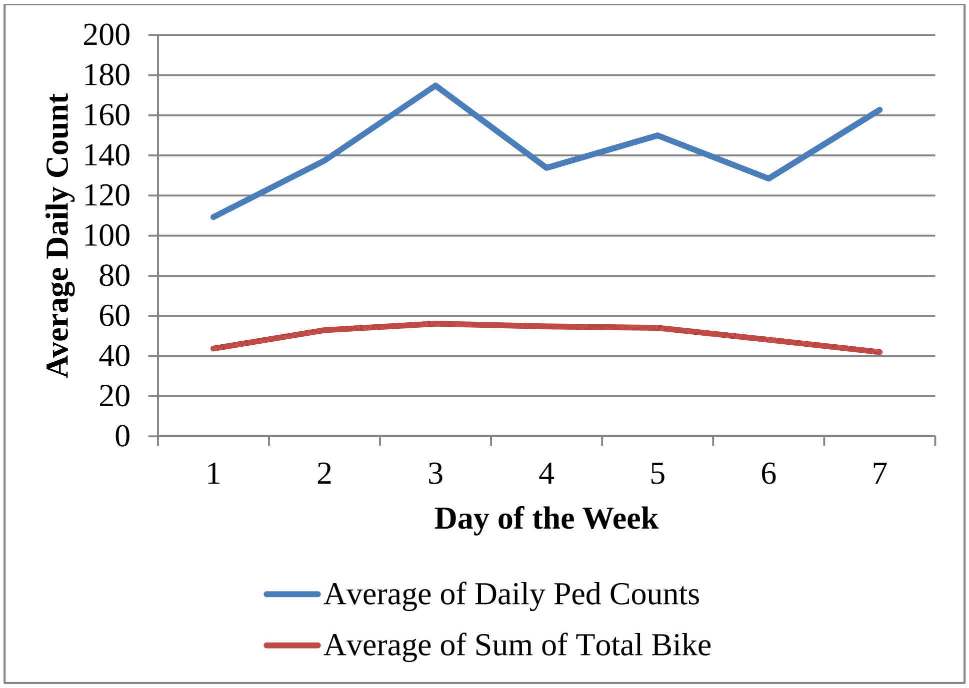

Figure 41. Comparison of Daily Patterns in Broomfield for Pedestrians Only and Bicyclists Only.

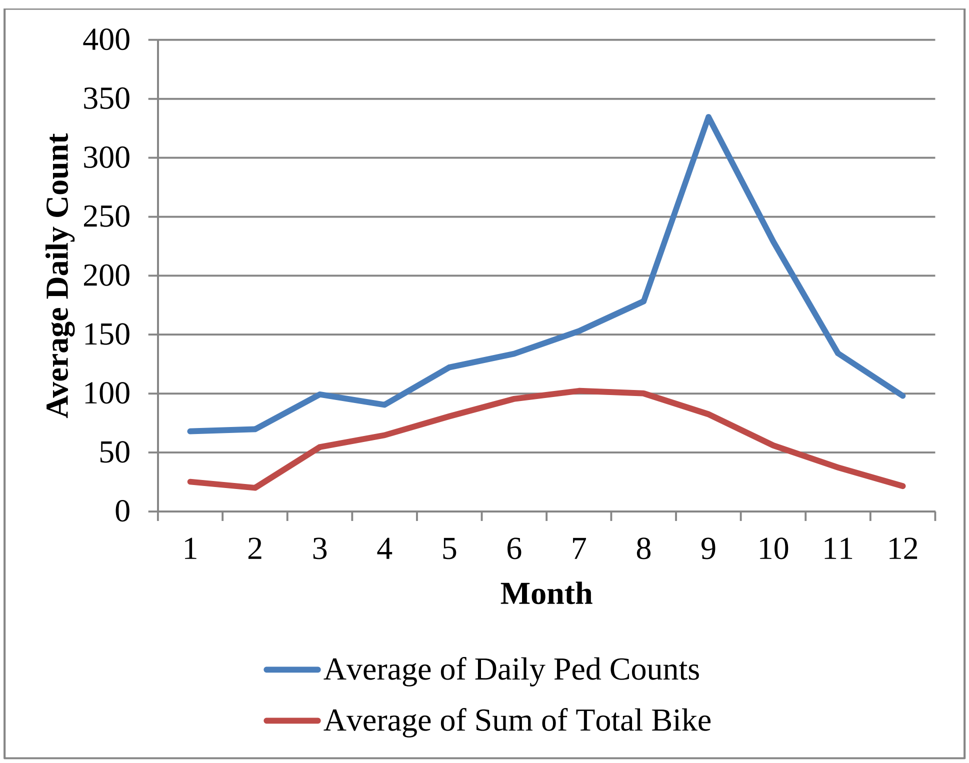

Figure 42. Comparison of Monthly Patterns in Broomfield for Pedestrians Only and Bicyclists Only.

Daily Patterns

In the daily counts, one can see that variation over the week occurs in two patterns: higher weekdays and higher weekends. Few sites show a pattern of constant traffic with day of week. As discussed above, it has been observed that bicyclists and pedestrians can have different travel patterns at the same site; thus, these user types will be discussed separately in the following analysis of daily non-motorized traffic patterns.

Bicyclist Daily Patterns

Most of the bicyclist only count stations were located in the Front Range, with the exceptions of Durango and Steamboat. Figure 43 shows that most of these stations had lower counts on weekends than weekdays, with the exceptions of US36, Durango, and Arvada. Note that of the weekdays, Thursday and Friday generally have lower counts, while Tuesday and Wednesday are the peak count days. This is not generally true for motor vehicle counts, as discussed in the previous section. Most of the stations generally follow a similar day of week traffic pattern.

Combined Bicyclist and Pedestrian Patterns

Figure 44 shows the patterns for all non-motorized users at the stations where combined bicycle and pedestrian counts were collected. To ease comparison, the scale on the y-axis is the same for both Figures 43 and 44. With the exceptions of Keystone and Broomfield, the stations all show higher volumes on weekends than on weekdays, the opposite of the pattern observed for the cyclist only stations.

Does this mean that cyclists and pedestrians have dramatically different behaviors and that bicyclists are just a minority in the combined stations? Unfortunately, we do not know what percentage of the counts at the combined stations are bicyclists. However, we do know that the characteristics of the locations of the count stations for the two mode types are different. The data for bicyclists are generally from the city roads and paths in the urban or suburban Front Range, while the data for combined non-motorized counts are generally on county paths in suburban or rural settings. Thus, the difference may be more related to the context of the trail than the mode of travel.

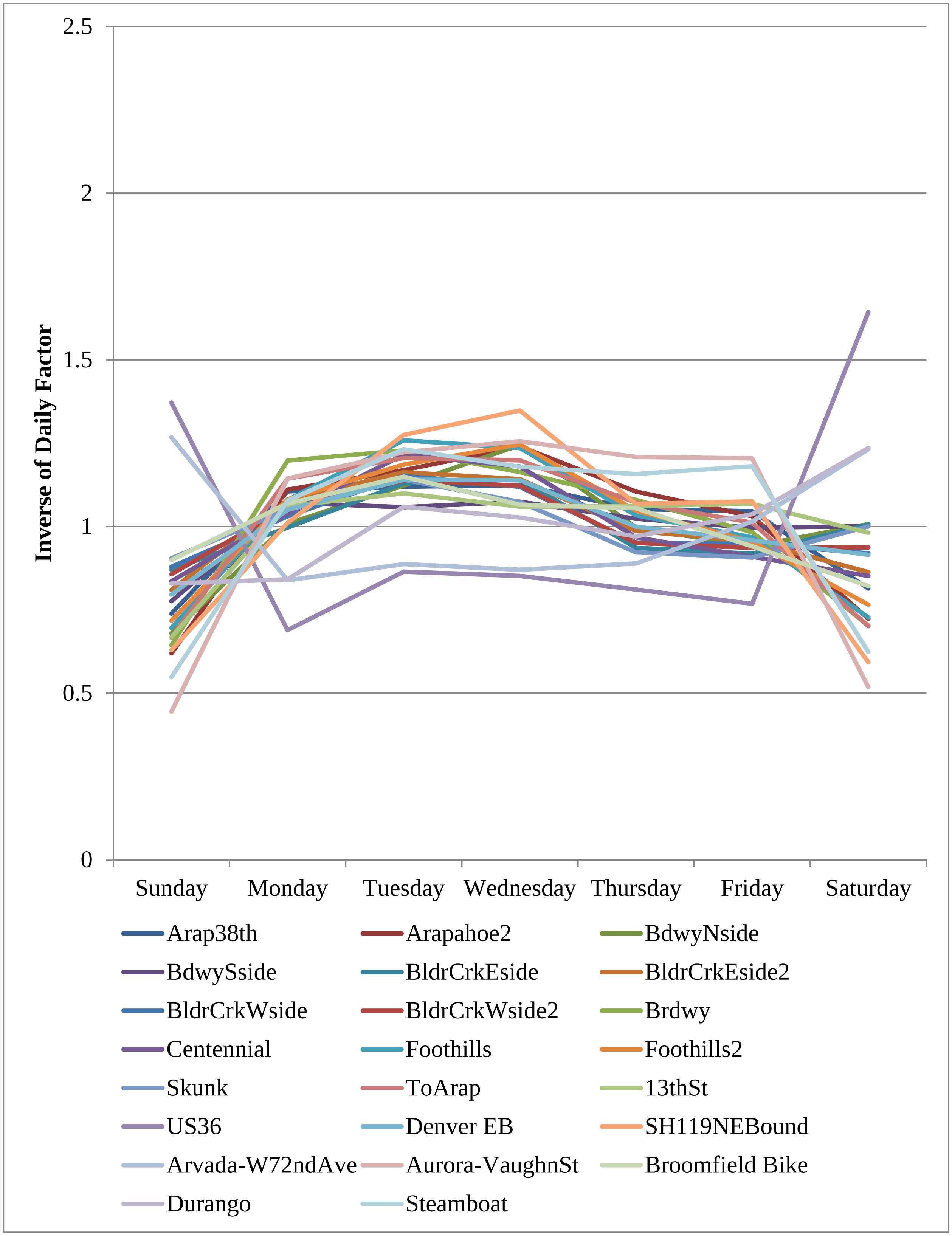

Figure 43. Daily Patterns for Bicyclists.

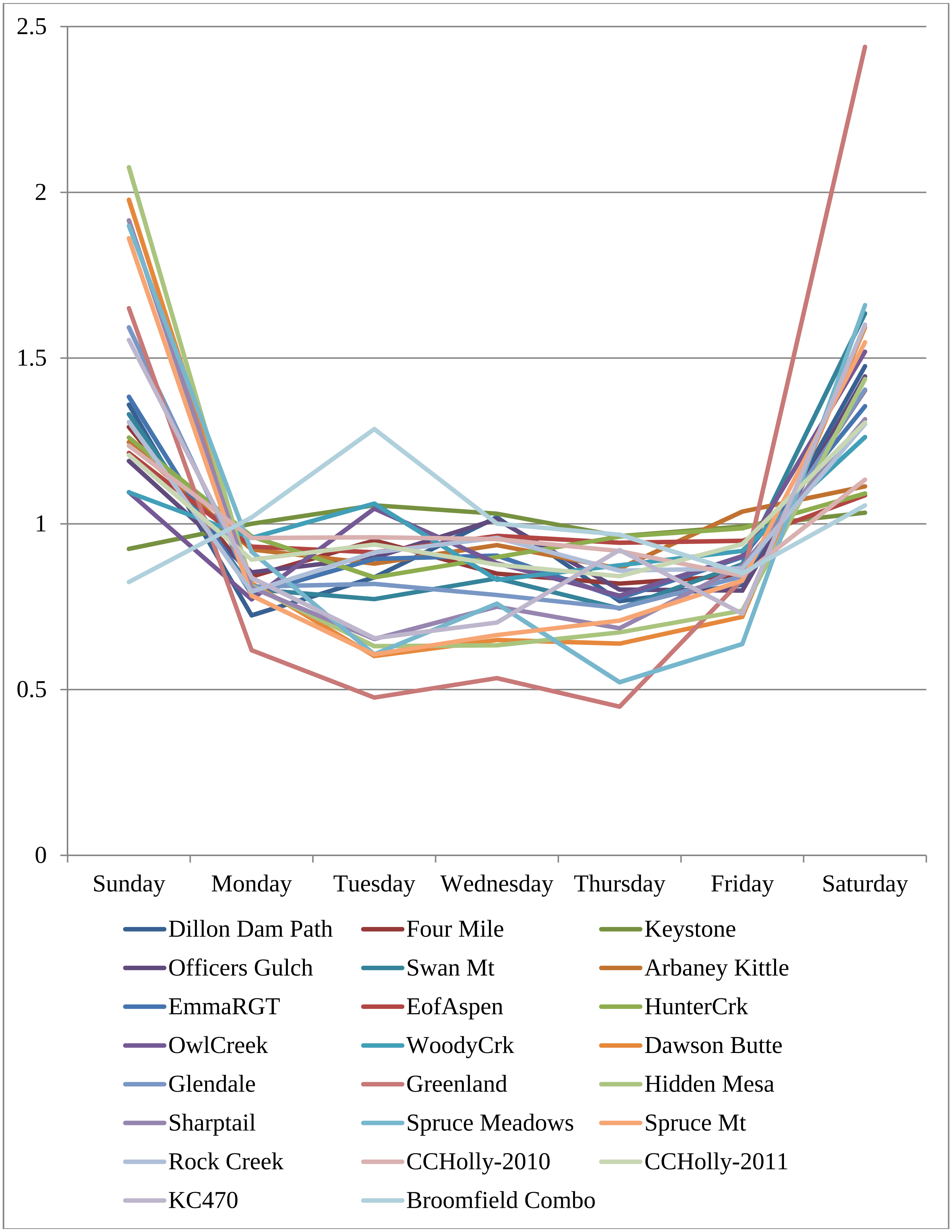

Figure 44. Daily Patterns for Combined Bicyclists and Pedestrian Counts.

Monthly Patterns.

Monthly patterns for the two mode types are plotted in Figures 45 and 46. As before, the y-axes, monthly average daily non-motorized traffic (i.e. MADB for bicyclists or MADPB for bicyclists and pedestrians combined) are the same for both figures to facilitate comparisons. Figure 45 shows that of the stations generally follow a similar traffic pattern by month. Notably, the city of Boulder locations have very similar patterns. Denver and Arvada show patterns similar to that of Boulder. Counts on SH119 in Boulder County and in Aurora show less variation with month, while counts on US36 directly north of Boulder show slightly more variation with month. There are some counters with low counts in July (bike counts in Boulder county and in Denver, perhaps due to vacation travel reducing commute traffic), but most seem to have a smoother bell curve. Durango counts seem to follow more of the Front Range counters, perhaps because they are more commute-related and at lower elevation than other mountain locations.

Figure 46 shows the monthly patterns for all non-motorized users at the stations where combined bicycle and pedestrian counts were collected. The variability in the patterns is striking. However, when a few outliers are removed in Figure 47, specifically Keystone and Sharptail, two general patterns seem to emerge: i) a similar pattern to that observed for the bicycle counts with less variation by month; and ii) a pattern with relatively higher peaks in the summer months and little or no traffic in winter.

Are these two patterns geographically based? To determine this, we also coded the locations geographically. This effort suggests that most of the locations with high summer patterns are in the mountains. Possible exceptions include: the C470 path in the Denver metro area, which has a high peak in July; and Hunter Creek, a Pitkin County site, without the high peak in summer. The C470 trail in the suburban Denver metro area seems to have a similar pattern to the mountains with a sharp peak in mid-summer, but the winter lows are not as low on the C470 as they are at mountain locations. The Douglas County counters have an unusual pattern with highs in spring and fall, perhaps related to school traffic. This indicates that while geography and climate are likely important factors, they are not the only factors to be considered in grouping the count sites for factoring.

