Methods for Estimating Bicycling and Walking in Washington State

WA-RD 828.1

Krista Nordback
Michael Sellinger

May 2014

Washington State Department of Transportation
Office of Research & Library Services

WSDOT Research Report

Research Report
Agreement GCB 1699, Task 3
Estimating Biking and Walking for Washington State Phase II (WSDOT)
WA-RD 828.1

METHODS FOR ESTIMATING BICYCLING AND WALKING IN WASHINGTON STATE

by

Krista Nordback, Ph.D., P.E.
Research Associate, Portland State University

Michael Sellinger
Graduate Research Assistant, Portland State University

Oregon Transportation Research and Education Consortium (OTREC)
Portland State University, P.O. Box 751
Fourth Avenue Building
1900 SW 4th Ave., Suite 175
Portland, Oregon 97201

Washington State Department of Transportation
Technical Monitor
Paula Reeves
Manager, Community Design, Olympia, WA

Prepared for

The State of Washington
Department of Transportation
Lynn Peterson, Secretary

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO. WA-RD 828.1	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
4. TITLE AND SUBTITLE METHODS FOR ESTIMATING BICYCLING AND WALKING IN WASHINGTON STATE		5. REPORT DATE May 2014 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Krista Nordback, Michael Sellinger		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Oregon Transportation Research and Education Consortium (OTREC) Portland State University, P.O. Box 751 Fourth Avenue Building 1900 SW 4th Ave., Suite 175 Portland, Oregon 97201		10. WORK UNIT NO. 11. CONTRACT OR GRANT NO. Agreement GCB 1699, Task 3
12. SPONSORING AGENCY NAME AND ADDRESS Research Office Washington State Department of Transportation Transportation Building, MS 47372 Olympia, Washington 98504-7372 Project Manager: Kathy Lindquist, 360-705-7976		13. TYPE OF REPORT AND PERIOD COVERED Research Report 14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

This study was conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

16. ABSTRACT:

This report presents the work performed in the first and second phases in the process of creating a method to calculate Bicycle and Pedestrian Miles Traveled (BMT/PMT) for the state of Washington. First, we recommend improvements to the existing Washington State Bicycle and Pedestrian Documentation Program to provide data for BMT/PMT estimates, including expanding the program geographically and installing permanent automated bicycle and pedestrian counters to complement the short duration count program. The method to estimate BMT/PMT relies on the assumption of a stratified random sample drawn from the set of all roads and paths divided into 16 groups. These groups are based on three spatial attributes, which were gathered from a review of the literature:

- Level of urbanism (2 categories): Urban and Rural
- Facility type (2 categories): Highway/Arterial and Other
- Geographic/climatic regions (4 regions): Coast Range, Puget Lowland, Cascades, Eastern Washington

This report describes the first steps being taken toward the goal of computing this metric. Count data from Seattle, Olympia, and the State's Count Program have been gathered. To account for temporal variation, seasonal, daily and hourly adjustment factors have been computed based on one year of count data collected from the Fremont Bridge in Seattle. The short duration count sites have been grouped by the attributes described above, though most fall into just two groups: Puget Lowland Urban Arterial/Highway and Puget Lowland Urban Local/Collector/Path. Little or no data are available in most of the other groups. The roads in the state have also been divided into these 16 groups in order to compute total centerline miles for each group. This report outlines a sample-based method that could be used to compute BMT/PMT for the state and identifies both the data available for such a computation as well as the data gaps. It also suggests other methods that could also be used to estimate BMT/PMT to compare to the count-based method.

Walking, Bicycling, VMT, Transportation planning, Bicycle Miles Traveled, Pedestrian Miles Traveled	18. DISTRIBUTION STATEMENT No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22616

19. SECURITY CLASSIF. (of this report)	20. SECURITY CLASSIF. (of this page)	21. NO. OF PAGES	22. PRICE
None	None		

DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Washington State Department of Transportation or Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

Contents

Disclaimer iii
Contents v
Executive Summary vii
  Phase I – Recommendations to Improve State's Count Program vii
  Phase II – Methods for Estimating Bicycling and Walking ix
Introduction 1
Review of Previous Work 3
  Pedestrian and Bicycle Demand Estimation Methods 3
  Pedestrian and Bicycle Miles Traveled Literature 5
  Vehicle Miles Traveled Literature 6
  Factors That May Impact Bicycling and Walking 8
Research Approach 16
  Identification of Data Sources 16
    WSDOT Bicycle and Pedestrian Documentation Project 16
    City of Seattle Count Data 18
    City of Olympia 19
  Evaluation of the State's Count Program 19
    Spatial Distribution 19
    Temporal Variation 25
  Methods to Analyze Temporal Variation of Count Data 26
    Computing Annual Average Daily Traffic at Permanent Count Sites 27
    Estimating Annual Average Daily Traffic at Short Duration Count Sites 28
  Methods to Estimate BMT and PMT 33
    Survey-Based Method 34
    Count-Based Method 35
    Sketch Planning and Aggregate Demand Methods 38
    Travel Demand Models 38
    Comparing Methods 39
Findings 40
  Analysis of Existing Count Data 40
    Limitations 40
    Adjustment Factors 41
    Hourly Variation 44
    Daily Variation 47
    Monthly Variation 49
  Analysis of Geographic Data 51
    Regions 52
    Road Type 53
    Urban/Rural 53
Conclusions 54
Recommendations 56
  Recommendations for the State's Count Program 56
  Recommendations for Phase III 57
Acknowledgments 59
References 60
Appendix A Text of Email Sent to State Lists 64
Appendix A Text of Email Sent to State Lists 1

EXECUTIVE SUMMARY

A key measure of motor vehicle traffic is vehicle miles traveled. No similar metric exists for bicycling and walking. Consistent with objectives identified in Washington State Department of Transportation (WSDOT)'s 2014-2017 Strategic Plan and the State of Washington Bicycle Facilities and Pedestrian Walkways Plan, this project is a step toward establishing a performance metric by which statewide progress with respect to bicycling and walking can be evaluated.

The work of creating a statewide bicycle miles traveled (BMT) and pedestrian miles traveled (PMT) estimation method is being conducted in three phases. This report summarizes the first and second phases of the work: recommendations on how to improve WSDOT's Bicycle and Pedestrian Documentation Project and an outline of how BMT and PMT could be estimated.

PHASE I – RECOMMENDATIONS TO IMPROVE STATE'S COUNT PROGRAM

One of the first steps was to identify bicycle and pedestrian count data sources. At this time the following bicycle and pedestrian count data have been identified:

- Manual bicycle and pedestrian counts at over 300 locations in 38 jurisdictions around the state from the State's Count Program,
- Manual bicycle and pedestrian counts and two continuous bicycle counters from the city of Seattle,
- Bicycle counts from the city of Olympia using pneumatic tube counters.

Next we investigated potential methods and comparison methods for calculating bicycle and pedestrian miles of travel for Washington State. To inform the work, we summarize three relevant areas of the literature: pedestrian and bicycle miles traveled estimates, motorized vehicle miles traveled (VMT) estimates, and analyses of factors that may impact bicycling and walking. We identified three spatial attributes which are both practical and found in the literature to relate to bicycle and pedestrian traffic and from which a representative sampling framework can be established.

- By level of urbanism (2 categories): Urban and Rural
- By facility type (2 categories): Highway/Arterial and Other
- By geographic and climatic regions (4 regions): Coast Range, Puget Lowland, Cascades, Eastern Washington

The combinations of the above categories theoretically result in 16 groups of possible locations from which to sample. The existing State Count Program is focused on urban areas in just two of the regions: Puget Lowlands and Eastern Washington. In order to understand statewide travel patterns, counts would also be needed in rural and mountain areas. Such areas may have lower volumes than in the city, but other states have seen that rural volumes are often higher than expected.

To better inform estimates of BMT and PMT by improving the program's ability to statistically represent the sampled area, we recommend improvements to the State's Count Program. The complete recommendations are listed in the Recommendations Section of this report. Below is a summary of the recommendations broken into two time horizons.

Recommendation for the coming years:

- Gradually expand count sites into rural areas, and both urban and rural areas in mountain areas.

- For each of the 16 sampling groups identified, install at least one permanent counter with separate automated bicycle and pedestrian counts.
- For sampling groups for which a permanent count site is available, allow short duration counts any Tuesday, Wednesday, or Thursday, May through October in order to increase the locations where counting is performed.

Recommendations for the next twenty years:

- For each sampling group, at least seven permanent bicycle and pedestrian counters are desired. Bicyclists and pedestrians should be counted separately.
- Count for at least seven days, 24 hours per day, at each short duration count location.
- At least 150 short duration count locations per sampling group would be beneficial to the accuracy of estimating bicycle and pedestrian miles traveled.
- Short duration count locations should be selected at random from each sampling group, even though this means counting at new sites some of which may have low volumes of cyclists and/or pedestrians.

PHASE II – METHODS FOR ESTIMATING BICYCLING AND WALKING

The objective of the proposed Phase II work is to create a method by which these data, combined with other sources of information, can be incorporated into an estimation of bicycle and pedestrian miles of travel across the state. While multiple methods were discussed, the method to use the existing count data to estimate bicycle and pedestrian miles traveled was detailed. Additionally, survey-based, sketch planning, aggregate demand model, and travel demand methods were also explored.