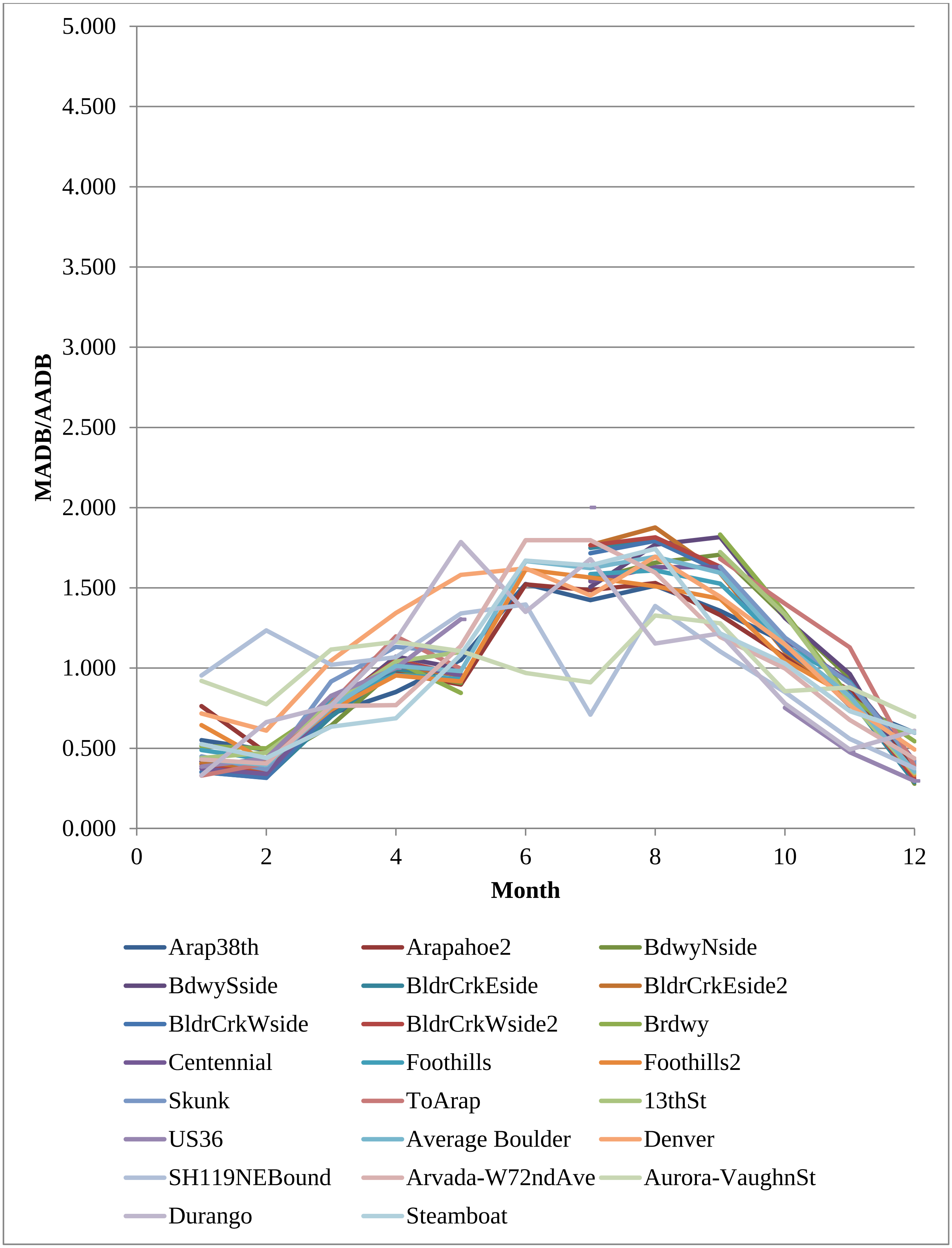

Figure 45. Monthly Patterns for Bicyclists.

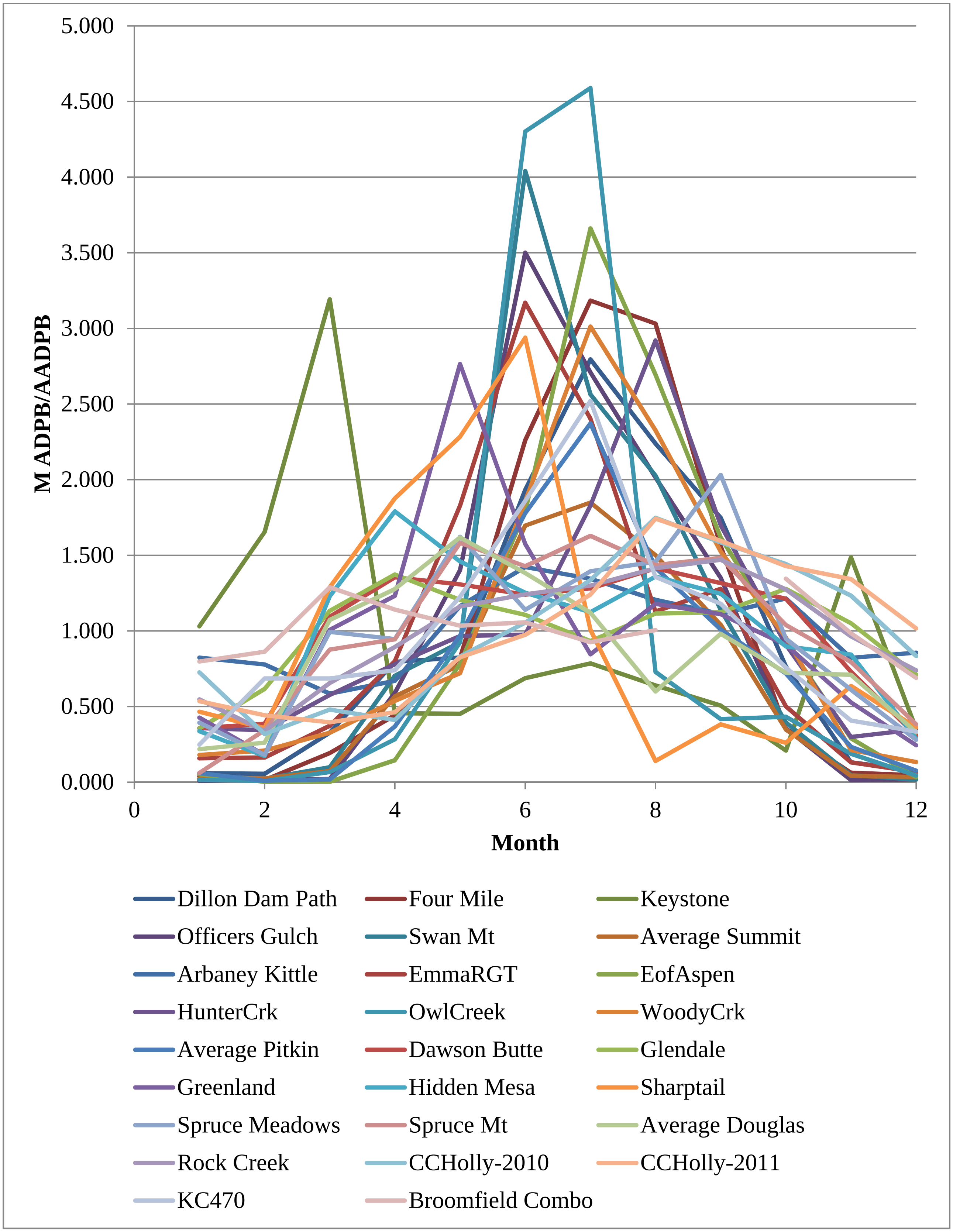

Figure 46. Monthly Patterns for Bicyclists and Pedestrians Combined.

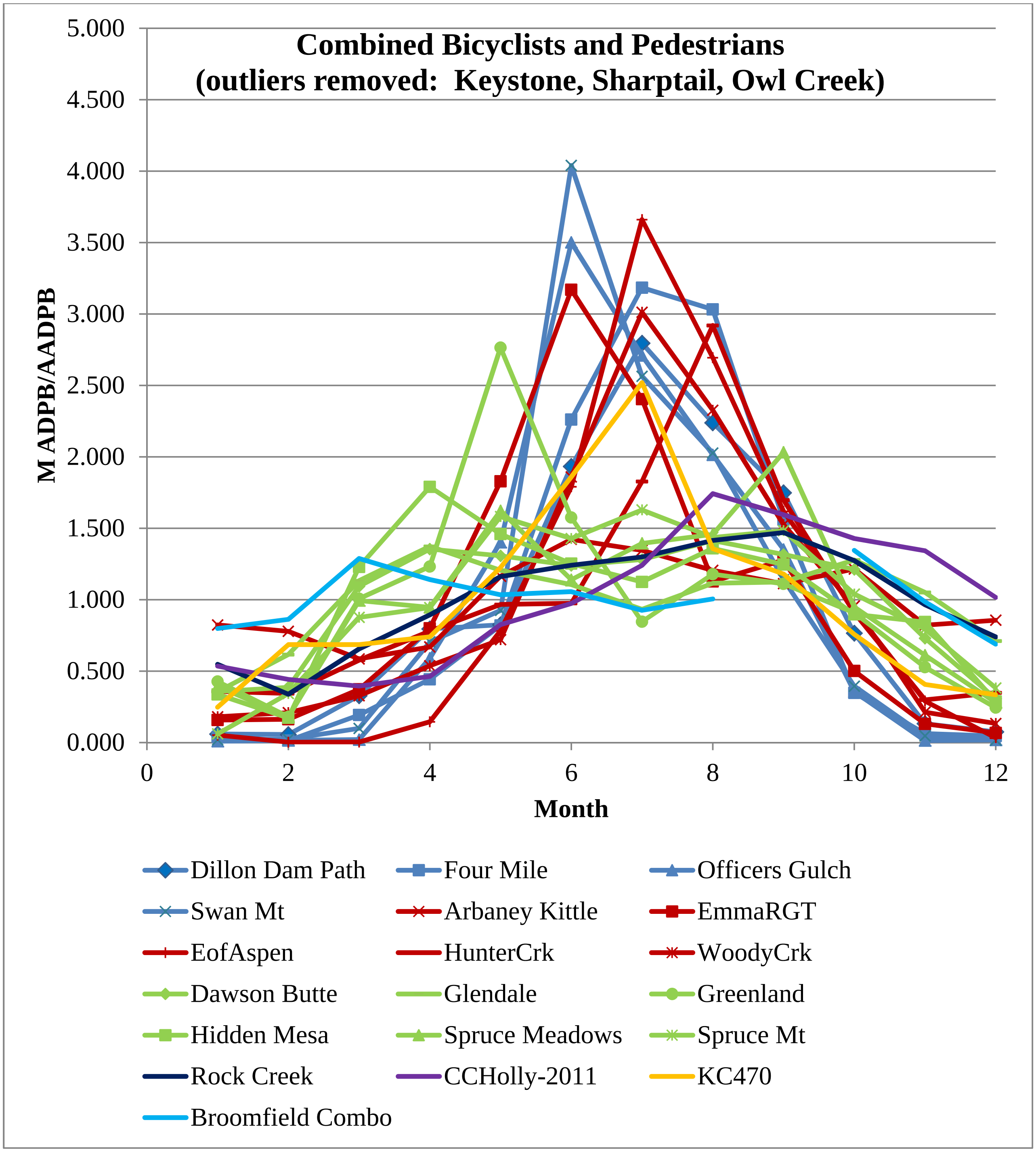

Figure 47. Monthly Patterns for Bicyclists and Pedestrians Combined with Outliers Removed (Keystone, Sharptail, and Owl Creek).

Factor Groups

Given the above discussion, how might factor groups be chosen? Turner recommended that CDOT divide their locations into three groups: commute/school, recreational/utilitarian, and mixed [2].

Miranda-Moreno *et al*. found four factor groups when examining a set of continuous count stations in Montreal: utilitarian, mixed utilitarian, recreational and mixed recreational [40]. In the earlier section, Boulder locations were divided into two groups: commute and non-commute.

To better group the count stations, some descriptive indices were employed to describe the ratio of average weekend to weekday traffic and the ratio of morning to midday traffic. After experimenting with different versions of these indices proposed by Miranda-Moreno *et al.* were chosen and are detailed below [40].

$$WWI = V_{we}/V_{wd}$$

where:

WWI = Weekend/Weekday Index

V_{we}=average weekend daily traffic

V_{wd}=average weekday daily traffic

and

$$AMI = \frac{\sum_{7}^{8} v_h}{\sum_{11}^{12} v_h}$$

where:

AMI = Average Morning/Midday Index

v_h = Average weekday hourly count for hour (h) where hours are given as starting time of the hour

Stations with higher counts on weekends than weekdays have a Weekend/Weekday Index (WWI) greater than one, so that the stations could be easily grouped. Stations with higher morning than midday counts on weekdays have an Average Morning/Midday Index (AMI) greater than one, so that hourly commute patterns could also be quickly identified. The metric, AMI, does not indicate if the evening peak hour is also high, so the metric may not completely indicate if there is or is not a commute pattern. However in most cases, the metric seemed to match the classifications from visual inspection of hourly patterns.

Cluster analysis was performed on the daily and monthly factors using that statistical program SAS 9.2. The analysis found two clear groups for the daily factors as shown in Figure 48. These results matched the groups observed visually, which shows that some stations have low weekends and high weekdays, and others have high weekdays and low weekends, but few are in between. There was 98% agreement between the groups identified in the cluster analysis and the groups identified as having Weekend/Weekday Index (WWI) greater than and less than one. For this reason, WWI is considered a good metric for grouping stations.

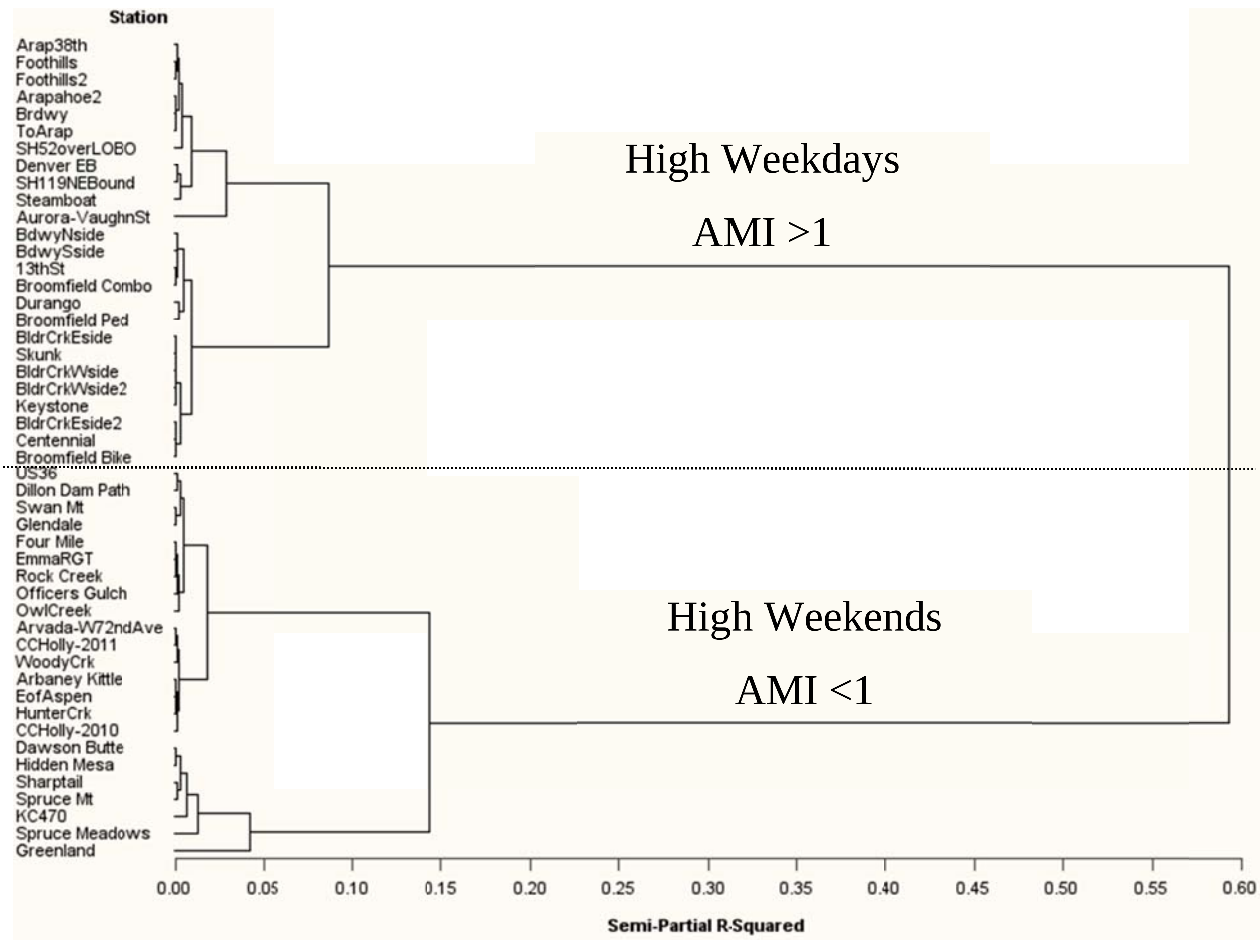

Figure 48. Results of Cluster Analysis by Daily Factor.

The cluster analysis of the monthly factors was not as clear cut. As shown in Figure 49, there are many outliers, primarily in mountain rural locations. After removing some of these outliers from the analysis, there was still not a clear grouping emerging that could be readily interpreted, as depicted in Figure 50. We investigated choosing an index that would represent the traffic variation by month but did not find one that was a particularly good match for the results from the cluster analysis.

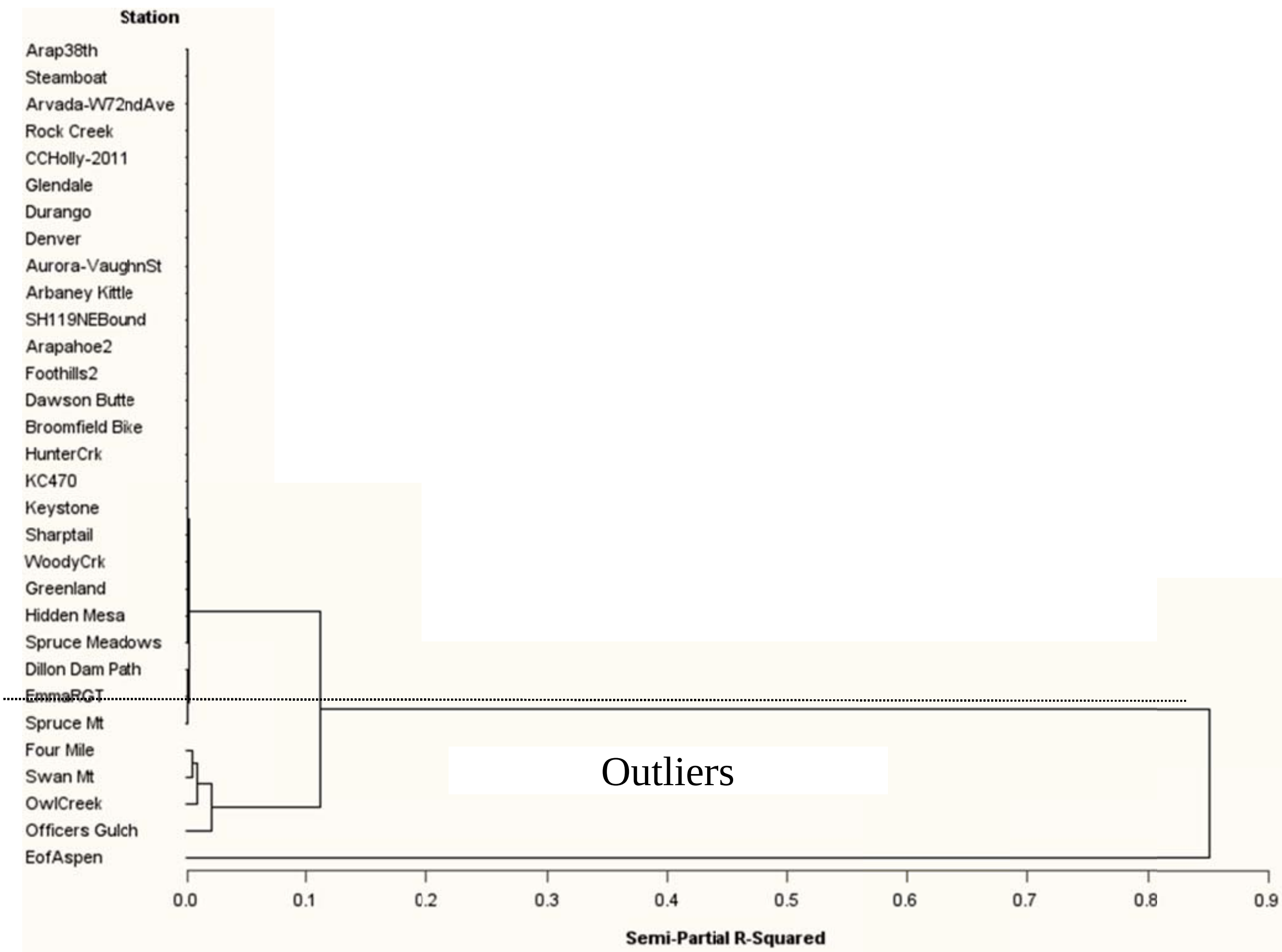

Figure 49. Results of Cluster Analysis by Monthly Factor.

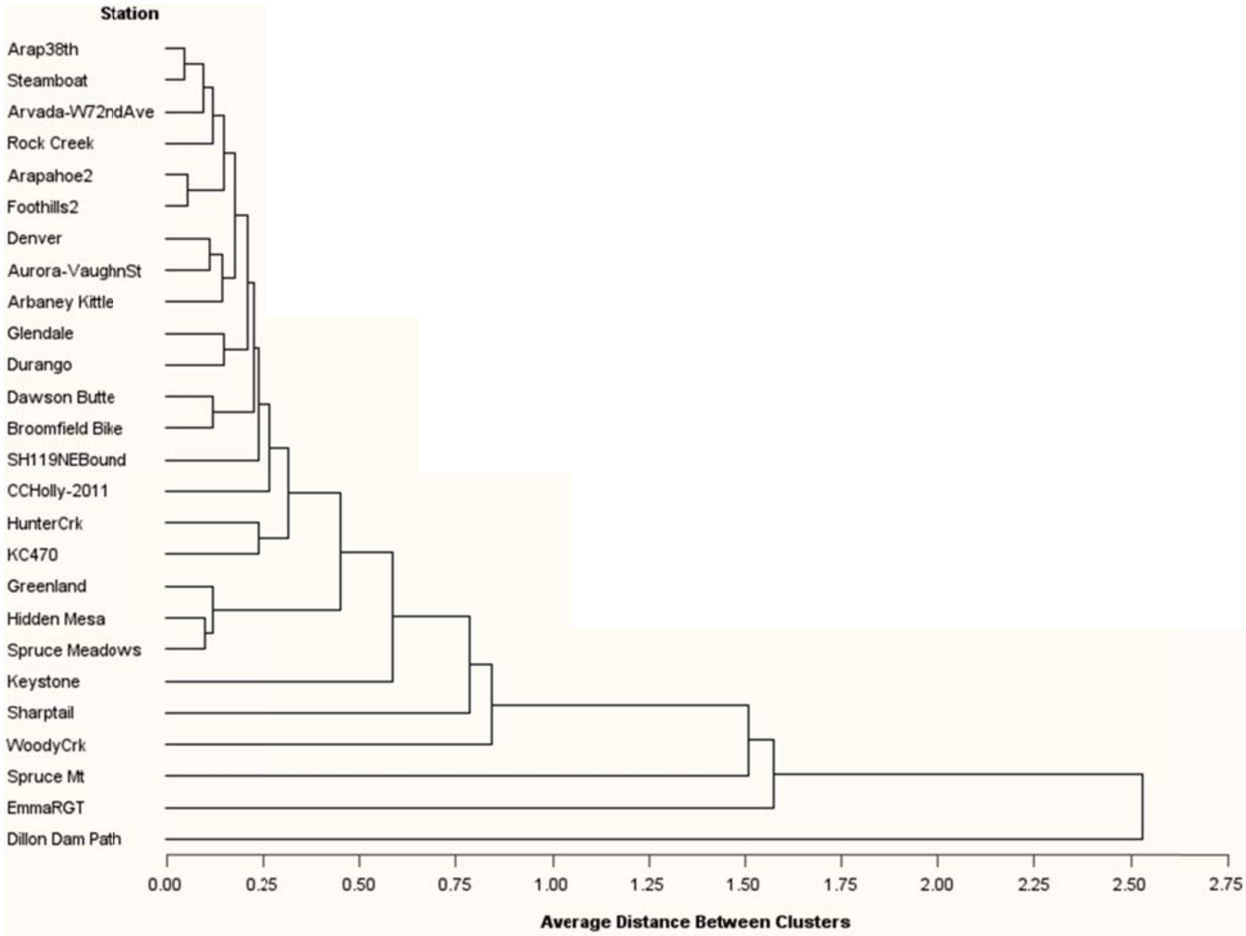

Figure 50. Results of Cluster Analysis by Monthly Factor after Removing Outliers.

Both cluster analyses and grouping by Weekend/Weekday Index (WWI) and Average Morning/Midday Index (AMI) mixed pedestrian and bicycle patterns in the same group. While most hourly commute patterns and high weekday counts were found at bicycle only stations, some similar patterns were identified in the combined bicycle and pedestrian data. Similarly, some bicycle only stations exhibited the high weekend and high midday counts that were usually associated with the combined bicycle and pedestrian count stations. For this reason, even though it is known that bicyclists and pedestrian travel patterns vary even at the same location, both mode types were grouped together.

However, it is still recommended that wherever possible, bicycles and pedestrians should be counted separately since it has been shown that they can exhibit extremely different traffic patterns at the same location. Counting bicyclists and pedestrians separately is likely to reduce the error in estimating annualized average daily traffic from short term counts.

We suggest the following basis for determining factor groups based on short term counts, which is displayed visually in Figure 51:

1. Determine daily patterns by day of week for the short term count data available at a given site. Generally the Colorado locations are expected to be either high weekend locations or low weekend locations. If another pattern is evident, we do not have the continuous counters necessary to create daily factors for this outlier.

2. If the location has high weekends, is it a mountain location on a recreational trail? If so, it should be categorized in the high summer peak group. Otherwise, it is more likely to follow the pattern of less variation by month. All locations in this group also have AMI less than one, so that is also an attribute of this group, though the AMI metric alone is not sufficient to describe this group.

3. Locations with low weekend patterns are expected to also follow the pattern of less variation by month. While this is a generalization, and there will be exceptions, it is necessary to group selection and only use data that will be available to CDOT staff.

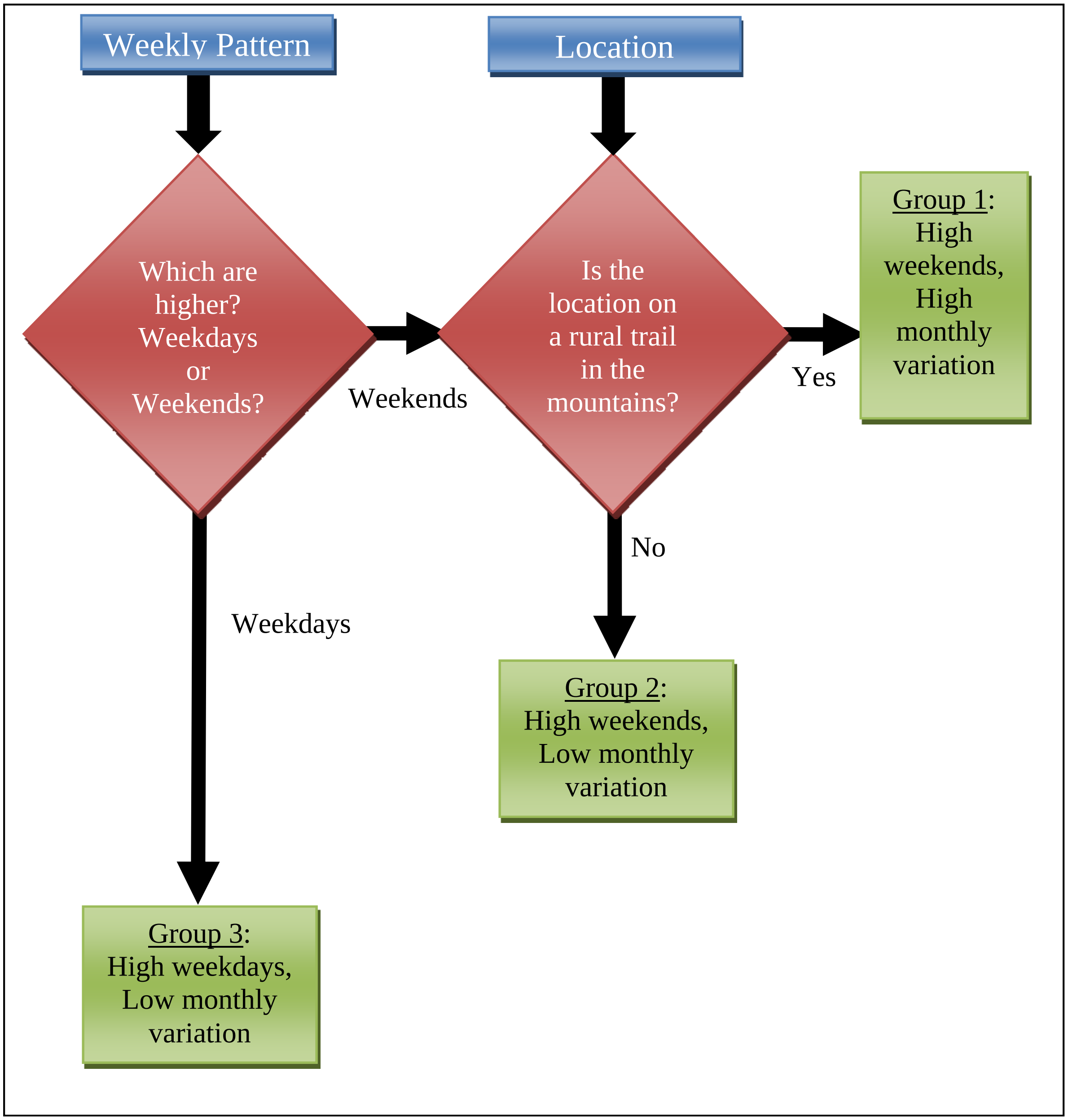

Figure 51. Flowchart for How to Group Stations.

The above selection process results in three factor groups, which could be described as follows:

1. **Mountain Non-Commute: High weekend, high monthly variation.**
   This could also be described as a rural mountain pattern with an hourly non-commute pattern (AMI less than one).
2. **Front-Range Non-Commute: High weekend, low monthly variation.**
   These locations are often associated with Front Range recreational or utilitarian, non-commute, patterns, though some mountain locations with higher utilitarian use or other use throughout the year are also included.
3. **Commute: Low weekend, low monthly variation.**
   This pattern was most often observed in the urban and suburban Front Range as well as urban Mountain areas. It is often found where hourly patterns show commute patterns, but not always.

Since none of the low weekend stations seemed to also exhibit high monthly variation, no separate group was created for that possibility. If future count stations show such variation, a fourth group can be added.

One could argue that some of the monthly patterns observed are of a flatter nature, indicating a third category of even lower variation by month. The stations that seem to show this type of pattern include: Arbaney Kittle in Pitkin County; Aurora; Broomfield; and SH119 and Rock Creek in Boulder County. Unfortunately, these locations do not seem to share any defining geographic or other characteristic that would separate them from the other locations. Some of these locations are in the mountains, and some are in the plains. Some of the locations are on paths, and some are on roads. However all of the locations are low counts locations, causing one to doubt whether these patterns are real or the result of random fluctuations in the data. For this reason, another category was not created.

In cases where continuous counters are located in the same community as a short term count location, the patterns are likely to be similar to what we see with the city of Boulder, Douglas County, Pitkin County, and Summit County stations showing patterns, generally more similar to each other than to counters in other cities or counties. For this reason, we recommend using factors from local counters first if available, but using the computed factors from the three groups in this report for other locations.

As mentioned previously, Turner *et al.* has recommended a strategy for grouping stations in Colorado [2]. How does the method proposed above compare to the earlier method? Both recommend three groups, and the general descriptions of the groups are similar with one group being primarily commuter traffic, another being recreational traffic, and a third a mix of the two. However, Turner's approach was more qualitative and required time to visually examine the hourly, daily and monthly (if available) patterns for each station. The method proposed here requires only two input variables: i) the weekly pattern, which can be computed in CDOT's traffic database by using the WWI value; and ii) the location, which can be indicated in the station description.

Turner's approach can also be automated using the two indices – Weekend/Weekday Index (WWI) and Average Morning/Midday Index (AMI) – to quantitatively evaluate the variation of hourly and daily traffic patterns. This was done for all of the stations in the study to compare the two systems. The automated interpretation of Turner's method agreed with the published groupings in six of the eight stations classified in the report. In the automated interpretation of Turner's method, stations that did not meet the descriptions of the three groups were excluded from the analysis. About 70% of the stations were classified into groups, meaning that 30% of the continuous bicycle and or pedestrian count stations were not grouped using this approach. While that may seem wasteful, it also excluded three of the seven outliers identified in the cluster analyses and visual inspection. There is value in excluding such outliers. The three identified in the visual inspection will be excluded from the factor groups.