Below is an outline of this proposed method of using bicycle and pedestrian counts to estimate BMT and PMT as applied to the state of Washington.

1. Identify sampling framework: all road and path segments in the state.
2. Determine appropriate groups: 16 groups were chosen based on the following attributes commonly found in the literature.
    a. By level of urbanism (2 categories): Urban and Rural
    b. By facility type (2 categories): Highway/Arterial and Other
    c. By geographic and climatic regions (4 regions): Coast Range, Puget Lowland, Cascades, Eastern Washington
3. Randomly sample sites from each group and collect short duration counts at each site.
4. Compute seasonal, daily and hourly adjustment factors based on continuous count data.
5. Apply factors to short duration counts to estimate annual average daily bicycle and pedestrian traffic (AADB and AADP) at each site.
6. Total the centerline miles in each of the groups.
7. Average the AADB and AADP estimates for all the sites in each group.
8. Multiply centerline miles in each group by the average AADB and AADP for each group.
9. Sum these estimates and multiply by 365 to estimate the annual BMT and PMT.

We recommend that the next stage of the work estimate BMT and PMT using multiple approaches on the statewide level: count-based, survey-based, and sketch planning (or aggregate demand model, if possible). The methods should be compared and resulting magnitudes estimated. Additionally, if time and budget allow, choosing a pilot community on which the methods can be applied in more detail would be beneficial to identify the pros and cons of each. Potential pilot communities include Seattle and Bellingham.

INTRODUCTION

A key measure of motor vehicle traffic is vehicle miles traveled (VMT). No similar metric exists for bicycling and walking. For this reason, this report addresses how such a metric could be estimated. We start by examining how data from WSDOT's Bicycle and Pedestrian Documentation Project, referred to in this document as the State's Count Program, can be improved and used to inform estimates of bicycle miles traveled (BMT) and pedestrian miles traveled (PMT). The report also identifies other potential methods that could be used to compute BMT and PMT and presents the first steps toward creating such estimates.

Since 2008, WSDOT has worked with more than 30 cities to collect annual bicycle and pedestrian counts through the State's Count Program. These data, combined with continuous bicycle and pedestrian counts, can be used to estimate PMT and BMT in the state. PMT and BMT computed from counts can provide a performance metric for pedestrian and bicyclist traffic on facilities throughout the state and inform the update of the State's Bicycle Facilities and Pedestrian Walkways Plan.

Consistent with objectives identified in WSDOT's 2014-2017 Strategic Plan and the State of Washington Bicycle Facilities and Pedestrian Walkways Plan, this project is a step toward establishing a performance metric by which statewide progress with respect to bicycling and walking can be evaluated. Such a metric is in line with the Governor's accountability goal (Results Washington 2014).

This report summarizes the findings of the first and second phases of a project to create methods to estimate bicycle and pedestrian miles traveled for Washington State. The primary objective of the first phase of the work was to conduct a review of the motorized and non-motorized traffic monitoring literature, and examine the State's Count Program. The objective of the second phase was to create a method by which the State's Count Program, combined with other sources of information, can be incorporated into an estimation of bicycle and pedestrian miles of travel across the state.

These tasks were completed with the goal of quantifying bicycling and walking in the state. In this report, we summarize the methods, results, and findings of both phases.

REVIEW OF PREVIOUS WORK

The investigation of potential methods and comparison methods for calculating bicycle and pedestrian miles of travel (BMT/PMT) for Washington state encountered four relevant areas of the literature: pedestrian and bicyclist demand estimation methods, pedestrian and bicycle miles traveled estimates, motorized vehicle miles traveled (VMT) estimates, and analyses of factors that may impact bicycling and walking. While each of these areas contain too much work to fully detail, a summary of each area is included below. Note that information on the soon to be released National Cooperative Highway Research Program (NCHRP) 08-78 is not included, but results from the guidebook to be produced from this project (which aims to provide practical methods to estimate and forecast bicycling and walking) may provide input once they are released early in 2014 (Kuzmyak 2014 forthcoming).

PEDESTRIAN AND BICYCLE DEMAND ESTIMATION METHODS

A common approach to estimating non-motorized travel is to use survey data. Barnes and Krizek (2005) combined census data with data from the National Household Travel Survey (NHTS) to produce estimates of bicycling at different geographic levels (Barnes and Krizek 2005). This method of estimation, often referred to as sketch planning, usually relies on readily available data, making it simple to conduct. While census data only capture bicycling for the purpose of commuting, the researchers used commuting bicyclists as an indicator for the total amount of bicycling in an area.

A number of approaches were discussed in the NCHRP 07-14, “Guidelines for Analysis of Investments in Bicycle Facilities.” In addition to discussing methods for estimating non-motorized travel, the report also included original research. Researchers investigated the effects of proximity to bicycle facilities on mode choice. The study found that individuals living close to on-street bicycle facilities were more likely to bicycle on a given day than individuals living further away. However, proximity to off-road bicycle facilities did not impact the likelihood of bicycling (Krizek et al. 2005).

Building on the NCHRP report, researchers used its guidelines to develop an online tool to estimate the costs, benefits, and demand for new bicycle facilities. Demand was calculated using basic information about the area (demographics, densities, and bicycling rates) in conjunction with the research from the report on proximity to bicycle facilities.

Aggregate demand models have also been used to estimate levels of non-motorized travel. This type of model explains non-motorized travel through spatially varying explanatory variables such as income, gender, and the level of bicycling facilities. Inevitably, aggregate demand models omit numerous variables that influence non-motorized travel, limiting their effectiveness. Additionally, aggregate demand models tend to be very location specific, making it difficult to apply these models to other geographic areas (Hankey et al. 2012; Wang et al. 2013; Schneider et al. 2012; Landis 1996; Jones et al. 2010; Miranda-Moreno and Fernandes 2011; Pulugurtha and Sambhara 2011; Lindsey et al. 2007).

In recent years, more and more Metropolitan Planning Organizations (MPOs) have included non-motorized travel in their regional transportation models. However, the non-motorized components of these models often suffer from data collection and measurement problems. Validation of the accuracy of these methods is also rare and the volume estimates for locations where no data are available are likely to be highly inaccurate (Barnes and Krizek 2005; Singleton and Clifton 2013; Liu, Evans, and Rossi 2012).

PEDESTRIAN AND BICYCLE MILES TRAVELED LITERATURE

Estimates of bicycle and pedestrian miles traveled, using count data from a spatially representative sample, have been made at the city or county levels, but not at the state level (Davis and Wicklatz 2001; Dowds and Sullivan 2012; Molino et al. 2009). Researchers at the University of Minnesota working for Minnesota DOT used a sample-based estimation method to compute bicycle miles traveled (BMT) for three counties in the Twin Cities area (Davis and Wicklatz 2001). The study created their sampling methods by adapting the guidelines found in the Federal Highway Administration's Guide to Urban Traffic Volume Counting (GUTVC) to bicycling. Data were collected using manual counts of video recordings of the selected sites. Overall, the project found that sample-based methods for determining VMT can be modified to calculate defensible BMT estimates. Looking forward, the researchers concluded that it is possible, but likely expensive, to use their methods to compute statewide BMT estimates.

Researchers at the University of Vermont created BMT and PMT estimates for Chittenden County, Vermont (Dowds and Sullivan 2012). Their study produced eight estimates of annual bicycle and pedestrian miles traveled for the county. The different estimates were calculated using two different sets of adjustment factors and four types of classification systems for links in the bicycle pedestrian network. The adjustment factors were determined by using infrared-sensitive lens counters at three sites that produced full year continuous data. They concluded that while their estimates varied from 74 million to 296 million BMT and PMT per year, this range was still higher than the 32 million BMT and PMT computed based on the NHTS data.

Other efforts are currently underway to estimate bicycle and pedestrian miles traveled in states such as Minnesota (Minnesota Department of Transportation 2013; Lindsey et al. 2013), and a soon to be released NCHRP report should also shed light on the process (NCHRP 08-78)(Kuzmyak 2014 forthcoming).

VEHICLE MILES TRAVELED LITERATURE

To collect motor vehicle traffic data a combination of continuous and short duration counts are used. Continuous count data are collected through using permanent counters which are usually embedded in the roadway. Typically, continuous count sites have been strategically selected by transportation agencies in important travel corridors. The FHWA presents a methodology for selecting continuous count sites based on the objectives of the monitoring program.

"The number and location of the counters, type of equipment used, array, sensor technology, and the analysis procedures used to manipulate data supplied by these counters are functions of these objectives. As a result, it is of the utmost importance for each organization responsible for the implementation of the continuous count program to establish, refine, and document the objectives of the program. Only by thoroughly defining the objectives and designing the program to meet those objectives will it be possible to develop an effective and cost-efficient program."(Federal Highway Administration 2013b)

Short duration counts are needed to collect data over the entirety of the street network. To achieve this, the FHWA guidelines recommend dividing the street network into homogeneous traffic volume segments. As a general rule, the traffic volume on each segment should vary by less than 10 percent. A schedule must then be created to ensure that each segment is counted at least once every six years. Roads in rapidly changing areas should be counted more often. The length of short duration counts can last up to a seven day period, but should not be for less than 48 hours.

Kumapley and Fricker conducted a review of a number of methods of estimating VMT (Kumapley and Fricker 1996). The methods they reviewed included using fuel sales, odometer recordings, surveys, transit models, and traffic count data from the Highway Performance Monitoring System (HPMS) (Federal Highway Administration 2013a).

Using fuel sale data is one of the oldest methods for estimating VMT, and it has been used since the 1950s. This method is susceptible to a high amount of error as it relies on estimating the fuel efficiency and driving patterns of all vehicles on the nation's roads. As a result it should only be used for preliminary estimates of VMT. Odometer recordings can also be used to estimate VMT. However, it is highly resource-intensive, making it a seldom used method. Additionally, odometer readings are subject to a number of sources of error making it difficult to measure the accuracy of this method.

The HPMS method, the most widely accepted of all methods, uses a formula to convert annual average daily traffic (AADT) data into a VMT estimate. Roads are first classified into one of seven functional classes, ranging from local streets to interstates. They are then further classified as urban or rural, creating a total of 14 functional systems. AADT is estimated for each road segment and AADT values are multiplied by the length of the segment to calculate daily vehicle miles traveled (DVMT). Expansion factors are then used to calculate VMT over desired geographic area and timeframe. While the HPMS method is the most widely accepted method, it is not free from shortcomings. Bias in the selection of count sites and incomplete traffic data can lead to error in the estimates.

FACTORS THAT MAY IMPACT BICYCLING AND WALKING

Many studies have investigated the spatial factors that correlate with areas of high bicycling and walking. A recent thorough literature review on the topic was conducted as part of Transit Cooperative Research Program (TCRP) Report 95, Chapter 16 (Pratt et al. 2012). Understanding what the important factors are in predicting bicycling and walking is important to creating a method for estimating bicycle and pedestrian miles traveled because it allows the sampling framework for the estimate to be based on what actually is correlated with biking and walking. Without this knowledge it might be easy to simply sample by road type or other easily accessible roadway attributes.

Tables 1 and 2 summarize the variables analyzed and found to be significantly correlated with walking and bicycling either positively or negatively in various studies (Dill and Voros 2007; Jones et al. 2010; Miranda-Moreno, Morency, and El-Geneidy 2011; Schneider et al. 2012; Hankey et al. 2012; Griswold, Medury, and Schneider 2011; McCahil and Garrick 2008; Pulugurtha and Repaka 2008).

Table 1 – Spatial variables found to be significantly correlated with pedestrian activity

Variable	Relationship with Pedestrian Activity	Source(s)
Employment density within ½ mile	+	Jones, Ryan, et al. 2010
Population density within ¼ mile	+	Jones, Ryan, et al. 2010
Presence of nearby retail	+	Jones, Ryan, et al. 2010
Population density within 400 M	+	Miranda-Moreno, Morency et al. 2011
Commercial space within 50 M	+	Miranda-Moreno, Morency et al. 2011
Open space within 150 M	-	Miranda-Moreno, Morency et al. 2011
Presence of subway station	+	Miranda-Moreno, Morency et al. 2011
Number of bus stops	+	Miranda-Moreno, Morency et al. 2011
Number of schools within 400 M	+	Miranda-Moreno, Morency et al. 2011
% of major arterials within 400 M	-	Miranda-Moreno, Morency et al. 2011
Street segments within 400 M	+	Miranda-Moreno, Morency et al. 2011
Four-way intersection	+	Miranda-Moreno, Morency et al. 2011
Distance to downtown	-	Miranda-Moreno, Morency et al. 2011
Employment within ¼ mile	+	Schneider, Henry et al. 2012
Households within ¼ mile	+	Schneider, Henry et al. 2012
High parking meter activity zone	+	Schneider, Henry et al. 2012
Slope of any intersection approach	-	Schneider, Henry et al. 2012
Traffic signal present	+	Schneider, Henry et al. 2012
% Non-white	+	Hankey, Lindsey et al. 2012
% with 4 year degree	+	Hankey, Lindsey et al. 2012
Crime rate	+	Hankey, Lindsey et al. 2012
Land use mix	-	Hankey, Lindsey et al. 2012
Distance from water	-	Hankey, Lindsey et al. 2012
Distance from CBD	-	Hankey, Lindsey et al. 2012
Arterial street	+	Hankey, Lindsey et al. 2012
Collector street	+	Hankey, Lindsey et al. 2012
Principal arterial street	-	Hankey, Lindsey et al. 2012
Employment within ¼ mile	+	Pulugurtha, Repaka 2008
Population within ½ mile	+	Pulugurtha, Repaka 2008
Urban residential area ¼ to 1 mile	+	Pulugurtha, Repaka 2008
Transit stops within ½ mile	+	Pulugurtha, Repaka 2008
Mixed land use within ¼ mile	-	Pulugurtha, Repaka 2008
Single-family residential ¼ mile	-	Pulugurtha, Repaka 2008
Speed limit ½ to 1 mile	-	Pulugurtha, Repaka 2008

Table 2 – Spatial variables found to be significantly correlated with bicycle activity

Variable	Relationship with Bicycle Activity	Source(s)
% Non-White	+	Hankey, Lindsey et al. 2012
% with 4 Year Degree	+	Hankey, Lindsey et al. 2012
Median HH Income	-	Hankey, Lindsey et al. 2012
Land Use Mix	-	Hankey, Lindsey et al. 2012
Distance from CBD	-	Hankey, Lindsey et al. 2012
Road is an Arterial	+	Hankey, Lindsey et al. 2012
Employment Density within ¼ Mile	+	Jones, Ryan, et al. 2010
Footage of Class I Bicycle Path within ¼ Mile	+	Jones, Ryan, et al. 2010
Number of Commercial Properties within 1/10 Mile		Griswold, Medury et al. 2011
Distance from University (UCB)	-	Griswold, Medury et al. 2011
Slope of Terrain within ½ Mile	-	Griswold, Medury et al. 2011
Connected Node Ratio within ½ Mile	+	Griswold, Medury et al. 2011
% Age 18-55	+	Dill, Voros 2007
Proximity to Regional Trail	+	Dill, Voros 2007
Street Connectivity	+	Dill, Voros 2007
Distance to Downtown	+	Dill, Voros 2007
Population Density in Census Tract	+	McCahill, Garrick 2008
Employment Density in Census Tract	+	McCahill, Garrick 2008

Based on these studies some types of variables are found repeatedly. For both bicycling and walking, one of the most common groups of variables related to density of employment or population or proximity to a major attractor such as a downtown area or a university. Another group of variables is related to road or path type. For pedestrians, proximity to transit was a factor. For biking, slope of the roadway was found to be significant. All of these main variable categories should be included in the consideration of how to create a count program.

All of these studies were examining non-motorized travel on the city or regional level, not on the state level. On the state level, additional factors may become important, such as climate, topography, and cultural differences. Washington has many different geographic zones, from mountain areas near the coast and in the Cascade Range to flat to rolling plains in the east, not to mention the fertile farm and urban areas surrounding the Puget Sound. Climate in the state of Washington varies in terms of precipitation from the wet west to the dry east, and in terms of temperatures from the ocean and sound-moderated temperatures of the west to the more extreme cool and warm variations of the inland east (Figure 1 and 2). The impacts of climate on cycling and walking have been studied by many and the importance of grade on cycling is documented (Rodríguez and Joo 2004; Griswold, Medury, and Schneider 2011). Both geography and climate are likely to impact cycling and, to a lesser extent, walking.

To account for both geography and climate, the research team sought a regional classification that would account for the main categories of both. WSDOT has created a map of Eco-regions which categorize the regions of the state as shown in Figure 3. While the regions were created based on local vegetation, they also represent the major regions of climate and geologic variation throughout the state. For the purposes of the study of cycling and walking, we grouped these regions into four categories (Figure 4): Coast Range in the west, Puget Lowlands, Cascades, and Eastern Washington in the east.

Culture may also have an impact on bicycling and walking. Less is known about this. To our knowledge there has been no study of attitude toward cycling for the state of Washington, though there have been some studies at the city level (Piatkowski 2013). For this reason, cultural differences in attitude toward cycling across the state were not investigated further.