Both systems were used to classify the continuous count stations. About 60% of the stations are categorized in the same group by both systems. One of the main differences between the approaches is that Turner's approach classifies patterns that have low weekly variation separately, while our proposed method separates the weekly variation into just two groups rather than three. Table 17 presents the groupings using both approaches.

Table 17. Comparison of Station Groupings.

Location	Station	Mode	Urban	Region	WWI	AMI	Factor Groups	TTI Groups
Boulder	Arap38th	Bike	Suburban	FrontRange	0.71	0.74	3	3
Boulder	Arapahoe2	Bike	Suburban	FrontRange	0.59	1.26	3	None
Boulder	BdwyNside	Bike	Urban	FrontRange	0.77	1.14	3	3
Boulder	BdwySside	Bike	Urban	FrontRange	0.84	1.06	3	3
Boulder	BldrCrkEside	Bike	Urban	FrontRange	0.92	0.74	3	3
Boulder	BldrCrkEside2	Bike	Suburban	FrontRange	0.79	0.98	3	3
Boulder	BldrCrkWside	Bike	Urban	FrontRange	0.87	0.85	3	3
Boulder	BldrCrkWside2	Bike	Suburban	FrontRange	0.87	0.89	3	3
Boulder	Brdwy	Bike	Suburban	FrontRange	0.60	1.28	3	None
Boulder	Centennial	Bike	Suburban	FrontRange	0.80	1.17	3	3
Boulder	Foothills	Bike	Suburban	FrontRange	0.64	1.72	3	1
Boulder	Foothills2	Bike	Suburban	FrontRange	0.68	1.81	3	1
Boulder	Skunk	Bike	Suburban	FrontRange	0.94	1.06	3	3
Boulder	ToArap	Bike	Suburban	FrontRange	0.61	1.12	3	None
Boulder	13thSt	Bike	Urban	FrontRange	0.74	1.36	3	3
Boulder	US36	Bike	Rural	FrontRange	1.89	0.66	2	2
Boulder County	SH119NEBound	Bike	Rural	FrontRange	0.54	2.03	3	1
Boulder County	Rock Creek	Bike/Ped	Suburban	FrontRange	1.49	0.59	2	2
Boulder County	SH52overLOBO	Ped	Suburban	FrontRange	0.61	1.19	3	None
Denver	Denver EB	Bike	Urban	FrontRange	0.58		3	1
Denver Metro	Arvada-W72ndAve	Bike	Suburban	FrontRange	1.39	1.37	2	3
Denver Metro	Aurora-VaughnSt	Bike	Suburban	FrontRange	0.40	3.96	3	1
Denver Metro	Broomfield Bike	Bike	Suburban	FrontRange	0.82	1.57	3	None
Denver Metro	CCHolly-2011	Bike/Ped	Urban	FrontRange	1.40	1.02	2	None
Denver Metro	KC470	Bike/Ped	Suburban	FrontRange	2.08	0.48	2	2
Denver Metro	Broomfield Combo	Bike/Ped	Suburban	FrontRange	0.76	1.00	3	3
Denver Metro	Broomfield Ped	Ped	Suburban	FrontRange	0.90	0.64	3	None
Douglas	Dawson Butte	Bike/Ped	Suburban	FrontRange	2.60	0.38	2	2
Douglas	Glendale	Bike/Ped	Suburban	FrontRange	1.87	2.11	2	None
Douglas	Greenland	Bike/Ped	Suburban	FrontRange	3.55	0.51	2	2
Douglas	Hidden Mesa	Bike/Ped	Suburban	FrontRange	2.46	0.53	2	2
Douglas	Sharptail	Bike/Ped	Suburban	FrontRange	2.09	0.75	Outlier	None
Douglas	Spruce Meadows	Bike/Ped	Suburban	FrontRange	2.67	0.37	2	2
Douglas	Spruce Mt	Bike/Ped	Suburban	FrontRange	2.38	0.45	2	2
Durango	Durango	Bike	Urban	Mtn	1.01	0.84	2	3
Pitkin	Arbaney Kittle	Bike/Ped	Rural	Mtn	1.27	0.64	1	None
Pitkin	EmmaRGT	Bike/Ped	Rural	Mtn	1.61	0.59	1	2
Pitkin	EofAspen	Bike/Ped	Rural	Mtn	1.22	0.42	1	None
Pitkin	HunterCrk	Bike/Ped	Rural	Mtn	1.26	0.23	1	None
Pitkin	OwlCreek	Bike/Ped	Rural	Mtn	1.47	0.14	Outlier	2
Pitkin	WoodyCrk	Bike/Ped	Rural	Mtn	1.27	0.14	1	None
Steamboat	Steamboat	Bike	Urban	Mtn	0.50	1.44	3	1
Summit	Dillon Dam Path	Bike/Ped	Rural	Mtn	1.72	0.91	1	None
Summit	Four Mile	Bike/Ped	Rural	Mtn	1.57	0.24	1	2
Summit	Keystone	Bike/Ped	Rural	Mtn	0.97	0.44	Outlier	None
Summit	Officers Gulch	Bike/Ped	Rural	Mtn	1.51	0.14	1	2
Summit	Swan Mt	Bike/Ped	Rural	Mtn	1.82	0.13	1	2

Both grouping systems provide adequate grouping of continuous counters. To simplify, only graphs of the proposed grouping are provided. The inverse factors created using the proposed grouping system are in Figures 52 to 55, with the counters in each group so one can assess the fit graphically.

Figure 56 then depicts how the proposed factors relate to the CDOT motor vehicle Group 3 factors for 2011. As expected, the daily motor vehicle traffic patterns do not match the non-motorized traffic patterns, primarily due to high motor vehicle traffic on Fridays and relatively low non-motorized traffic on that day. However, the monthly motor vehicle Group 3 pattern does match the proposed Group 3 pattern relatively well. While computing non-motorized traffic monthly factors is expected to yield more accurate estimates of AADB and AADBP, if such factors are not available for a site with high weekday counts, CDOT's existing Group 3 for motor vehicles could provide a next best estimate of monthly factors.

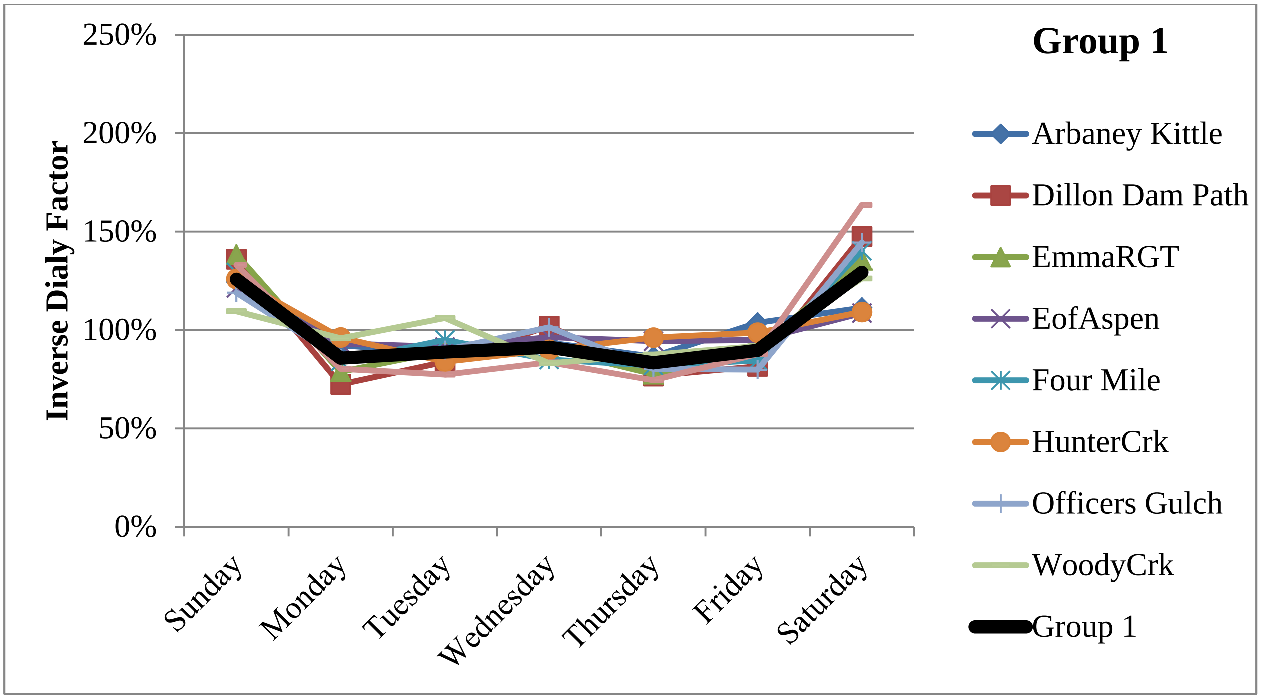

Figure 52. Inverse of Proposed Daily Factors for Group 1.

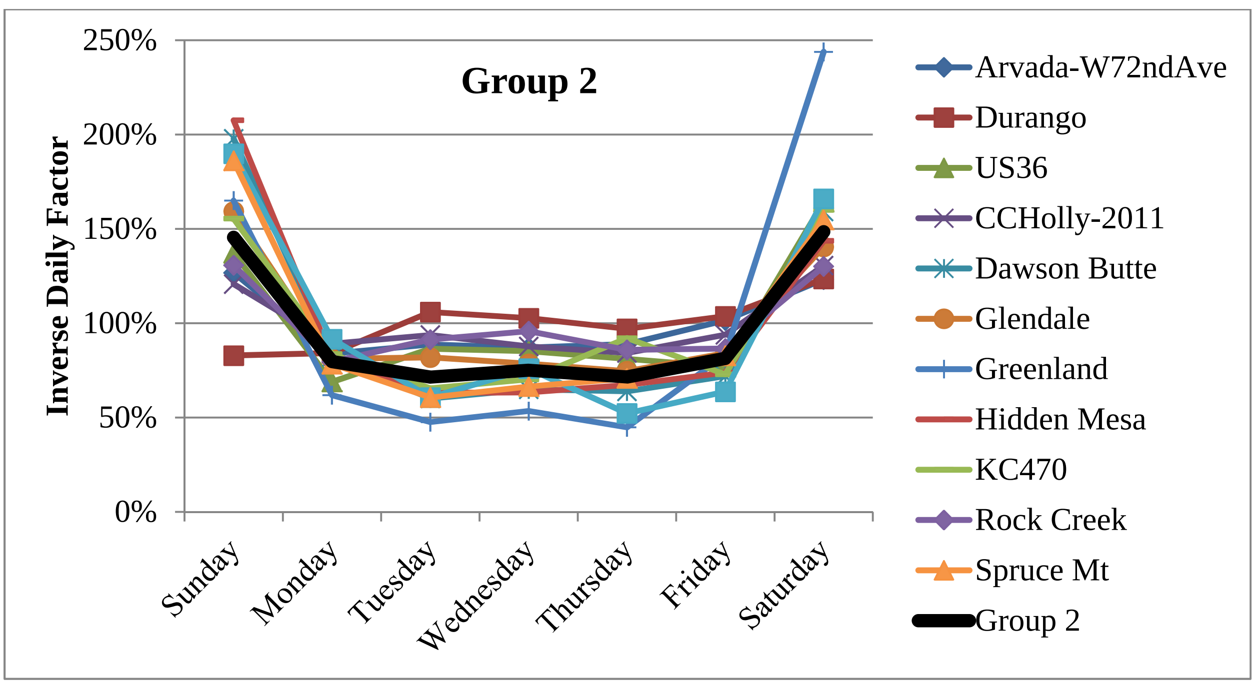

Figure 53. Inverse of Proposed Daily Factors for Group 2.

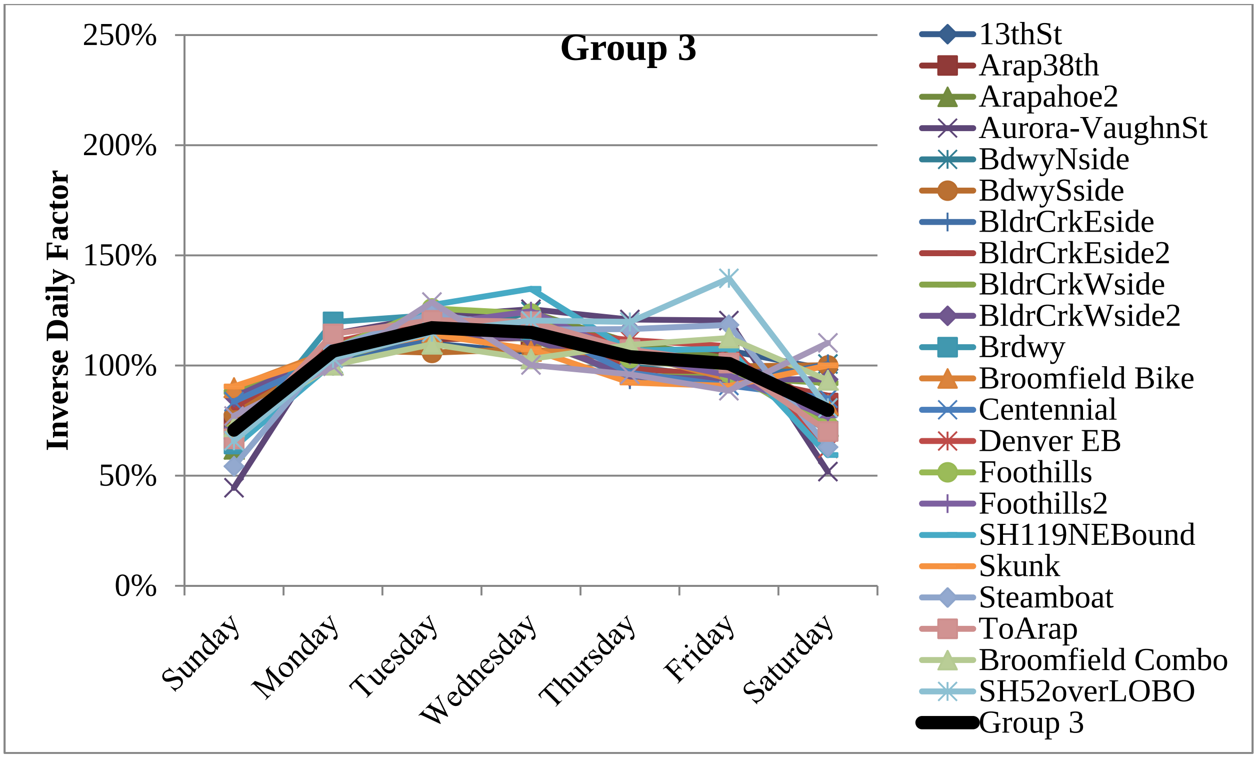

Figure 54. Inverse of Proposed Daily Factors for Group 3.