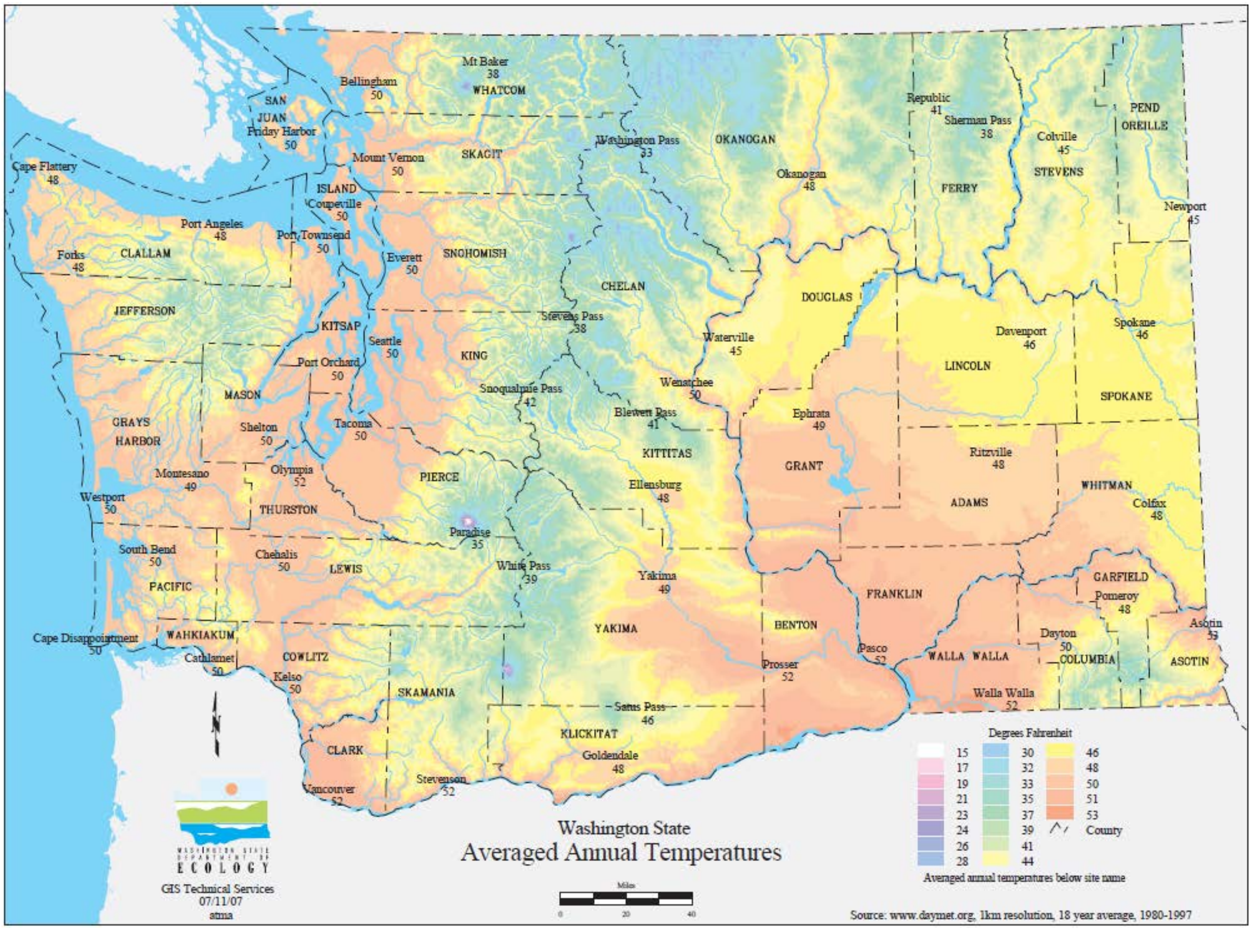

Figure 1 - Average Annual Temperatures in Washington State. (Washington State Department of Ecology 2007)

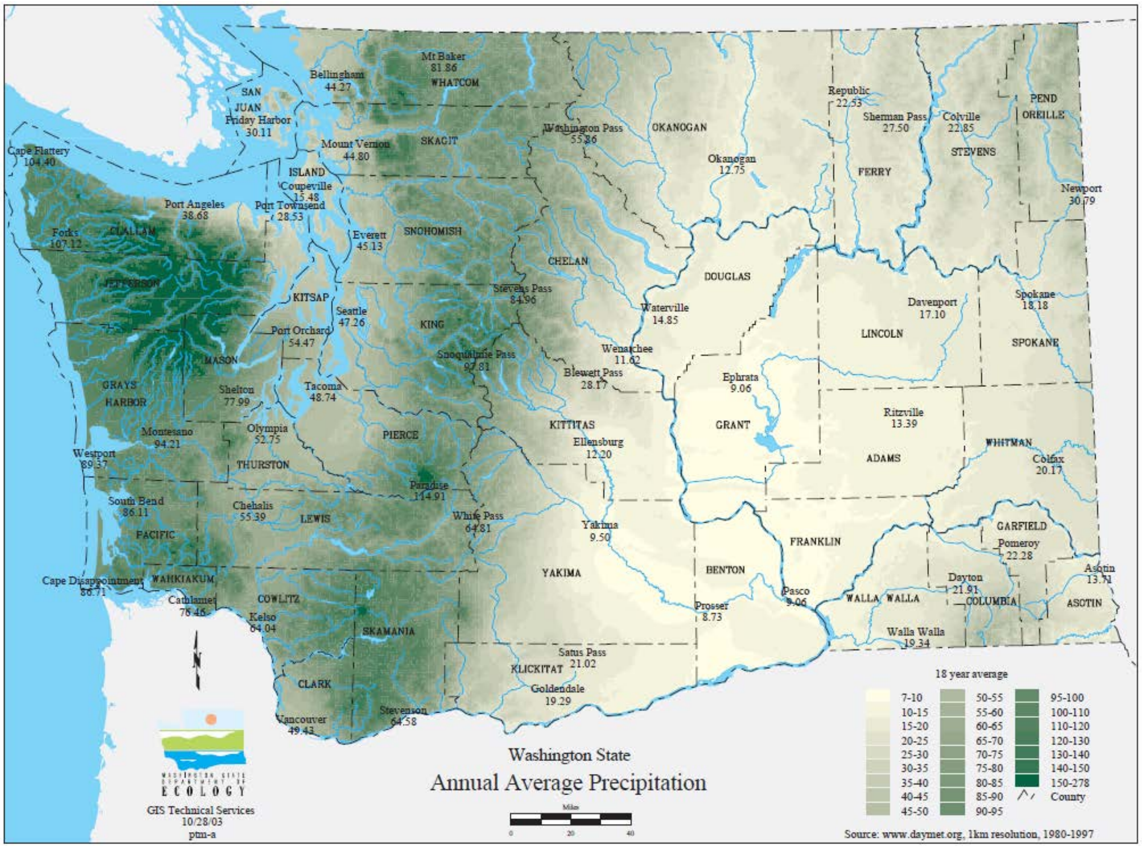

Figure 2 - Average Annual Precipitation in Washington State. (Washington State Department of Ecology 2003)

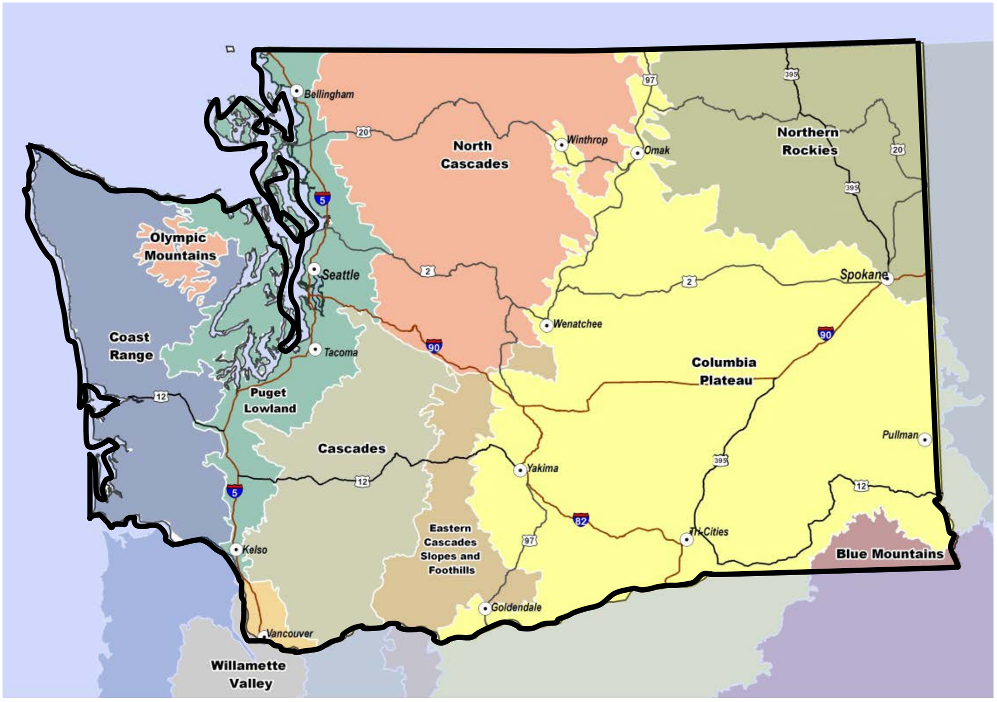

Figure 3 – Eco Regions. (WSDOT 2013)

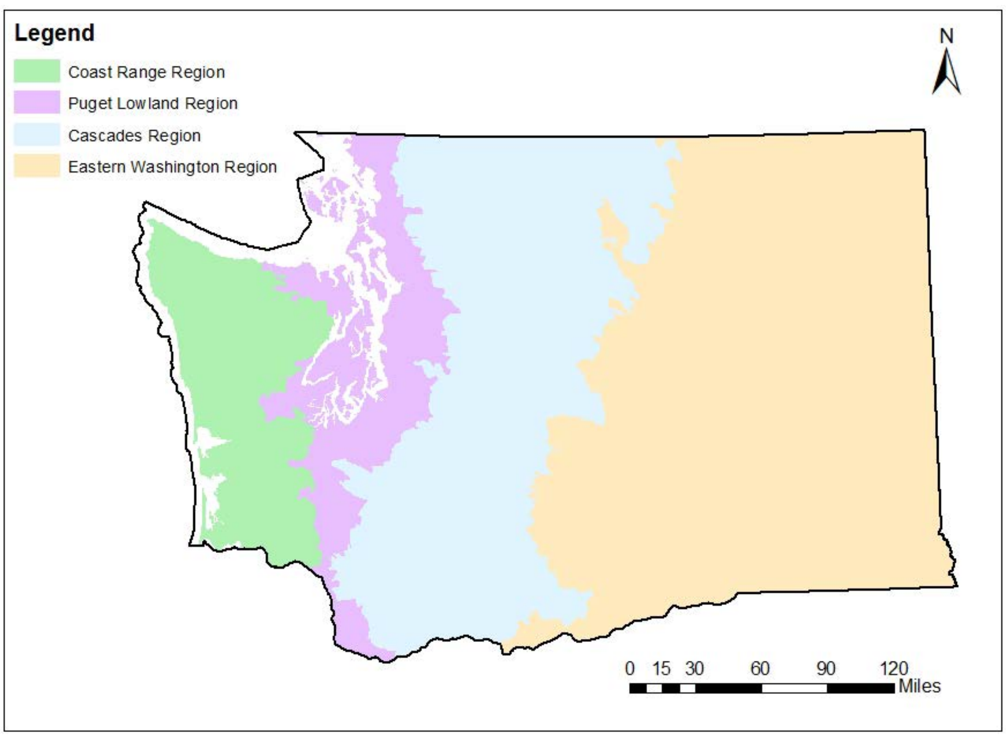

Figure 4 –Simplified Regions.

In summary, the following spatial attributes seem relevant to cycling and walking:

- Level of urbanism (population or employment density, distance to major attractor such as downtown, intersection density and other street network related variables).
- Road or path type.
- Proximity to transit, for walking.
- Slope, for biking.
- Geographic and climatic region.

RESEARCH APPROACH

This section discusses the available count data, the evaluation of the State’s Count Program for the purposes of estimating bicycle and pedestrian miles traveled, and the analysis of the existing counts. It then presents potential methods for computing bicycle and pedestrian miles traveled across the state.

IDENTIFICATION OF DATA SOURCES

At this time the following bicycle and pedestrian count data have been identified: data from the State’s Count Program, counts from the city of Seattle including two continuous counters, and counts from the city of Olympia using tube counters. Email was sent by WSDOT staff to multiple statewide lists requesting additional count data, but no such data were identified. The text of the email is reported in Appendix A.

WSDOT Bicycle and Pedestrian Documentation Project

The primary data source available is the State’s Count Program. According to the 2012 report on the program, prepared for WSDOT by the Cascade Bicycle Club, the documentation project has been ongoing since 2008 when it started with 19 communities and has expanded to 38 jurisdictions for the 2012 count (Cascade Bicycle Club 2013). In 2012, WSDOT facilitated the collection of bicycle and pedestrian data at over 300 locations in 38 jurisdictions shown in Figure 5. All of the data were collected over a three day mid-week period in September.

The report indicates that the program began in 2008 with 16 cities chosen using the following process:

"In 2008, WSDOT selected cities for bicycle and pedestrian counts on the basis of population and geographic distribution across Washington. The state was divided into four quadrants, and the largest cities were selected from each quadrant. The selection of cities was not equally distributed across each quadrant, given the greater population density in Western Washington. Thus, there were more cities selected in this part of the state. Initially, 16 cities were selected to conduct counts, with an additional three cities volunteering to provide counts at select locations within their city." (Cascade Bicycle Club 2013)

Data from the 2013 count program were collected on October 1, 2, and 3, 2013, and are still being compiled. According to the project webpage, counts were focused on 42 cities around the state (Washington State Department of Transportation 2013).

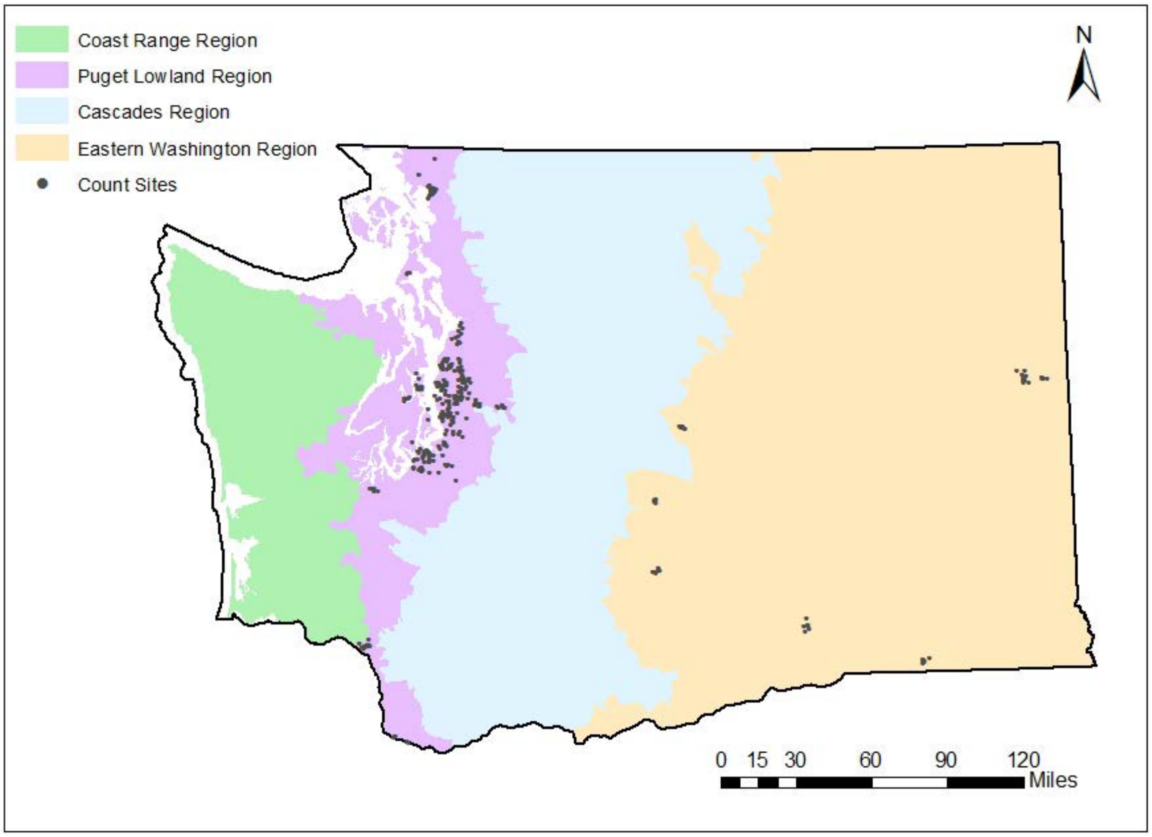

Figure 5 – Count Locations and Regions.

City of Seattle Count Data

The city of Seattle has conducted manual bicycle counts since 1992. This includes a more recent extended count program in conjunction with WSDOT and supplementing the statewide program. Manual counts have been conducted quarterly at 50 locations around the city since 2011 (Seattle Department of Transportation 2013a). The quarterly counts are conducted in January, May, July, and September as recommended by the National Bicycle and Pedestrian Documentation Project (NBPDP), at the following times: 5:00 PM to 7:00 PM and 10:00 AM to noon on weekdays, and noon to 2:00 PM on Saturdays. These data are available on the city's website.

Additionally, in October 2012, the city installed its first continuous bicycle count station on the Fremont Bridge. A second such counter was later installed on an access path on the east end of the Spokane Street Bridge (Seattle Department of Transportation 2013b).

City of Olympia

Since 2008, the city of Olympia counts bicyclists using portable pneumatic tube counters on paths and roadways for seven-day continuous periods at each location (Lindsey 2013). In 2008 the city counted at 9 locations and increased this to 17 locations in subsequent years and 19 locations in 2012. The city conducts counts three times per year in March, June, and October. The equipment used is commonly used to count motor vehicles, and the manufacturer (TimeMark™) claims that it can also be used to count bicycles, but independent verification has not confirmed this. The city reports counts in terms of average daily count per location by month and year.

EVALUATION OF THE STATE'S COUNT PROGRAM

In order to recommend potential improvements for the State's Count Program, the program was evaluated based on its ability to provide repetitive samples to inform estimates of bicycle and pedestrian miles traveled. Two aspects of this were considered separately: the spatial distribution of the program and the temporal distribution of counts. Each is addressed separately below.

Spatial Distribution

The State's Count Program provides a sample of the spatial variation across the state. The 16 initial cities were chosen to represent four quadrants of the state, but were more heavily weighted toward large urban areas. Specific count locations within each city were up to the discretion of the local organizer. The State's Count Program with over

40 participating jurisdictions represents a larger spatial extent than most other state-run bicycle and pedestrian count programs in the country, though other states are in the process of creating or expanding their programs. This purposed-based sampling methodology is successful in sampling urban areas across the state.

The end goal of this line of research is to create a method by which to estimate the BMT and PMT across the state of Washington. Toward that end, we have identified five spatial attributes which the literature identifies as important to bicycle and pedestrian traffic as listed above. From these, a representative sampling framework can be established. For example, Table 3 details a set of potential attributes that could be used to divide all the possible locations where one could count bicyclists and pedestrians in the state of Washington into 32 categories for cyclists and 32 categories for pedestrians from which a sample could be taken.

How do the existing count locations fit into these categories? Most if not all of the existing counts are in urban areas by design. The locations do represent a spectrum of road types, access to transit, and slope. However as shown in Figure 5, all of the existing locations are either in the Puget Lowland or Eastern Washington, and none are in the Coast Range or the Cascades. While this makes sense, since there is a higher concentration of people and hence cyclists and walkers in the non-mountain areas, it leaves us with no way to estimate bicycle and pedestrian volumes in the sparsely populated areas of the state. Such non-motorized travel would include recreational trips, which may generate revenue for local communities from tourists visiting from other areas of the state and beyond.