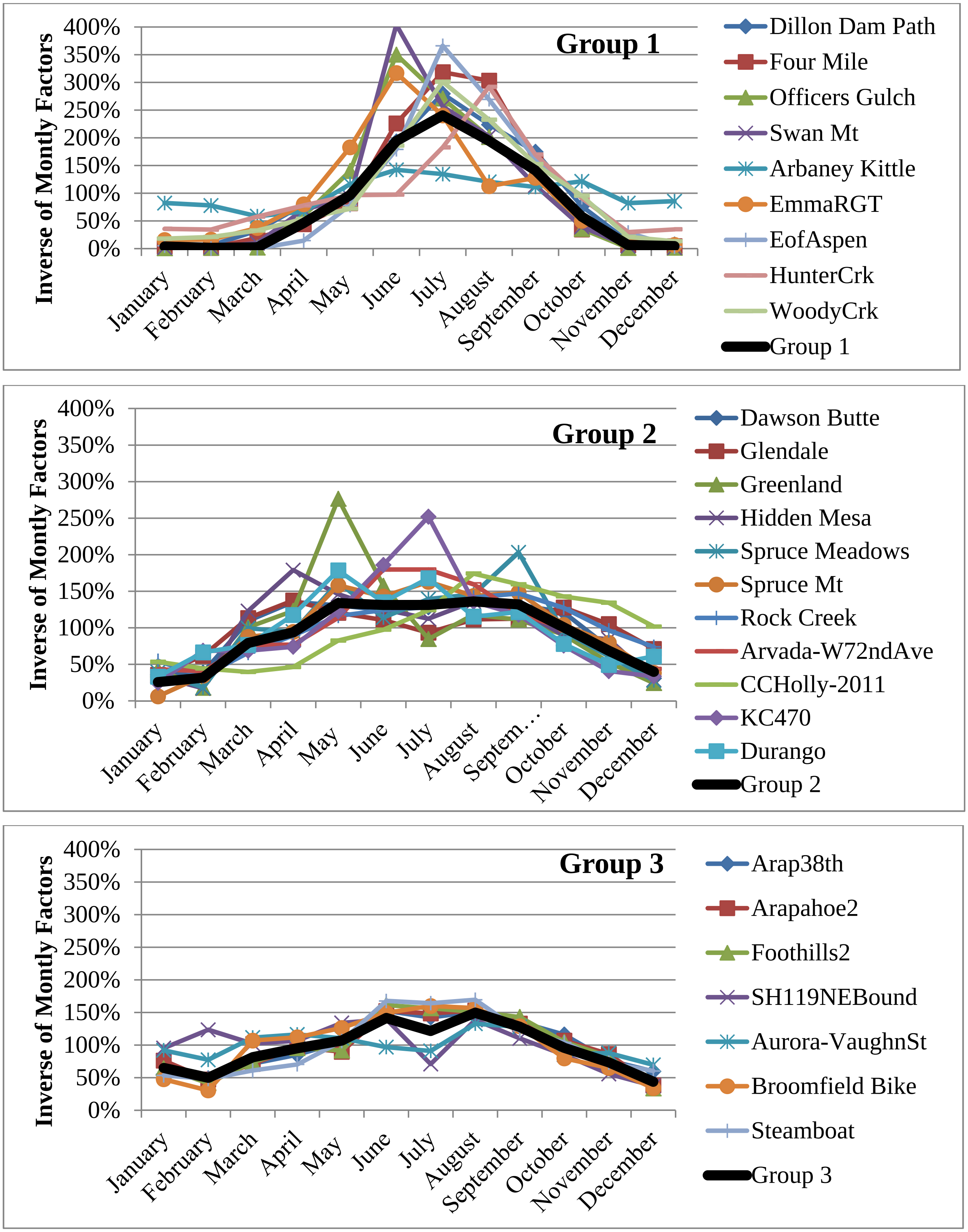

Figure 55. Inverse of Proposed Monthly Factors for All Groups.

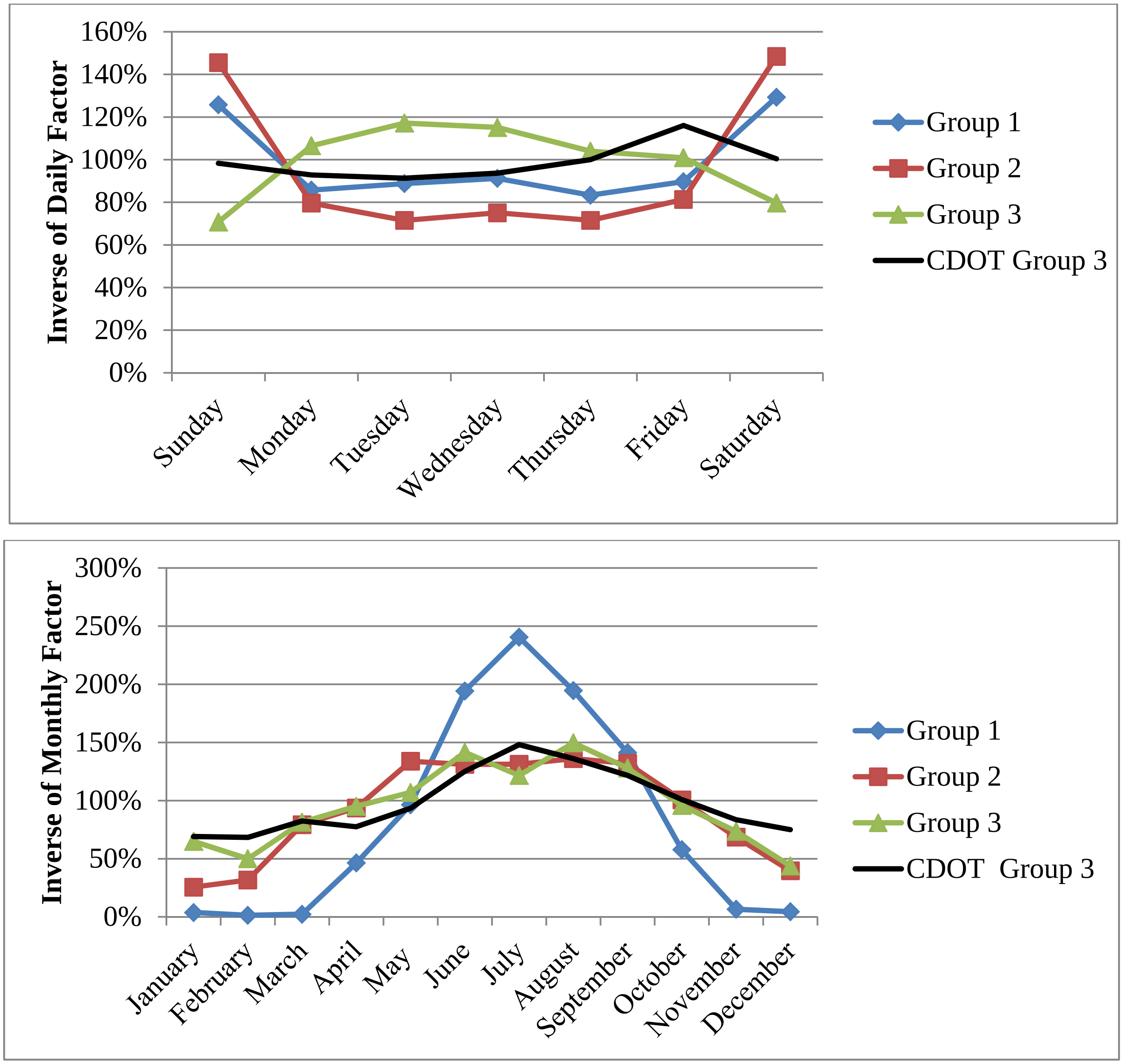

Figure 56. Inverse of Proposed Factors Compared to Motor Vehicle Factor Group 3.

Task 2B: iii) Validate Colorado Model

The factors were validated by using them to compute AADB for three continuous count stations where a full year of count data for 2011 was available, one validation site for each Factor Group:

- For Group 1, the infrared bicycle and pedestrian counter at the intersection of the Emma and Rio Grande Trails (EmmaRGT).
- For Group 2, the infrared bicycle and pedestrian counter on the C470 path in the south Denver suburbs south of Ken Caryl Ave (C470).
- For Group 3, the inductive loop bicycle counter in Steamboat Springs, a mountain resort town in western Colorado known for its skiing in (Steamboat).

All three locations had average annual daily non-motorized traffic (AADB or AADBP) less than 250 users per day, so that all were considered low to medium volume locations. Because low volumes tend to fluctuate more as a percent of the total (i.e. have more variability), estimates of AADB or AADBP based on such counts are expected to have more error than higher volume locations. For this reason, these locations may show more error than estimates based on higher volume locations.

To study the error in AADB and AADBP from the three factors groups, the known AADB or AADBP for each location was compared to the estimated for various lengths of short-term counts: 24-hours, one week, two weeks, and four weeks. For each time period at each location, the average absolute percent difference error and the standard deviation of the error were computed using non-motorized as well as motor vehicle factors to estimate AADB or AADBP, as appropriate. These errors are reported in Tables 17 through 19, averaged from test periods throughout the year using the same method as applied in Table 15 and as presented in [4, 41].

Motor vehicle factors (from CDOT's recreational grouping, coincidentally also labeled Group 3) were also used to compute AADB in an effort to understand how well such factors can estimate non-motorized travel. Motor vehicle Group 3 seems to exhibit a very seasonal pattern, which is why it is the most likely to match non-motorized use patterns.

The error for each estimate was computed for each day of the year, and the error averaged over the year. The error was computed as the average of the absolute percent difference between the estimated and actual AADB.

The error for the various lengths of short-term counts is presented in Tables 17 to 19 and plotted in Figures 57 to 59 for the three locations representing the three factor groups. For the Group 1 example (EmmaRGT), a highly recreational location, the percent error increased 15 to 20 percentage points when motor vehicle factors were applied instead of non-motorized. For the Group 2 and 3 examples, motor vehicle factors produce similar estimates of AADB if a week or more of short-term count data are available. For Steamboat Springs, the motor vehicle factors produce a slightly better estimate, but it should be noted that this location has a commute pattern and is therefore more likely to match with motor vehicle patterns, which are less influenced by weather.

For Steamboat Springs, the proposed Group 3 factors were modified by removing the Steamboat Springs factors from the factor calibration process, so that the same data would not be used to validate itself. Not including the Steamboat count data in the factoring process increased the error by 2 to 3 percentage points. Since this was not a big change, similar analyses were not performed for the other locations.

For all three cases, August and September had the lowest error. Days and months with the least error are summarized in Table 20. No day of the week found consistently low error, though it makes sense that weekdays had lowest AADB estimation error for the commute site (Group 3), and that at least one weekend day had lower estimation error for the Front-Range Non-Commute site (Group 2).

Note that the Factor Group 1 factors were only applied to April through November. This is because the factors from December through March were so high that they created enormous errors. They were created from a group of counters with low counts, indicating high variability (see the blue and red lines on Figure 57). For this reason, for Group 1 sites, estimates of AADB or AADBP should not be made from short-term counts collected in the December through March timeframe as these counts are too variable to make accurate estimates.

In general, separate bicycle and pedestrian daily and monthly factors should be computed for non-motorized road users. For bicycle or bicycle and pedestrian data that exhibits commute patterns, motor vehicle factors from Factor Group 3 may provide adequate estimates. However, care should be taken as motor vehicle traffic patterns have been found to differ from bicycle and pedestrian patterns, even along the same corridor. In general, motor vehicle traffic varies much less with season and is higher on Fridays than non-motorized counts, so the bicycle and pedestrian daily and monthly factors provided in this report should be applied to the short-term counts collected in 2011 as shown in the example in Tables 17 to 19.

In summary, the proposed three non-motorized factor groups are able to estimate AADB or AADBP as well as or better than similar estimates using factors computed for motor vehicles. Group 1 factors result in the highest error (45% to 56%, depending on the length of short-term counts available), but that is unavoidable given the variability of low-volume, mostly recreational mountain locations. For Group 1, motor-vehicle factors resulted in much greater error than from using the appropriate Group 1 factors for non-motorized users proposed in this report. Average error for Group 2 and 3, if 7-days of counts are available, is around 20%. While this may seem high, it is much lower for the low error months and days reported in Table 20. August and September are the best months for short-term counts if low AADB or AADBP error is desired.

Table 17. Error Estimates using EmmaRGT Data (Group 1).

2011	Using Group 1 Factors (April-Nov. only)		Using Group 2 Factors		Using Motor Vehicle Factors	
Days of Known Counts	Average Absolute % Difference	Average Absolute % Difference	Average Absolute % Difference	Average Absolute % Difference	Average Absolute % Difference	Standard Deviation of Absolute % Difference
1	56%	68%	68%	53%	76%	57%
7	52%	58%	58%	45%	67%	44%
14	49%	56%	56%	45%	65%	44%
28	45%	55%	55%	44%	62%	44%

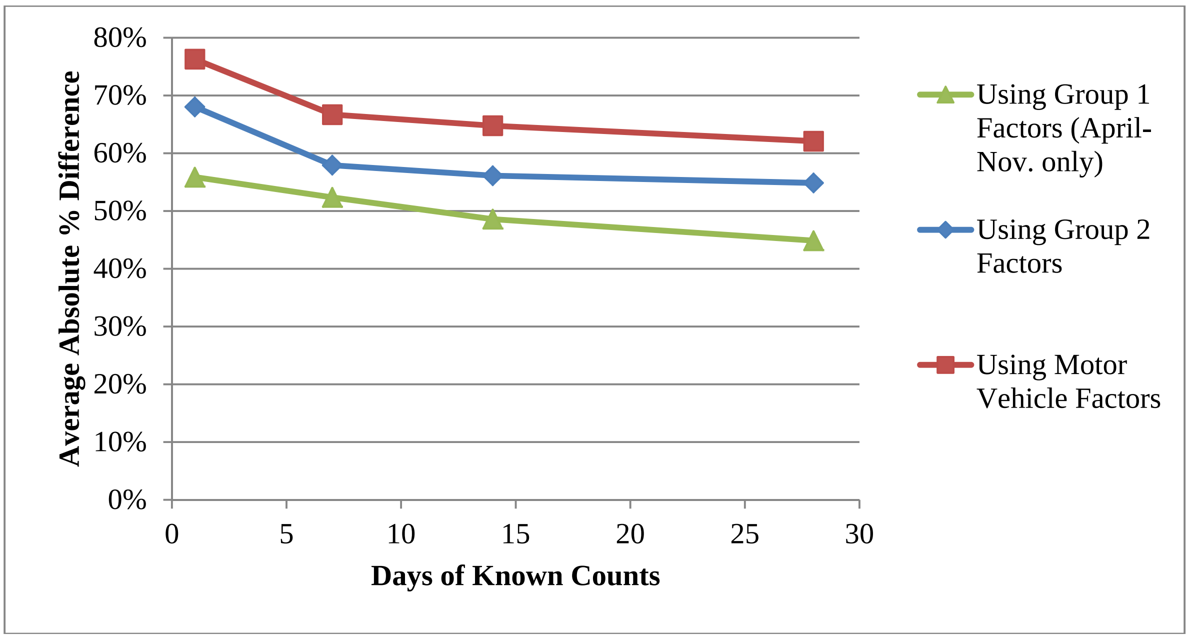

Figure 57. Error Estimates using for Various Short-Term Count Length using EmmaRGT Data (Group 1).

Table 18. Error Estimates using C470 Data (Group 2).

2011	Using Group 2 Factors		Using Group 3 Factors		Using Motor Vehicle Factors	
Days of Known Counts	**Average Absolute % Difference**	**Standard Deviation of Absolute % Difference**	**Average Absolute % Difference**	**Standard Deviation of Absolute % Difference**	**Average Absolute % Difference**	**Standard Deviation of Absolute % Difference**
1	32%	26%	76%	110%	36%	26%
7	22%	16%	41%	50%	19%	13%
14	21%	15%	37%	42%	18%	12%
28	19%	12%	33%	34%	17%	11%

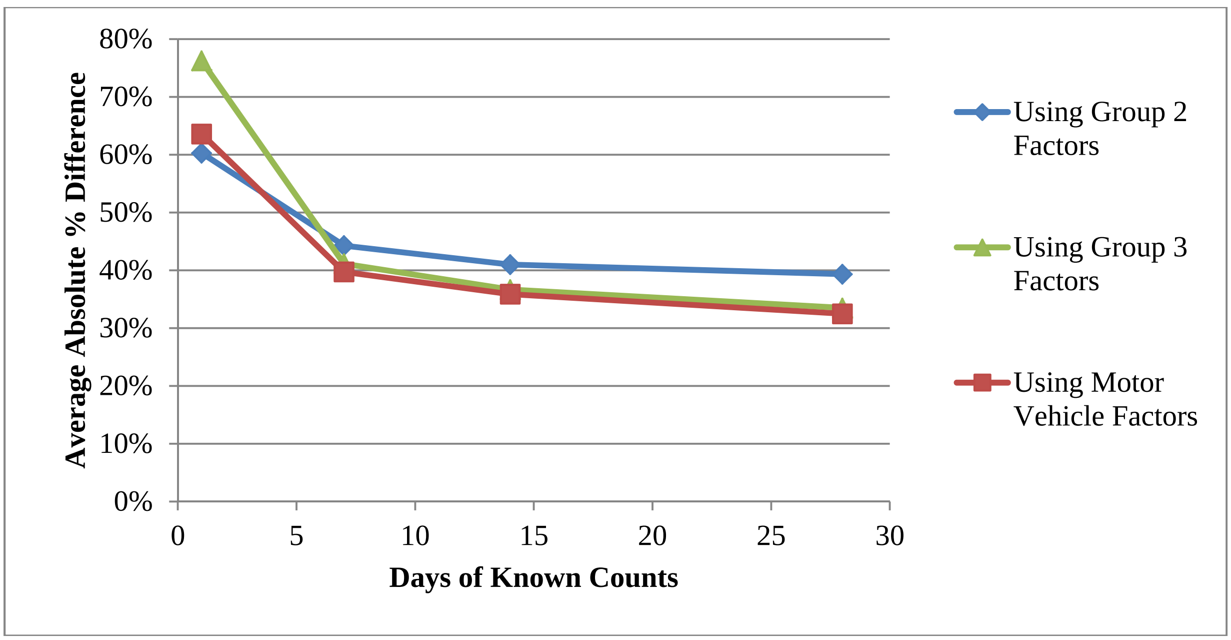

Figure 58. Error Estimates using for Various Short Term Count Length using C470 Data (Group 2).