Table 3 - Potential Sampling Groups for Bicycle and Pedestrian Count Locations

Attribute	Recommended Categories	Number of Categories	Readily available in GIS?
Level of urbanism	Urban Rural	2	Yes (through roadway types)
Road or path type	Arterials & highway, Local Roads, Collectors, & Paths	2	Yes, but not all paths are in the State's GIS
Proximity to transit (walking only)	Transit Route within 0.5 mile No Transit Route	2	Not all transit routes.
Slope (cycling only)	Greater than a given percent grade Less than a given percent grade	2	No, but could be determined.
Geographic and climatic regions	Coast Range Puget Lowland Cascades Eastern Washington	4	Yes.

Ideally, a random sample would be taken from each of the sampling groups. However, due to political, organizational, and practical constraints, this is rarely achieved in the area of traffic counting. Also, abandoning existing count sites is to be avoided so as not to interrupt the historical record. However, as more permanent count sites become available, they will be able to better record changes over time allowing short duration count sites to be counted every other year or on a three or even six year rotation as is common in motor vehicle counting programs. Since a network of such permanent count stations has not yet been established, abandoning or rotating existing count sites is not recommended at this time.

Since multiple count sites would theoretically be needed in each of the sampling groups, this random stratified sampling approach would require a greatly expanded count program. This would be difficult if the all-volunteer program is the sole source of data. For this reason, the recommended program is a simplified version of this approach.

Instead of the full 32 categories from Table 3, we recommend that count stations be sampled from the following categories.

- By level of urbanism (2 categories): Urban and Rural
- By facility type (2 categories): Highway/Arterial and Other
- By geographic and climatic regions (4 regions): Coast Range, Puget Lowland, Cascades, Eastern Washington

The full set of 16 sampling groups needed for the above categories are detailed in Table 4 and the number of count stations currently available in each category is estimated. Figure 6 shows the existing count sites by region with urban areas identified, clearly showing that most count sites are in urban areas.

Table 4 - Recommended Sampling Groups for Bicycle and Pedestrian Count Locations

Sampling Groups			Number of Continuous Stations Available	Stations Available in State's Count Program
Region	Level of urbanism	Road/Path Type		
Coast Range	Rural	Arterial/Highway	0	0
	Rural	Local/Collector/Path	0	0
	Urban	Arterial/Highway	0	0
	Urban	Local/Collector/Path	0	0
Puget Lowland	Rural	Arterial/Highway	0	1
	Rural	Local/Collector/Path	0	0
	Urban	Arterial/Highway	1	157
	Urban	Local/Collector/Path	1	99
Cascades	Rural	Arterial/Highway	0	0
	Rural	Local/Collector/Path	0	0
	Urban	Arterial/Highway	0	0
	Urban	Local/Collector/Path	0	0
Eastern Washington	Rural	Arterial/Highway	0	0
	Rural	Local/Collector/Path	0	0
	Urban	Arterial/Highway	0	37
	Urban	Local/Collector/Path	0	6
			Total	304
Note: There are 13 count sites for which the location is ambiguous or unknown.				

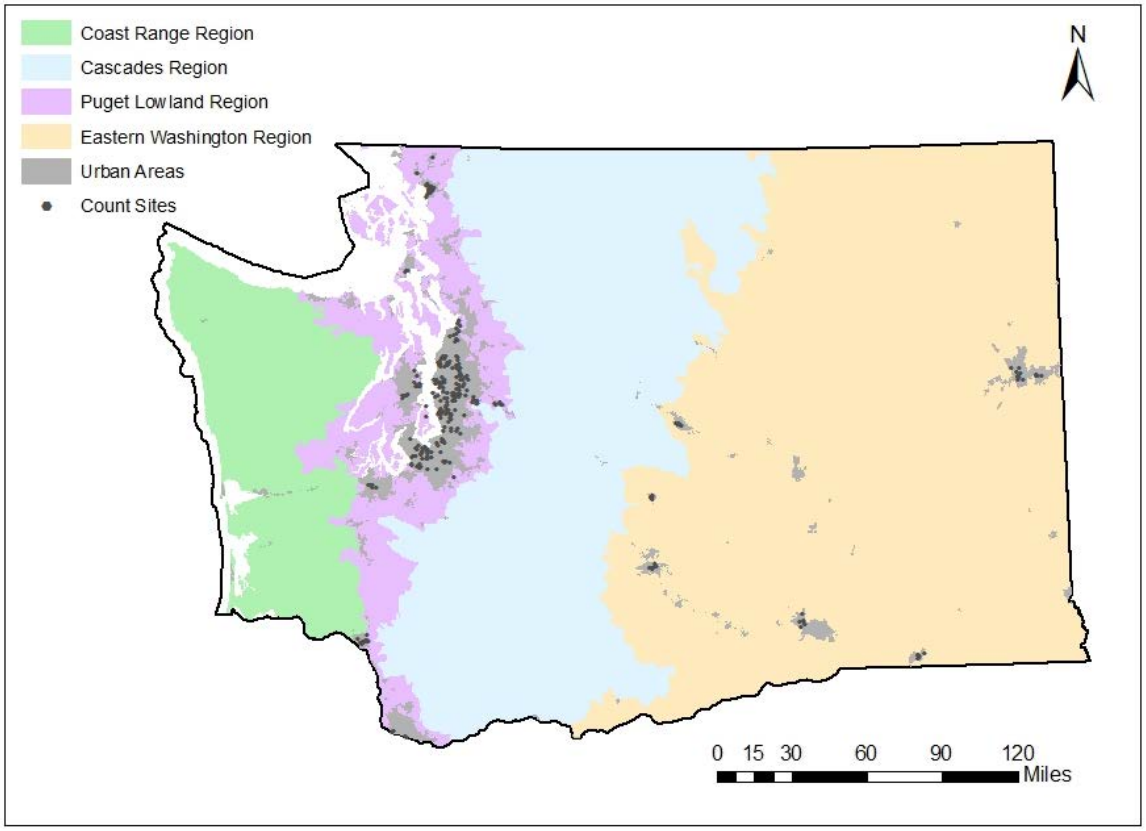

Figure 6 – Count Locations by Region with Urban Areas Identified.

The combinations of the above categories theoretically result in 16 groups of possible locations from which to sample. For practical reasons, fewer sites would be collected in areas with less bicycle and pedestrian activity, though statistically more would be desirable. More counting stations would ideally be needed in areas with less activity because in such areas traffic volumes are likely to be more variable. We recommend expanding the areas where counts are conducted to include rural and mountain areas. Such areas may have lower volumes than in the city, but other states have seen that rural volumes are often higher than expected.

Another way to reduce variability is to collect more than two hours of count data at each location. Ideally at least seven days of count data would be obtained in order to capture weekly variation (Nordback et al. 2013). However, if only two hours of counting can be done at each location, the state has chosen one of the times most likely to give good estimates of AADT if appropriate factors are computed (Nordback 2012).

Temporal Variation

While spatial variation of bicycle and pedestrian travel is an important aspect of estimating bicycle and pedestrian miles traveled for the state, understanding temporal fluctuation is also important in order to obtain a reasonable estimate of annual average daily non-motorized traffic at each count location.

The current State's Count Program tries to eliminate the need for any adjustment to the average day of the year by counting on weekdays during the same representative day of the year every year. While the days of the year chosen are usually the most advantageous for this purpose, in some years weather conditions are unfavorable and result in reduced counts on the predefined days. Without adjustment this would lead to a full year of reduced bicycle or pedestrian miles traveled for the state. For this reason, it is important to be able to adjust the counts for time of day and day of year using continuous count data from the state.

This process inherently includes adjustment for weather as long as the continuous count data from which the factors are created share the same weather. To understand seasonal variation, the addition of at least one automatic counter in each of the 16 identified groups would be helpful. These counters provide full year continuous data and are essential for determining seasonal and day-of-week adjustment factors. Even if the counters were inaccurate, their data can still be used if the counts are proportional to the actual pedestrians or bicyclists, since it is the relative change in volume over time that is of interest from these, not the absolute volumes.

If continuous count data were available, this would allow volunteers to count any peak hour Tuesday, Wednesday, or Thursday in the higher volume months, generally May through October, instead of being restricted to just one week in September or October. This would be possible because each day could be adjusted using appropriate factors computed from the continuous counters. These factors would account for changes by month and day of the week.

METHODS TO ANALYZE TEMPORAL VARIATION OF COUNT DATA

Counts from the State's Count Program, the city of Olympia, and the city of Seattle were processed and analyzed. This section describes the methods used to analyze the data. Since one of the primary data sources is manual two hour count data, some method for estimating the average day based on two or more peak hours of count data was needed.

Seasonal, daily and hourly adjustment factors were computed using the one year of available data from Seattle's Fremont Bridge continuous bicycle counter. This is the only permanent non-motorized traffic counter with a full year of available data that we are aware of in the state. While applying such factors to all sites in the city of Seattle and beyond is not appropriate, these factors were used as a placeholder until better data become available.

One full week of continuous hourly bicycle count data was available at 19 locations around the city of Olympia. The annual average daily bicyclists was estimated at each location for 2012 using the monthly adjustment factors computed from the Seattle data to demonstrate how this can be done. Hourly and daily patterns were plotted as a function of percent of annual average daily traffic. Volumes at all locations were less than 200 bicyclists per day, but the city did not provide an error adjustment factor to account for any over or undercounting, so this may not correctly represent the volumes at these locations in Olympia.

The following section details the computations used in this process.

Computing Annual Average Daily Traffic at Permanent Count Sites

The data were provided by Seattle Department of Transportation in hourly increments from October 2, 2012 to September 30, 2013. The counter records bicycle crossings on the bridge in both directions. No continuous record of pedestrian counts was available.

Annual average daily bicyclists (AADB) were computed using the AASHTO method (AASHTO 1992) for computing annual average daily traffic (AADT). In the description of the method below, the acronym AADT is used, but it could be replaced by AADB or annual average daily pedestrians (AADP) as appropriate. The AASHTO procedure of determining AADT using continuous counts is as follows:

1. Calculate the average for each day of the week for each month to derive each monthly average day of the week.
2. Average each monthly average day of the week across all months to derive the annual average day of the week.
3. The AADT is the mean of all of the annual average days of the week.

The formula for the AASHTO method for determining AADT is:

$$AADT = \frac{1}{7}\sum_{i=1}^{7}\left[\frac{1}{12}\sum_{j=1}^{12}\left(\frac{1}{n}\sum_{k=1}^{n} DT_{ijk}\right)\right] \quad (1)$$

where

DT= daily traffic for day *k*, of day of the week *i*, and month *j*

i = day of the week

j = month of the year

k = index to identify the occurrence of a day of week *i* in month *j*

n = the number of occurrences of day *i* of the week during month *j*

Estimating Annual Average Daily Traffic at Short Duration Count Sites

For the rest of the count sites across the state the AADB/AADP was not known and had to be estimated. Estimates were made by adjusting the short duration counts collected by either the monthly or daily/hourly adjustment factors.

Computing Adjustment Factors

Monthly and daily/hourly adjustment factors were computed using the one year of available data from Seattle's Fremont Bridge continuous bicycle counter, the only permanent bicycle or pedestrian counter with a full year of data identified in the state.

Monthly Average Daily Traffic (MADT) was calculated for each month by averaging the average daily count for each day of the week in that month as detailed in Equation 2 below.

$$MADT_j = \frac{1}{7}\sum_{i=1}^{7}\left[\frac{1}{n}\sum_{k=1}^{n} DT_{ijk}\right] \quad (2)$$

where

$MADT_j$ = Monthly Average Daily Traffic

The average daily traffic (ADT) for each day of the week was computed separately for each month as:

$$ADT_{ij} = \frac{1}{n}\sum_{k=1}^{n} DT_{ijk} \qquad (3)$$

where

ADT_{ij} = Average daily traffic for day i of the week in month j.

Hourly averages were computed for hours in which short duration counts were made, specifically for each month of the year:

- Tuesdays, Wednesdays, and Thursdays (TWR) from 7:00 AM to 8:00 AM
- TWR from 8:00 AM to 9:00 AM
- TWR from 10:00 AM to 11:00 AM
- TWR from 11:00 AM to 12:00 PM
- TWR from 4:00 PM to 5:00 PM
- TWR from 5:00 PM to 6:00 PM
- TWR from 6:00 PM to 7:00 PM
- Saturdays from 10:00 AM to 11:00 AM
- Saturdays from 11:00 AM to 12:00 PM

$$HT_{hj} = \frac{1}{m} \sum_{l=1}^{m} HT_{hjl} \quad (4)$$

where

HT_{hj} = hourly count for month j and hour-day combination h

h = one of the nine hour-day combinations listed above during which manual counts were conducted

m = the number of occurrences of one of the nine hour-day combinations listed above during month j

l = index to identify the occurrence of hour-day combination h in month j

The monthly factors were then calculated by dividing AADT by MADT.

$$M_j = \frac{AADT}{MADT_j} \quad (5)$$

where

M_j = monthly adjustment factor

Next, daily factors, D_{ij}, for each month were calculated. This was done by dividing *MADT* by the average number of crossings on a given day of the week in that month as shown in Equation 6. For example, the daily factor for a Monday in January was derived by dividing the *MADT* for January by the average number of crossings on a Monday in January. This produced a total of 84 daily factors (12 months x 7 days).

$$D_{ij} = \frac{MADT_j}{ADT_{ij}} \tag{6}$$

where

D_{ij} = daily expansion factor for day i of the week in month j

Finally, hourly factors by month were created for the hours that Seattle Department of Transportation (SDOT) and WSDOT conduct bike count collections. The following steps were used to create the hourly factors:

1. Calculate the average number of cyclists for each hour of the day by day of the week and month.
2. Calculate adjustment factors for Saturday. This was accomplished by dividing the MADT for each month by the corresponding hourly average traffic for that month. For example, the expansion factor for a Saturday at 10–11:00 AM in January is equal to January AADT divided by the average traffic for a Saturday at 10–11:00 AM in January. This process was repeated for 11:00 AM–noon, and then for each month.
3. Calculate weekday adjustment factors. For the weekday factors, hourly averages for Tuesday, Wednesday, and Thursday were averaged to create a weekday average. MADT is then divided by the weekday average of the desired hour in the corresponding month to produce the expansion factor.

$$H_{hj} = \frac{MADT_j}{HT_{hj}} \qquad (7)$$

where:

H_{hj} = hourly/daily adjustment factor for hour-day combination h in month j

Note that as defined above the daily adjustment factor (D_{ij}) and the hourly/daily factor (H_{hj}) should not both be applied. If a full 24 hours of short duration count data are available, the daily adjustment factor should be applied in combination with the monthly factor M_j. If only one or two hours of count data are available, the hourly/daily factor should be applied in combination with the monthly factor.

Computing AADT Using Adjustment Factors

To compute AADT using one full continuous week of count data, multiply the average daily count by the monthly factor as shown in Equation 8.

$$AADT = M_j \times \frac{1}{7}\sum_{i=1}^{7} DT_{ij} \qquad (8)$$

where

DT_{ij} = the observed non-motorized traffic volume during a 24-hour period, midnight to midnight, on day of the week i in month j.

To compute AADT using 24 hours of count data, multiply the full 24-hour count by the monthly factor and the daily factors as shown in Equation 9.

$$AADT = DT_{ij} \times M_j \times D_{ij} \qquad (9)$$

To compute AADT using one hour of manual count data (during one of the nine standard count times listed), multiply the bicyclists and/or pedestrians observed during the one hour time period by the monthly factor and the hourly factor as expressed in Equation 10.

$$AADT = HT_{hj} \times M_j \times H_{hj} \qquad (10)$$

where

HT_{hj} = the observed non-motorized traffic volume during a one-hour period

If more than one hour or day of count data is available, estimate AADT for each period and average the resulting estimates.

METHODS TO ESTIMATE BMT AND PMT

Based on the review of the literature, there are several types of approaches to estimating BMT and PMT and these are usually implemented at the local level. No such estimates were found at the state level. Methods include approaches based on national or regional survey responses and approaches based on count data using a sampling approach. In addition to these approaches, there are sketch planning approaches, aggregate demand models, and approaches based on origin-destination models.

Survey-Based Method

BMT and PMT can be estimated based on the responses to questions in the National Household Travel Survey (NHTS), but this approach requires broad assumptions, and has been found by others to underestimate bicycle miles traveled (Dowds and Sullivan 2012). Dowds and Sullivan created their NHTS-based estimate by incorporating "person-trip weights" in an effort to correct for survey bias.

Kumapley and Fricker report a method of estimating VMT based on national survey data by multiplying number of licensed drivers for each gender and age cohort by estimated average miles traveled for that type of survey respondent. They caution that this method is highly affected by survey bias (Kumapley and Fricker, 1996).

Many have made estimates of avoided VMT including studies specific to the state of Washington (Frank et al. 2011; Moudon and Stewart 2013). Some of these estimates have computed bicycle or pedestrian miles traveled as a step in the calculation process. An early example of this was a study of the environmental benefits of cycling and walking which quantified the bicycle and pedestrian miles traveled (Federal Highway Administration 1993). This study used data from national travel surveys including the National Personal Transportation Study to estimate the number of cyclists and pedestrians making trips of five types: commuting, personal, commercial, recreational, and child-related. The typical number of miles traveled for each trip type and days per year of walking and cycling were estimated from various sources. The resulting computation estimated 21,300 million to 5,000 million bicycle miles traveled and 44,100 million to 20,000 million miles walked in the United States in 1991.

A more recent computation was conducted as part of the Non-motorized Transportation Pilot Project (NTPP) (Federal Highway Administration 2012). This report documents a method developed by the Volpe Center referred to as the "NTPP Model" which uses NHTS mode share data and uses changes in count data over time to estimate changes in bicycling and walking mode share, but only computes averted VMT not bicycle and pedestrian miles traveled. The report documents the lack of accepted methods for these computations.

Count-Based Method

BMT and PMT could be estimated using count data if all facilities were counted or if counts were representative of the sampled groups. The current count data were not randomly sampled, but such a sampling method is suggested in this report. Below is an outline of this proposed method as applied to the state of Washington.