Table 19. Error Estimates using Steamboat Springs Data (Group 3).

2011	Using Group 3 Factors		Using Group 2 Factors		Using Motor Vehicle Group 3 Factors		Using Group 3 Factors created without Steamboat	
Days of Known Counts	Average Absolute % Difference	Standard Deviation of Absolute % Difference	Average Absolute % Difference	Average Absolute % Difference	Average Absolute % Difference	Standard Deviation of Absolute % Difference	Average Absolute % Difference	Standard Deviation of Absolute % Difference
1	30%	32%	80%	65%	32%	26%	36%	26%
7	20%	22%	41%	38%	22%	13%	19%	13%
14	18%	21%	38%	33%	21%	12%	18%	12%
28	16%	19%	34%	26%	19%	11%	17%	11%

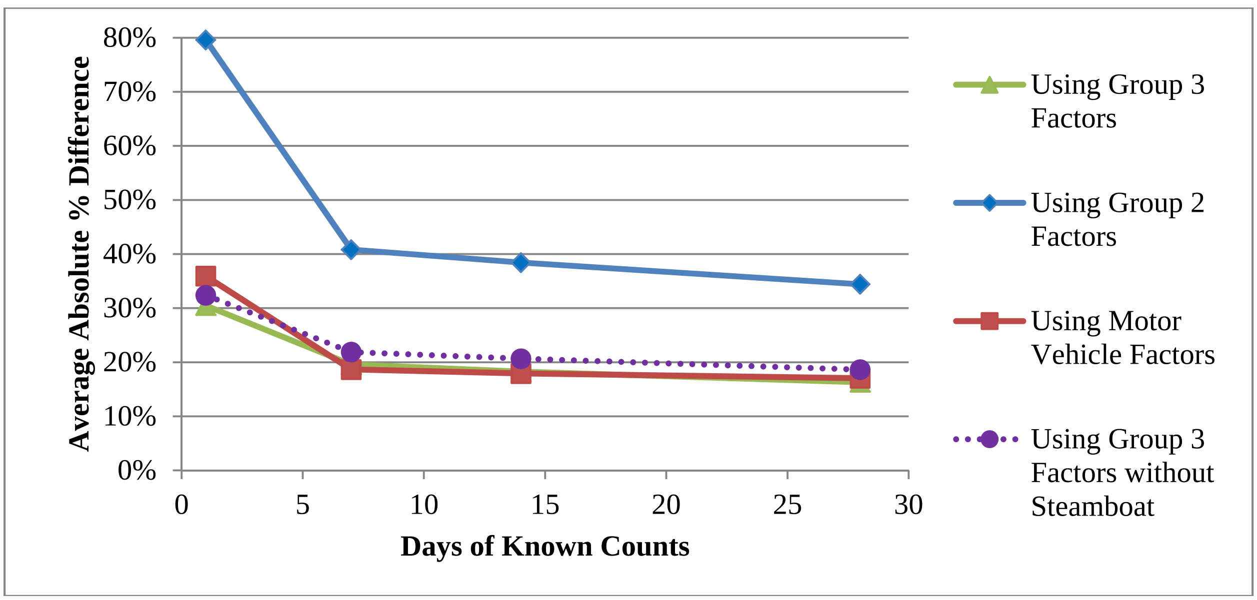

Figure 59. Error Estimates using for Various Short Term Count Length using Steamboat Data (Group 3).

Table 20. Comparison of Error in AADB or AADBP Estimates.

Factor Group (Validation Station)	Days with Least Error	Months with Least Error	Average Absolute % Difference Error from 7-day Count using Appropriate Factor Group
Group 1 Mountain Non-Commute (EmmaRGT)	Similar error for each day of the week	July to September	52%
Group 2 Front-Range Non-Commute (C470)	Tuesdays and Saturdays	March to May; August to October	22%
Group 3 Commute (Steamboat)	Mondays and Wednesdays	August to October	20%

TASK 3: DOCUMENTATION AND DISSEMINATION

In this section, a three-step method for annualizing bicycle and pedestrian counts is presented. The method assumes that: i) at least one week of continuous hourly count data is available at each short-term count station; and ii) the location exhibits the behaviors of one of the factor groups presented. A set of daily and hourly factors for each factor group is also presented.

Step 1: Collect Continuous Counts

This process requires continuous counts in order to compute factors. At least five continuous counters are recommended per factor group. As shown in this report, non-motorized count data from approximately 70 permanent or semi-permanent count stations across the state were collected. Since bicycle and pedestrian travel patterns can differ even at the same location, as we see in the case of Broomfield, it would be best if bicyclists and pedestrians counts are collected separately. Most of the non-motorized count data collected was either cyclists in urban environments or combined bicyclist and pedestrian counts in rural environments. It would be advantageous to collect non-motorized counts at more of a variety of locations, such as pedestrian counts in urban areas and bicyclist counts in rural areas.

Step 2: Calculate Factors

Most of the work presented in this report applies to this step. Multiple methods of estimating AADB and AADBP were investigated, but in the end, a methodology akin to the standard factor method used for motor-vehicles was found to be both simple and effective. Below is an outline of how these factors can be computed:

1. Compute daily and monthly factors for each station. These can be computed in a variety of ways, but the method recommended by AASHTO seems to be effective [37].
2. Group locations into at least three groups, using the daily pattern of travel and the location for the site as detailed in Figure 51. Note that since bicycle and pedestrian travel patterns are similar in nature, they can both be members of the same factor group.
3. Average the factors in each factor group.

The factors computed for the three non-motorized factor groups outlined herein are listed in Table 21. Factors for Group 1 were only given for April through November, because applying factors to counts for the winter months leads to extremely high error (i.e., error greater than

100% in some cases). Computing a separate set of daily factors for each month, as CDOT currently does for motor vehicle factors, is expected to increase the accuracy of the estimates. The factors below are given as an example.

Table 21. Daily and Monthly Factors for 2011.

Day	**Group 1 Mountain Non-Commute**	**Group 2 Front-Range Non-Commute**	**Group 3 Commute**
Sunday	0.795	0.687	1.414
Monday	1.166	1.256	0.939
Tuesday	1.126	1.399	0.854
Wednesday	1.096	1.332	0.869
Thursday	1.200	1.398	0.962
Friday	1.115	1.229	0.991
Saturday	0.773	0.674	1.255
Month	**Group 1 Mountain Non-Commute**	**Group 2 Front-Range Non-Commute**	**Group 3 Commute**
January		3.904	1.540
February		3.150	2.002
March		1.262	1.229
April	2.155	1.067	1.052
May	1.037	0.747	0.934
June	0.515	0.763	0.707
July	0.416	0.762	0.822
August	0.514	0.735	0.668
September	0.708	0.758	0.781
October	1.730	0.994	1.044
November		1.458	1.360
December		2.516	2.280

As more data becomes available, these factors should be updated for future years. As more count stations are put in place at different types of locations, additional factor groups may be added. Below are the equations that were used to compute the factors above:

$$M_m = \frac{\sum_{i=1}^{n}\left(\frac{AADBP_i}{MADT_{m_i}}\right)}{n}$$

where:

M = the monthly factor for a given month

$AADBP$ = the annual average daily bicyclist and/or pedestrian traffic $MADT_m$

= the monthly average daily bicyclists and/or pedestrian traffic

n = the number of stations in the factor group

m = the given month, m

i = a counting variable for the number of stations in the factor group

and

$$D_{dm} = \frac{\sum_{i=1}^{n}\left(\frac{1}{12}\sum_{m=1}^{12}\frac{MADT_{m_i}}{C_{dm_i}}\right)}{n}$$

where:

D = the daily factor for the day and year when the count was taken

$MADT_{mi}$ = the monthly average daily bicyclist and/or pedestrian traffic for month m at station i

C_{dm} = the average for each day of the week of the average daily counts for each day of the week for each month. For example, given the average daily counts of all the Tuesdays in January, the average of all the Tuesdays in February, the average Tuesdays in March, etc., average all of these Tuesday averages to compute C_d for that day of the week.

n = the number of stations in the factor group

m = the given month, m

i = a counting variable for the number of stations in the factor group

Step 3: Collect Short-Term Counts

The CDOT already collects short-term counts from around the state. The factors computed in Step 2 can then be multiplied by the short term counts currently collected by CDOT. It is recommended that the factors be applied to each day of the week for which data was collected. The resulting estimates can then be averaged to obtain a final estimate of AADB or AADBP at each location.

$$AADBP = D_{dm} * M_m * C$$

where:

$AADBP$ = the annual average daily bicyclist and/or pedestrian traffic

D_{dm} = the daily factor for the day, month, and year when the count was taken

M_m = the monthly factor for the month when the count was taken

C = the total count for that day

For locations where more than one day of counts is available, use the above equation to estimate AADBP for each day that short-term counts are available and then average the AADBP estimates to obtain the final AADBP estimate. Table 22 lists the short-term count locations for which at least one week of count data are available.

Two examples are given below: one for estimating AADBP from twenty-four hours of counts, and one for estimating AADBP from a full week of counts.

Table 22. Factor Groups for Short-Term Count Locations.

City	Station	Location	Front Range?	Weekend High?	Factor Group
Denver	B00001	PlatteRiver Trail at REI	1	1	2
Highlands Ranch	B00002	C470 Path at Santa Fe	1	1	2
Lakewood	B00003	C-470 Trail South Side of 285	1	0	3
Denver	B00004	Cherry Creek Trail West of Cook Park	1	1	2
Lone Tree	B00005	C470 Path at Quebec	1	1	2
Wheatridge	B00006	Clear Creek Path at Wadsworth	1	1	2
Castle Rock	B00009	East Plum Creek Trail - Meadows Parkway Southwest of SH85	1	1	2
Colorado Springs	B00010	Sand Creek Trail - S. Chelton Rd. east of S. Murray Blvd.	1		3
Glenwood Springs	B00011	Rio Grand Trail North of 23rd	0		2
Aurora	B00014	High Line Canal Trail at Exposition Ave west of Havana St.	1	0	3
Castle Rock	B00015	Festival Park Trail southwest of 2nd St. & Wilcox St.	1	1	2
Grand Junction	B00017	Pedestrian Bridge north of Colorado River - 27 3/8 rd north of Cheyenne Dr.	0		2
Loveland	B00018	US 34 Underpass - Between Boise Ave & Denver Ave.	1		2
Denver	B00019	Highland Pedestrian Bridge - 16th St. /Central St. West of I-25	1		2
Colorado Springs	B00020	Rock Island Trail at Constitution Ave. east of N. Circle Dr.	1		2
Fort Collins	B00021	Spring Creek Trail NB/SB - Redwing Rd. south of Bay Rd.	1		3
Fort Collins	B00023 B00038	Spring Creek Trail EB/WB at Redwing Rd. south of Bay Rd.	1	0	3
Durango	B00026	Animas River Trail east of SH550; Swinging Bridge north of 15th	0		2
Denver	B00033	8th Ave./ Valleje St. Pedestrian Bridge	1	0	3
Denver	B00034	6th Ave. Frontage Rd at Knox	1	0	3
Denver	B00035	Cherry Creek Trail E/O Colorado Blvd	1	1	2
Denver	B00036	Cherry Creek Trail west of Cherry St.	1	1	2
Steamboat Springs	B00037	Yampa River Core Trail south of 10th St./Yampa St. near ambulance barn	0	1	2
Pueblo	B00039	Arkansas River Trail SE of SH96/Chapa	1		2
Pueblo	B00040	Fountain Creek Trail W/O 8th/Erin St.	1	1	2
Engelwood	B00041	Bear Creek Trail Pedestrian Bridge at Irving St. north of Bear Creek Dr.	1	0	3
Engelwood	B00042	Irving St. south of Quincy St.	1	0	3

Example of Estimating AADBP from Short-Term Counts

To illustrate the methods outlined above, one example location was chosen, 8th and Vallejo in Denver. This site, shown in Figure 60 is located on the wide sidewalk of a bridge that carries both bicycle and pedestrian traffic. Counts were collected at the site using an infrared counter, which did not differentiate between the two user types. Thus, only the combined bicyclist and pedestrian count is known.

Figure 60. Location of Bicycle and Pedestrian Counts at Bridge on 8th and Vallejo in Denver. Source: CDOT.

In this section, two examples are given: i) if only 24-hours of counts were collected for this site; and ii) if the 19 full days of counts were collected.

Estimating AADBP from 24-hours of Counts

If we know how many bicyclists and pedestrians or just bicyclists passed a given location in a twenty-four hour period, the factors computed in Step 2 can be used to estimate AADBP. For example, from midnight to midnight on Wednesday, May 25, 2011, 655 bicyclists and pedestrians were counted at the pedestrian bridge on 8th and Vallejo in Denver.

The first step is to determine the appropriate factor group for the site. Consulting the flow chart in Figure 51, one can see that two pieces of information are needed: the weekly pattern and the location. With only 24-hours of counts, it is not possible to know the weekly traffic pattern or whether weekdays are higher than weekends or not, but the location is known. The site is in an urban setting, not a mountain trail. For this reason, one can rule out Group 1 as a potential factor group choice for this location.

This leaves two potential factor groups: Group 2, Front-Range Non-Commute; and Group 3, Commute. To determine which might be more appropriate, the pattern of how the traffic varies by hour is next examined, as shown in Figure 61.

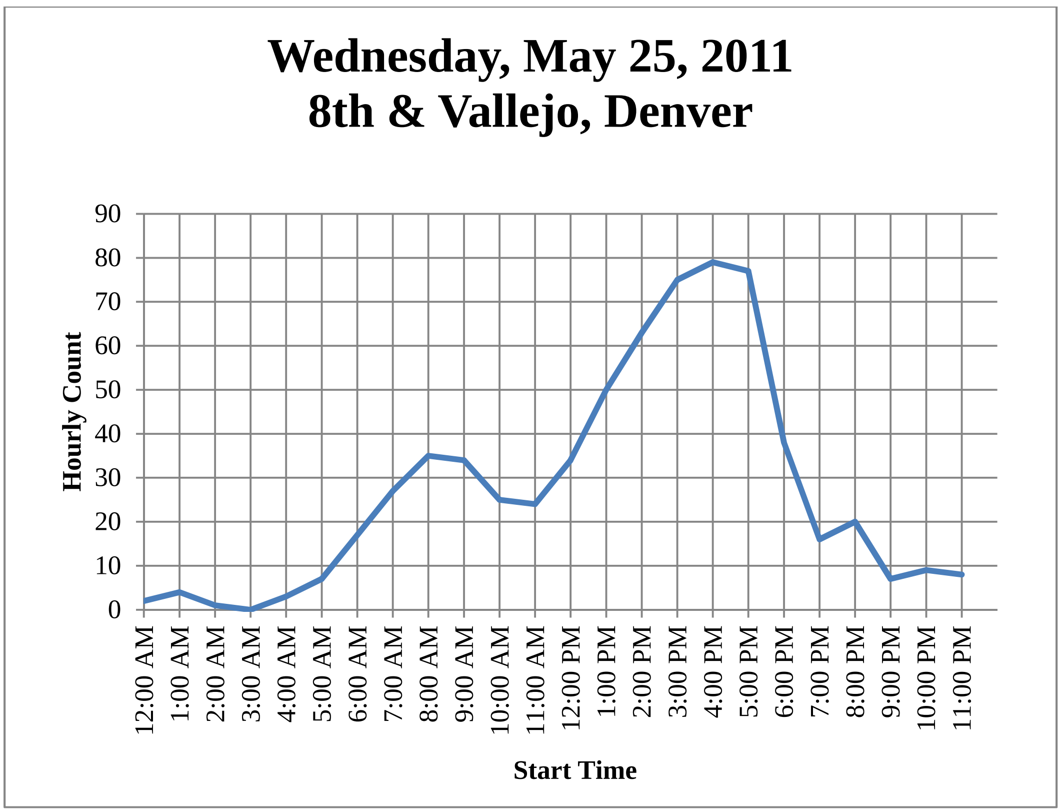

Figure 61. Twenty-Four Hours of Bicycle and Pedestrian Counts at bridge on 8th and Vallejo in Denver.

Looking at the hourly counts for the day, there are two peaks, one between 8:00 AM and 10:00 AM and the other between 3:00 PM and 6:00 PM. These correspond to common commute times; so it is likely that a commute pattern is common at this site. For this reason, Group 3 (Commute) factors seem appropriate. Using the factors reported in Table 21, we find that the daily factor (*D*) for Wednesdays for Group 3 is 0.869 and the monthly factor (*M*) for May is 0.934 for Group 3. To find the estimate of AADBP for this site, the following calculation is made:

$$AADBP = D * M * C$$

where
D = the daily factor
M = the monthly factor
C = the 24- hour count
$AADBP$ = 0.869 * 0.934 * 655= 532

This shows that while the total counts for this day in May are 655, the expected annual average daily counts (532) are less, because May is known to be higher than average for commute sites in urban areas, like this location.

Example of Multiple Days of Counts

If more days of count data were available, we have more information by which to determine which factor group the location belongs to. Specifically, if at least one week of counts are available, one can observe whether weekdays or weekends are higher. For example, at the 8th and Vallejo location in Denver, 19 days in May are available (May 12 to 30th). Thus, the first step is to plot the average count by day of the week. As shown in Figure 62, weekdays are generally higher than weekends for this site. Now all the information needed to work through the flow chart in Figure 51 is available. Because weekdays are lower than weekends, this helps verfiy the choice of Group 3 as the appropriate factor group for this location.

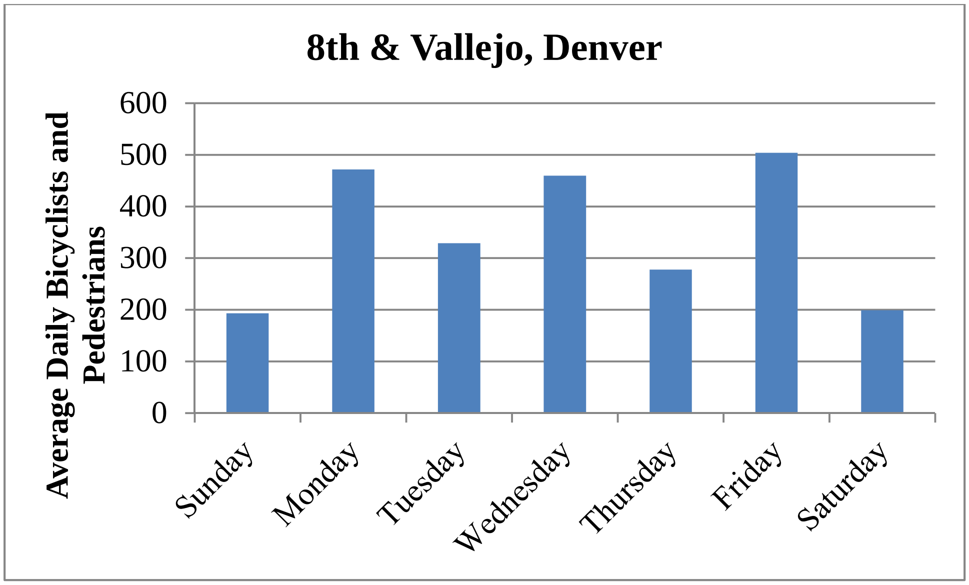

Figure 62. Average Daily Bicycle and Pedestrian Count in May by Day of Week at 8th and Vallejo in Denver.

AADBP for each day was then estimated and the results averaged. In the case of the example site, counts were collected for 19 continuous days in May as shown in Table 23. Averaging the AADBP estimates for all the days gives an average estimate of 322, which is likely to be more representative of the actual AADBP than the estimate based on just the 24 hours of counts discussed above. The more days of counts are available, the more accurate the estimate should be.

Table 23. Example of 19 Days of Counts Used to Estimate AADBP.

Date	Daily Count	Daily Factor	Monthly Factor	AADBP estimate from 24-hr count
Thursday, May 12, 2011	140	0.962	0.934	126
Friday, May 13, 2011	646	0.991	0.934	598
Saturday, May 14, 2011	140	1.255	0.934	164
Sunday, May 15, 2011	93	1.414	0.934	123
Monday, May 16, 2011	565	0.939	0.934	496
Tuesday, May 17, 2011	395	0.854	0.934	315
Wednesday, May 18, 2011	264	0.869	0.934	214
Thursday, May 19, 2011	211	0.962	0.934	190
Friday, May 20, 2011	330	0.991	0.934	306
Saturday, May 21, 2011	267	1.255	0.934	313
Sunday, May 22, 2011	244	1.414	0.934	322
Monday, May 23, 2011	523	0.939	0.934	459
Tuesday, May 24, 2011	263	0.854	0.934	210
Wednesday, May 25, 2011	655	0.869	0.934	532
Thursday, May 26, 2011	482	0.962	0.934	433
Friday, May 27, 2011	536	0.991	0.934	496
Saturday, May 28, 2011	190	1.255	0.934	223
Sunday, May 29, 2011	243	1.414	0.934	321
Monday, May 30, 2011	327	0.939	0.934	287
			Average AADBP	**322**

CONCLUSIONS AND RECOMMENDATIONS

Summary

Colorado Department of Transportation (CDOT) is one of the leading DOTs in estimating AADB and AADBP. Given their investment in count technologies and the growing datasets available for understanding non-motorized traffic, CDOT is well positioned to begin publishing annualized average bicycle and pedestrian daily traffic volumes (AADB and AADBP). This report summarizes a simple method for computing these values, which can be implemented in the existing traffic data software. While we did investigate more complex statistical methods for computing AADB and AADBP, the additional accuracy gained by including weather data and other variables is small compared to the time and effort costs. For this reason, we recommend the simpler approach.

At four locations where bicycle and pedestrian continuous counters were located along the same corridor or in proximity motor vehicle automate traffic recorders (ATRs), motorized and non-motorized traffic patterns were compared. While one location showed some similar patterns, the patterns between modes differed despite being in similar locations. Generally motor vehicles had highest counts on Fridays while non-motorized users had highest counts on other days; and non-motorized use varied much more with season.

This report classifies the studied bicycle and pedestrian count stations into three factor groups based on geographic region of the state (mountain or front-range) and use pattern (commute or non-commute). The method for classifying a short-term count location is given in Figure 43. Factors for each group were created for 2011 using the existing continuous bicycle and pedestrian count data from CDOT and six local jurisdictions: City of Boulder, City of Denver, Douglas County, Boulder County, Pitkin County and Summit County. The 2011 bicycle and pedestrian daily and monthly factors are listed by group in Table 21.

The factors are validated and shown to produce estimates of AADB and AADBP with varying levels of average absolute percent difference error. Group 1 has the highest average error (greater than 46%), while Groups 2 and 3 have roughly 20% average error, averaged over the entire year. AADB and AADBP estimation error is least in the months of August and September. Error is substantially reduced in all three of the validation cases when seven or more days of short-term count data are available. For short-term count duration periods longer than seven days, additional error reduction occurs but is not as substantial as the difference between error in estimates from 24-hour counts versus that for seven-day counts.

This report provides a practical method, directions for implementation, assessment of accuracy of the method, and Colorado-specific factors to use for estimating AADB and AADBP from short-term counts collected in Colorado.

Recommendations

Bicycle and pedestrian daily and monthly factors should be computed for non-motorized road users as outlined in this report. Bicycle and pedestrian daily and monthly factors provided in this report should be applied to the short-term counts collected in 2011 as shown in the example in Table 23. Additional factors should be computed for subsequent years using existing CDOT database management software and using data collected from as many local jurisdictions as possible.

In general, it was found that using at least seven continuous counters per factor group is desirable for obtaining sufficient precision in the factors created. The Traffic Monitoring Guide (TMG) recommends at least five continuous counters per group, so it seems reasonable that non-motorized counts, which are more variable, would require more continuous counters to obtain reliable factors.

Because bicyclists and pedestrians at the same location can exhibit different traffic patterns, it is best to count each mode separately wherever possible.

Short-term counts should be taken on roads and paths around the state. The following specific recommendations for short-term count collection will improve the accuracy of AADB or AADBP estimation:

- Collect short-term counts in high volume months, if possible. **August and September** are generally the best months for short-term count collection if low AADB/AADBP estimation error is desired. This is especially important for mountain regions where short-term counts should be collected in non-winter months. Do not collect short-term counts for mountain non-commute sites from November through March.
- At least **7-days** of counts is the most cost-effective length of time to collect short-term counts. Shorter counts, such as 24-hours, result in substantially higher error while longer counts, such as one month, do increase accuracy but not substantially.
- Since days with extreme weather events and special bicycle or pedestrian events (such as Bike to Work Day in June, Ride the Rockies, and other location specific events) can greatly impact the estimates of annual bicycle and pedestrian traffic volumes, such days should be excluded from the short-term count data used to estimate AADB or AADBP.

The methods for creating bicycle and pedestrian specific factors presented in this report will provide more accurate estimates of AADB and AADBP than using existing factors computed for motor vehicles. In order to use this methodology, existing and future short-term and continuous count stations must be categorized into one of the three factor groups, as presented in Figure 43. The factors for each group for 2011 are presented in Table 21. Existing data management software can be used to compute similar factors for future years using methods currently used for motor vehicles.

Future Work

Using the full 84 factors daily for non-motorized users, instead of the 7 given in this report, as CDOT currently does for motor vehicles is expected to result in greater accuracy of AADB and AADBP estimation. This approach should be verified, but could be implemented by CDOT if desired.

The existing permanent continuous count stations cover some geographic areas well but are lacking in other regions. More specifically, additional stations are needed in urban areas outside of the Denver metropolitan area such as Colorado Springs, Fort Collins, Pueblo, Alamosa, Grand Junction, as well as towns in the eastern plains and west of the Rockies. Counters in these locations may reveal different use patterns. Additionally further work could be done to refine the factor groups and perhaps subdivide the three proposed groups as more data becomes available.

The existing short-term count program should be further expanded to cover more facilities in more communities around the state. If possible, short-term counters could be moved every seven days during the summer to maximize the locations where AADB and AADBP can be estimated. Eventually, this expanded network of short-term counters may allow CDOT to estimate the bicycle and pedestrian miles traveled around the state. In order to do this in the most effective manner, a statistical sampling program should be implemented by which short-term count locations can be selected at random, not as it is currently done via a location recommended by local contacts. This will result in some count locations with very low counts, which is problematic, but it will also result in data that are more representative of the communities and facilities studied. Without such random sampling, accurate estimates of bicycle and pedestrian miles traveled would require that samples be collected on every road and path segment around the state. For this reason, we hope that the state considers undertaking the creation of a random sampling program for their bicycle and pedestrian short-term counts.

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APPENDIX A. RESPONSE TO STATE EMAIL REQUEST FOR INFORMATION

Table A-1 details the responses received from states concerning bicycle and pedestrian counting.

Table A-1. State Email Request Responses.

State	Traffic Monitoring Program Contact	Position	Email	Response	Date of Response
Alabama	Charles W. Turney	Traffic Engineer	turneyc@dot.state.al.us	No response.	
Alaska	Mary Ann Dierckman	Transportation Planner	maryann.dierckman@alaska.gov	No response.	
Arizona	Mark Catchpole	Planner IV	mcatchpole@azdot.gov	No response.	
Arkansas	Elizabeth Mayfield-Hart	Staff Planning Engineer, Technical Services	elizabeth.mayfieldhart@arkansashighways.com	Pedestrian counts in conjunction with turning movement counts. No continuous bike or ped counts.	12/20/11
California	Joe Avis	Chief, Traffic Data and Photolog Branch	joe_avis@dot.ca.gov	wrong address	
Connecticut	Kerry Ross Katherine Rattan	Transportation Supervising Planner Non-Motorized Transportation Coordinator	kerry.ross@po.state.ct.us katherine.rattan@ct.gov	No. Infrequent peak hour bike ped data for planning, design or safety audit. No continuous counts.	12/27/11
District of Columbia	Yusuf Aden	Traffic Safety Engineer	yusuf.aden@dc.gov	No response.	
Florida	Joey D. Gordon Dwight Kingsbury	Supervisor, Traffic Data Quality FDOT Safety	joey.gordon@dot.state.fl.us	1/30/12 - counts may be being taken on shared-use paths by maintaining agencies, e.g., former	2/7/12

State	Traffic Monitoring Program Contact	Position	Email	Response	Date of Response
		Office	dwight.kingsbury@dot.state.fl.us	Office of Greenways and Trails (now part of FDEP Division of Recreation and Parks). 2/7/12 - FDOT district offices (District 4) just started a program to collect, annually, 24-hour cyclist and pedestrian counts (in November) at about 18 locations in Broward and Palm Beach counties. Their consultant took counts (from video) at 25 locations last November, but collected only 12-hour counts at some of them.	
Georgia	Tim Christian	QC & Data Reporting Branch Chief	tim.christian@dot.state.ga.us	No response.	
Hawaii	Napoleon Agraan	Engineer (Civil) V, DOT-Highways Division, Planning Branch	napoleon.agraan@hawaii.gov	No response.	
Idaho	Glenda Fuller; Maureen Gresham	Roadway Data Manager Bicycle and Pedestrian Coordinator	glenda.fuller@itd.idaho.gov maureen.gresham@itd.idaho.gov	No, but do hope to start in the near future.	12/21/2011

State	Traffic Monitoring Program Contact	Position	Email	Response	Date of Response
Illinois	Rob Robinson Mike Miller	Data Management Unit Chief Traffic Data Manager	rob.robinson@illinois.gov michael.miller@illinois.gov	No count program.	12/21/2011
Indiana	Scott MacArthur	Traffic Monitoring Section Engineer	smacarthur@indot.in.gov	No response.	
Iowa	Phillip Meraz	Systems Monitoring Manager	phillip.meraz@dot.iowa.gov	No response.	
Kansas	Alan Spicer	Traffic and Field Operations Engineer	spicer@ksdot.org	No response.	
Kentucky	Ted Noe	Transportation Engineering Branch Manager	ted.noe@ky.gov	wrong address	
Louisiana	James C. Porter	Planning Support Engineer	jimporter@dotd.la.org	wrong address	
Maine	Deborah Morgan	Traffic Monitoring Manager	deborah.morgan@maine.gov	No response.	
Maryland	Karl Hess	Manager-Traffic Monitoring System	khess@sha.state.md.us	No response.	
Massachusetts	Stephen R. Greene	Supervisor Statewide Traffic Data Collection	stephen.greene@mhd.state.ma.us	No response.	
Michigan	Mike Walimaki	Transportation Planner	walimakim@michigan.gov	wrong address	

State	Traffic Monitoring Program Contact	Position	Email	Response	Date of Response
		Manager			
Minnesota	Gene Hicks Lisa Austin	Principal Engineer ABC Ramps Coordinator / Bicycle and Pedestrian Planner	gene.hicks@dot.state.mn.us lisa.austin@state.mn.us	MnDOT does not do any counts right now. Several cities, state and parks agencies, MPOs etc. are doing counts. We are in the process of collecting information about who all is doing counts. And we have a research project underway to develop a methodology for sharing this information and for counting bikes and peds in a consistent manner.	12/20/11
Mississippi	Jeff Altman	Engineering Analysis Manager	jaltman@mdot.state.ms.us	No response.	
Missouri	Mary Beth Anthony	Planning Supervisor	marybeth.anthony@modot.mo.gov	No response.	
Montana	Tedd Little	Weigh In Motion Analyst	tlittle@mt.gov	No response.	
Nebraska	Rick Ernstmeyer	Traffic Analysis Supervisor	rickernstmeyer@dor.state.ne.us	No response.	
Nevada	Michael W Lawson Randy Travis	Traffic Information Division Chief Traffic Information Chief	mlawson@dot.state.nv.us rtravis@dot.state.nv.us	No bike/ped count program. Only for specific site study.	1/23/2012
New York	Kurt Matias	Associate Transportation Analyst	kmatias@dot.state.ny.us	The Traffic Monitoring Unit does not take bike or Ped counts. Some of our Regions have taken a few counts here and there, but nothing on a regular basis. NYCDOT NYC has an	12/21/2011

State	Traffic Monitoring Program Contact	Position	Email	Response	Date of Response
				extensive Ped count program. There is a Pedestrian Program at the Main Office, but counts on an irregular basis. Contact:Jim Ercolano(518) 457-087jercolano@dot.state.ny.us Bike and Pedestrian Section, Planning Division Eric Ophardt 518-457-0922 eophardt@dot.state.ny.us	
New York	Eric Ophardt	Statewide Bicycle and Pedestrian Section	eophardt@dot.state.ny.us	No. The Department does not maintain any 24 hour continuous bicycle or pedestrian counts. New York City Department of Transportation (NYCDOT) has 24 hour bicycle and pedestrian counts at key bridge crossing points and on major shared-use pathways, http://www.nymtc.org/project/NYMTC_Bicycle_Data_Collection_Program/www_html/index.htm	12/23/2011
North Carolina	Kent Taylor	State Traffic Survey Engineer	kltaylor@dot.state.nc.us	No response.	
North Dakota	Robert Olzweski	Senior Transportation Project Manger	rolzwesk@nd.gov	No response.	
Ohio	Dave Gardner	Manager, Traffic Monitoring Section	dave.gardner@dot.state.oh.us	No response.	
Oklahoma	Jay Adams	Assist.		1. No, 2. N/A and 3. No.	2/7/2012

State	Traffic Monitoring Program Contact	Position	Email	Response	Date of Response
	John R. Bowman	Division Mgr. - Planning & Research; Planning and Research Division Engineer	jadams@odot.org jbowman@odot.org		
Oregon	Don R. Crownover	TSM Unit Team Leader	don.r.crownover@odot.state.or.us	Currently we only have one permanent bike count site in the I-205 bike path. We only count bikes and peds as part of manual counts done on a project basis. But the non-motorized part is often not a part of any bike/ped plan. The Portland metro area and I think Eugene also does bike counts.	12/20/11
Pennsylvania	Laine Heltebridle Jeremy M. Freeland	Manager, Transportation Planning Division Transportation Planning Manager	lheltebrid@state.pa.us jfreeland@pa.gov	No count program. Data is only collected on a case by case basis. Delaware Valley Regional Planning Commission (DVRPC). Scott Brady, sbrady@dvrpc.org , collects counts.	12/22/2011
Rhode Island	David A. Doyle, Jr.	Senior Planner	ddoyle@dot.ri.gov	While RIDOT did initially count the bike paths with soft rubber tubes, the practice was discontinued for the safety of bicyclists, pedestrians, and others.	12/21/2011
South Carolina	Angela Hance	Assistant Chief of Road Data Services	hancema@scdot.org	No response.	

State	Traffic Monitoring Program Contact	Position	Email	Response	Date of Response
South Dakota	Kenneth E. Marks	Engineering Supervisor	ken.marks@state.sd.us	No, Not sure maybe the city of sioux falls, sd	12/20/11
Tennessee	Steve Allen	Director - Project Planning Division	steve.allen@state.tn.us	No state count program.	12/22/2011
Tennessee	Jessica L. Wilson	Bicycle and Pedestrian Coordinator, TDOT Long-Range Planning	jessica.l.wilson@tn.gov	At present, some of the major MPOs within TN do collect counts in their region. Knoxville TPO and the Nashville Area MPO recently conducted counts, and Chattanooga and Memphis MPOs may in the near future. Knoxville bike/ped counts: http://bikeknoxville.blogspot.com/2011/10/new-bicycle-counts-available.html Nashville bike/ped counts: http://www.nashvillempo.org/docs/News/RELEASE_09.22.11_Regional_Bike_Ped_Counts.pdf	1/4/2012
Utah	Toni Butterfield	Research Analyst	tbutterfield@utah.gov	No response.	
Vermont	Jon Kaplan	Bicycle and Pedestrian Program Manager	jon.kaplan@state.vt.us	One counter has been installed on a sidewalk for over 5 years. We plan to install a counter specific to bikes on a shared use path this summer and it will be a permanent counter. Chittenden County MPO has some semi-permanent sits. Contact Daryl Benoit at dbenoit@ccrpcvt.org or	1/30/2012

State	Traffic Monitoring Program Contact	Position	Email	Response	Date of Response
				802.660.4071 x12 http://www.ccrpcvt.org/data/bikeped/	
Virginia	Cindy Engelhart	District Bicycle and Pedestrian Coordinator	cindy.engelhart@vdot.virginia.gov	We are using Miovision cameras and software. In answer to your inquiry: 1. No 2. Not applicable 3. A. The County of Arlington, Virginia is collecting continuous counts primarily on trails (maybe on a bike lane or two). Contact dpatton@arlingtonva.us. The Northern Virginia District of VDOT collects a mix of 24 hour counts, 15 hour counts and 12 hour counts. So far the data has been used to support the need for more facilities in the region or as supplemental information regarding the presence of bikes and peds in the general area of a project.	
Washington	Ian Macek	State Bicycle & Pedestrian Coordinator	maceki@wsdot.wa.gov	Currently we only have one continuous (24hr/365) permanent bicycle and pedestrian counter installed (as of this summer). In the past, WSDOT has used tube counters and volunteers for specific projects. Since 2008, WSDOT has conducted an annual count in 30 cities across the state collecting both am and pm peak bicyclist and	1/23/2012

State	Traffic Monitoring Program Contact	Position	Email	Response	Date of Response
				pedestrian counts. We have altered the NPBD methodology to fit for Washington State. Our counts are used for planning, design, safety, and monitoring volumes/trends to reach our state goal. We have also partnered with our largest RTPO/MPO who plans to use the data for modeling purposes. In 2010, the Puget Sound Regional Council partnered with WSDOT for the annual count, but I don't believe they currently collect continuous counts. Seattle, Vancouver, Redmond, Everett and Olympia are a few of the cities in the state that conduct counts and I believe most have 24hr+ bicycle count information at various locations.	
West Virginia	Tom Myes	Transportation Manager	tmyers@dot.state.wv.us	wrong address	
Wisconsin	Jill Mrotek Glenzinski	WisDOT Bicycle & Pedestrian Cooridnator	jill.mrotekglenzinski@dot.wi.gov	Some trail counts and counts where a trail crosses a state highway using an infrared counter (Eco-Counter) for 2 wks to a couple of months.	1/27/2012

State	Traffic Monitoring Program Contact	Position	Email	Response	Date of Response
Wyoming	Sherman Wiseman	Supervisor, Transportation Surveys	sherman.wiseman@dot.state.wy.us	No count program.	12/20/11

Note: Texas and Delaware were not included in the original list.

APPENDIX B. RESPONSE TO TRAFFIC DATA COMMITTEE EMAIL REQUEST FOR INFORMATION

On December 20, 2012, an email was sent to the 236 members on CDOT's Traffic Data Committee email list with the following request:

> *Dear Traffic Data Committee members, The University of Colorado Denver is assisting CDOT to develop a method to estimate annual bicycle and pedestrian volumes based on existing continuous bicycle and pedestrian counts. To do this we first need to gather all the continuous bicycle and/or continuous pedestrian count data in Colorado (continuous meaning over 24 hours of continuous data per location). Currently we have the data from CDOT's EcoCounters and the city of Boulder's 12 inductive loop counters. Do you know of any other locations where automated continuous counters of bicyclists and pedestrians are available? If so, where are these counters, and who should we contact to get a copy of this data? Please let us know if you have any data before January 6th so we can be sure to include it in the study. Thank you for your help! Have a great holiday season!*

An additional request was posted in the Newsletter of the Colorado Local Technical Assistance Program which was sent out around January 5, 2012:

> *The University of Colorado Denver is assisting CDOT to develop a method to estimate annual bicycle and pedestrian volumes based on existing counts. To create this method, we need as much Colorado continuous bicycle and/or continuous pedestrian count data (continuous meaning over 24 hours of continuous data per location) as possible. If you are aware of any such counts other than those already collected by CDOT, please email Krista Nordback, Krista.Nordback@ucdenver.edu, by January 12.*

Table A-1 summarizes the responses received from the committee. Three counties and one city indicated that they do have infrared (bike and pedestrian counts combined) continuous counts: Douglas, Boulder, and Summit Counties and the city of Longmont. Douglas and Summit counties use TRAFx brand infrared counters to count pedestrians, cyclists and some equestrians on recreational trails. Boulder county use 3 JAMAR and 7 TRAFx infrared counters. The city of Longmont uses an active infrared trail counter made by Ivan Technologies. The city of Denver sent the counts June through December 2011 from their continuous video counter (Iteris brand) on eastbound 16th St bike lane just west of Grant in downtown Denver.

Table B-1. Traffic Data Committee Data Request Responses.

Name/agency/email/phone **Date of response**	**Response**
Steve Cook DRCOG scook@drcog.org 303-480-6749 12/20/11	I am glad to see this work being done and have been following from the sidelines for the past month and have a question. The phrase “estimate annual bicycle and pedestrian volumes” is pretty broad. What specific value definition is desired by CDOT? – is it the annual bicycle/ped volume on a specific roadway where a bicycle/ped count was conducted? Or is there more to it?
Amy Branstetter Douglas County abranste@douglas.co.us 303-660-7490 12/20/11	Douglas County Open Space Department, Mr. David Hause (jhause@douglas.co.us), currently has a few pedestrian counters placed at trailheads and dog parks. Please contact Mr. Hause for additional information. I'm sorry that currently Douglas County Traffic Engineering's traffic counts do not include continuous pedestrian or bicycle data. We do have intersection peak hour turning movement counts at numerous intersections in the County which includes pedestrians and bicycles. If that data would be helpful please let me know what general areas you would be interested in and I can provide the turning movement counts.
David Hause jhause@douglas.co.us Douglas County 12/21/11	I installed our new TraX counters at our trailheads and dog parks in June of this year. The counters have proven to be highly accurate and reliable. Please be aware that we count hikers, bikers and equstrians. The master summary (attached) has counts through September. Glendale and Greenland Dog Park will only include people in the count (no bikers or horses). <Attached file>
Anne Tully atully@arvada.org City of Arvada	12/20/11 Arvada has data. I will have John send you the info. 12/21/11 It appears we have already submitted the data.
Bennett, Kristin kbennett@springsgov.com Senior Transportation Planner Nonmotorized Transportation and School Safety Programs Manager City of Colorado Springs	Krista – we only had some of CDOT’s eco-counters installed on two trails for a couple weeks earlier in 2011, but they were only loaners for a short time frame. If you need these counts (the actual data reports), I could track them down or you can get them from Steven Abeyta at CDOT (he handled the loaners for us and downloaded the data and sent

(719) 385-5622 12/20/11	it to us). Staff has budgeted in 2012 to purchase some counters to be installed for continuous counting on various bicycle facilities in Colorado Springs so we will have more to add to this data picture in the near future if all goes as planned.
Jerry Smith specialprojectcoordinator@town.morrison.co.us City of Morrison 12/21/11	The Town of Morrison does not monitor this as our routes are primarily along state highways or county roads. Jefferson County is in the process of updating its bike and pedestrian plan. Will Kerns is the responsible party. wkerns@jeffcous . I am not sufficiently familiar with the plan to know whether they are maintaining the type data you are interested in. Mr. Kerns is in the county transportation department. The draft plan update is available on line at the Jefferson County Colorado Transportation department web site. Just search for it in general terms and it will pop up.
Brad Eckert brade@co.summit.co.us Resource Specialist Summit County Open Space & Trails PO Box 5660 Frisco, Colorado 80443 970-668-4213 12/21-22/11 & 12/30/11 data sent	12/21/11 - attached is a spreadsheet with the trail traffic counts for the past 3-years. There is only data for summer months, and I started with one counter in 2009, and now have five in 2011. Let me know if you have any questions. 12/22/11 - we had 2 counters stolen from us, so now there are 5 counters total. They are still out there, I am leaving them out this winter as a test case to see if they work in the cold, and also to gather continuous data. I have not really had a chance to analyze the data, it is on my list for Jan/Feb.
Larry Haas larry.haas@dot.state.co.us CDOT Region 4 12/22/11	Your list looks complete for the permanent counters that I am aware of in Region 4.
Bill Hange hangeb@ci.loveland.co.us 12/27/11	Thank you for the email. Derek Schuler will respond to your request. I don’t know of any locations that have not already been submitted.
Kirk Hayer khayer@c3gov.com Commerce City GIS administrator 1/3/12	I response to your request to Rose Clawson, in our Public Works Department, for annual bicycle and pedestrian volumes, I passed it along to our Parks and Recreation folks to see if they have such information. They indicated that the City of Commerce City does not collect bicycle / pedestrian volume information for its bike or walking tails.
Phil Greenwald phil.greenwald@ci.longmont.co.us City of Longmont Transportation Planner 303-651-8335 1/11/12	Sorry, the best bike/ped counts we have are cumulative (so you'll have to take the difference of the two numbers). I would have liked to smooth this data out before sending this out, but it sounded like you needed this info quickly.
Michelle Bowie mbowie@bouldercounty.org	We currently have a total of 28 counters (a combo of pedestrian and vehicle counters) located at our properties

Education and Outreach Specialist Boulder County Parks and Open Space 303-678-6219 1/18/12	around the county that we collect data from year round. I am in the midst of compiling the 2011 data and I can send it to you as soon as it is completed. Additionally, we have data from our 5-year study which provides statistics on the percent of visitors who are biking/hiking/riding horses/etc on each property. Those numbers could be applied to the overall visitation numbers to estimate the number of biking visitors versus pedestrian visitors on each property. Let me know if you are interested and I can work on this. Here is a link to the study if you would like to take a look - http://www.bouldercounty.org/live/environment/land/posresearch/2010posfiveyear.pdf To get you started, I have attached a copy of our 2010 end of year visitor report. This will give you an idea of how we calculate visitation and what our visitation estimate has been in the past. Let me know if there is anything else I can do to help you out. Also, when you complete your project would you please send me the report so I could see it? That would be great!

Table B-2. Agency Contacts who Provided Bicycle and Pedestrian Count Data

Agency	**Department**	**Contact Name**	**Phone**	**Email**
City of Boulder	Public Works, transportation	Michael Gardner-Sweeney	303-441-3162	sweeneym@bouldercolorado.gov
City of Boulder	Public Works, signals	Jeff Bunker	303-829-4203 cell, 303-413-7104 office	bunkerj@bouldercolorado.gov
Boulder County	Bicycle Planner/ Employee Transportation Coordinator	Brian Graham	720-564-2667	bgraham@bouldercounty.org
City and County of Denver	Public Works, signals	Tom Castro	720-490-0376	thomas.castro@denvergov.org
Douglas County		Dave Hause		jhause@douglas.co.us
Pitkin County	Open Space and Trails	Alan Feder		alan.feder@co.pitkin.co.us
Summit County	Summit County Open Space & Trails	Brad Eckert	970-668-4213	brade@co.summit.co.us

APPENDIX C. BOULDER DATA CLEANING

The continuous counts provided by the city's old Canoga counters 2001 to March 2011 plus all of the counts provided by the EcoCounters July 2010 to January 2012 were assessed for accuracy by manual counts at most locations and by looking at the data over time to determine if systematic under or over counts occurred during specific time periods. The result was that the following counts were deleted:

- At Broadway and Baseline, counts between January 2007 and March 2009 were found to be undercounting by 58% to 67%. Consequently these data were removed from the dataset.
- At Broadway and Table Mesa, counts between January 2001 and December 2005 were removed because they appeared to be significantly lower than later counts and unrealistically low.
- At Foothills and Arapahoe, counts prior to 2007 were treated as a separate facility from counts there after due to a large construction project that reconfigured the intersection and added a bicycle and pedestrian underpass below Arapahoe. Counts after 2007 undercount cyclists by 18 to 78 percent when compared to manual counts. These counts were adjusted by the factors determined by manual count comparisons.
- At Foothills and Pearl, all counts on the Pearl Parkway Path at the northwest corner of the northbound Foothills on-ramp and Pearl Parkway were deleted. These counts were higher for the first few years and then very low for most of the years, but there was no apparent reason for the sudden decline in counts. Over all these counts were low, with highs of 4 or 5 bicycles per hour.
- At Foothills and Pearl the counts on the southwest corner were found to be over twice as high as observed during a manual count. However fewer than 10 bicycles were counted during the count. Since the counts overall appear consistent over time, the data was not deleted.

City of Boulder Canoga counters collected data in 2 hour bins for the earlier part of the decade prior to 2007, but the exact time depends on location. At those sites counts were converted to one hour counts by dividing the two hour counts by 2.

Adjustments for Accuracy:

Prior to analysis, correction factors were applied to locations where such correction factors were available based on over 100 manual bicycle counts as compared to the automated detector counts. While validation tests were performed at most of the locations as shown in Table 6, finding fewer than 50 bicyclists was common. At only two locations were sufficient bicycles counted to provide accurate adjustment factors (13th St. at Walnut; and Folsom St. at Arapahoe). At the other locations, no adjustment factor was applied.