1. Identify sampling framework: all road and path segments in the state.
2. Determine appropriate groups: 16 groups were chosen based on the following attributes commonly found in the literature.
    a. By level of urbanism (2 categories): Urban and Rural
    b. By facility type (2 categories): Highway/Arterial and Other
    c. By geographic and climatic regions (4 regions): Coast Range, Puget Lowland, Cascades, Eastern Washington
3. Randomly sample sites from each group and collect short duration counts at each site.
4. Compute seasonal, daily and hourly adjustment factors based on continuous count data.

5. Apply factors to short duration counts to estimate annual average daily bicycle and pedestrian traffic (AADB and AADP) at each site.
6. Total the centerline miles in each of the groups.
7. Average the AADB and AADP estimates for all the sites in each group.
8. Multiply centerline miles in each group by the average AADB and AADP for each group.
9. Sum these estimates and multiply by 365 to estimate the annual BMT and PMT.

This method can also be stated mathematically as follows for bicyclists and pedestrians.

$$BMT = 365 \times \sum_{p=0}^{16} \left(\frac{L_p}{m_p} \sum_{q=0}^{m} AADB_{pq} \right) \qquad (11)$$

$$PMT = 365 \times \sum_{p=0}^{16} \left(\frac{L_p}{m_p} \sum_{q=0}^{m} AADP_{pq} \right) \qquad (12)$$

where

BMT = Bicycle miles traveled in the state

PMT = Pedestrian miles traveled in the state

AADB = Estimated annual average daily bicyclists at a given count site *q* in group *p*

AADP = Estimated annual average daily pedestrians at a given count site *q* in group *p*

L_p = the total centerline miles for each group *p*

m_p = the number of count sites in group *p*

p = a counting variable indicating one of the 16 groups into which the roads, paths and count sites of the state have been divided by region, urbanity and facility type as described above

q = a counting variable indicating one of the counting sites in group *p*

Re-evaluation of Groups

In the future, it may be appropriate to subdivide the existing 16 groups differently for bicyclists and pedestrians. For example, proximity to transit has already been identified as a variable that impacts pedestrian volumes. The existing 16 groups might be further divided into those that are close to transit and those that are not. This would increase the number of groups to 32 for pedestrians, but may improve accuracy. It may also be redundant with the urban vs rural categorization, so it may not improve accuracy sufficiently. This is just an example of what should be considered as the project progresses.

Additionally, as more count data become available, the groupings presented in this report should be re-evaluated. Are the AADB/AADP estimates for each group similar in magnitude? If not, additional subgroups may be needed or the existing groups may be joined. For example, if the magnitude of estimated AADB seems independent of the facility type but is significantly higher for urban areas than rural, the grouping by arterial/highway and other might be removed. Similarly, if suburban locations seem significantly different than either urban or rural locations, the WSDOT should consider adding a grouping for suburban locations.

Sketch Planning and Aggregate Demand Methods

As discussed in prior sections, most aggregate bicycle and pedestrian demand estimation models have been focused on the local level, estimating use in a specific community. Their applicability beyond the communities in which they were created is suspect and many of the variables used, such as number of bus stops or distance to the ocean, would be more difficult to use and less applicable on the state level. Multiple sketch planning efforts have also focused on the local or facility levels, such that these also do not offer an easy way to be applied at the state level. While some help might be offered by the forthcoming NCHRP 08-78, discussion with the authors suggests that its findings are also most relevant to the local level, and might be difficult to scale up to the state level.

Since the existing models do not seem applicable at the state level, for the purposes of the next phase of research it may be best to use the data from the State's Count Program to create a model based on variables readily available statewide, such as population or employment density, region, facility type, road network density and/or other available data. This Washington-specific model might provide a rough method applicable at the state level.

Travel Demand Models

While some jurisdictions have begun to include bicycling and walking in their regional travel demand models (Singleton and Clifton 2013), using such a model at the state level would be challenging and is beyond the scope of this project. A simplified origin and destination approach employed by Lowry has been shown to produce valid bicycle volume estimates at the facility level (McDaniel, Lowry, and Dixon 2014).

However, this method is best used at the local level. While it is not appropriate for the state level at this time, it might be useful if a pilot study of one community is conducted.

Comparing Methods

The count-based method could provide more information on the facility level than approaches based on survey data, but the survey methods may be simpler to compute and require less detailed data than the origin-destination methods, which might be more appropriate on the local level.

To compare these methods, we suggest the following strategy:

- Compute BMT and PMT statewide using three methods: the count-based method using estimated and assumed values where no data are available, a sketch planning method (or aggregate demand model, if possible), and a survey-based method. Particular attention should be paid to developing the count-based methods and identifying recommendations for future work to improve the method and provide better input data to it.
- Choose a study city in which to pilot the methods. This will allow a finer grained estimate so that the pros and cons of each method can be compared more clearly. Potential pilot cities include Seattle and Bellingham.

FINDINGS

The project team is beginning the first steps toward estimating BMT and PMT using the count-based method outlined in the previous section. In this report we summarize the analysis of the existing data, creation and application of seasonal adjustment factors, and estimation of centerline miles in each of the 16 categories chosen.

ANALYSIS OF EXISTING COUNT DATA

Counts from the city of Seattle were used to estimate monthly and daily/hourly seasonal adjustment factors as described in the previous section. These seasonal and daily/hourly adjustment factors were then applied to the short duration counts in both the Seattle and statewide count program to illustrate how estimates of the annual average daily bicyclists and pedestrians (AADB/AADB) could be made.

Limitations

It is not appropriate to apply these factors to all the locations in the city of Seattle because many locations are likely to have patterns that differ from the highly commute-related patterns observed on the Fremont Bridge. It is even less appropriate to apply these factors to locations around the state which experience different climate, school schedules and work patterns than those in the Seattle area. It is also not appropriate without further information to apply factors computed for bicyclists to pedestrian traffic which is known to often exhibit different behavior at the same locations (Nordback, Marshall, and Janson 2013). However, no other factors were found that would be more appropriate. For this reason, please, consider this calculation not as an accurate estimation, but as a placeholder to demonstrate how the appropriate factors would be used in the future when more data are available and appropriate climate-specific factors can be computed.

Adjustment Factors

Using the methods for computing adjustment factors detailed in the previous section, the following factors were computed using the Seattle Fremont Bridge data (October 2012 to September 2013). The Annual Average Daily Bicyclists (AADB) for this time period is 2,461 computed using the AASHTO method detailed in the Research Approach section of this report. No other permanent count locations were identified with which to compute such factors, and no permanent pedestrian count data were available. Table 5 lists the monthly factors and Table 6 lists the daily/hourly factors developed using the Fremont Bridge data using the methods detailed in the Research Approach section of this report.

Table 5 - Monthly Adjustment Factors for 2012-2013 Seattle Commute Patterns

Month	Monthly AADB	Factor
January	1,448	1.7
February	1,787	1.4
March	2,132	1.2
April	2,400	1.0
May	3,502	0.7
June	3,237	0.8
July	3,806	0.6
August	3,373	0.7
September	2,691	0.9
October	2,254	1.1
November	1,688	1.5
December	1,173	2.1

Table 6 - Daily/Hourly Adjustment Factors for 2012-2013 Seattle Commute Patterns

	7-8 AM Week-day	8-9 AM Week-day	10-11 AM Week-day	11-Noon Week-day	4-5 PM Week-day	5-6 PM Week-day	6-7 PM Week-day	Noon-1 PM Satur-day	1-2 PM Satur-day
January	9.0	6.1	26.5	32.3	11.0	5.5	8.1	28.3	21.0
February	8.8	6.0	28.4	33.4	11.2	5.4	7.8	17.1	16.3
March	9.9	7.1	29.4	39.3	13.2	6.3	8.6	13.9	12.5
April	8.2	6.2	25.7	31.4	10.0	5.3	6.7	26.9	33.1
May	8.7	6.7	29.9	41.0	12.1	5.6	7.5	21.4	17.5
June	9.3	7.1	27.8	34.8	11.4	5.7	7.3	16.2	14.4
July	10.3	7.5	25.7	33.9	12.0	6.2	7.9	19.2	18.0
August	9.8	6.8	24.6	33.4	11.7	5.7	7.1	22.1	19.8
September	8.7	5.8	23.7	31.6	10.8	4.9	6.2	27.6	24.5
October	14.5	15.2	17.4	17.0	14.4	15.3	22.0	25.1	22.8
November	8.1	5.8	24.0	31.0	9.4	5.5	8.4	17.0	19.9
December	8.6	5.6	24.2	33.6	10.1	5.3	8.3	24.7	25.1

For locations other than the Fremont Bridge, the AADB was estimated by applying the monthly and daily/hourly factors listed above to the short duration counts available. For Seattle, both factors were needed since the short duration counts were composed of manual two hour counts. Since these counts were taken at multiple time periods throughout the year, they could be averaged. At most locations in Seattle, peak hour (5 to 7 PM), off-peak and weekend 2-hour counts were collected during four times per year (January, May, July, and September as recommended by the National Bicycle and Pedestrian Documentation Project) at each of the 50 locations included in the count program. The factors were applied to each count and averaged for each month and then averaged for the year. The average estimated AADB is shown by month and by location in Figure 7, with the thick black line indicating the average AADB estimate over the year. Estimates range from just 35 bicyclists per day at the intersection of Martin Luther King Way and South Othello Street to 1905 bicyclists per day at the intersection of Fremont Ave and 34th St.

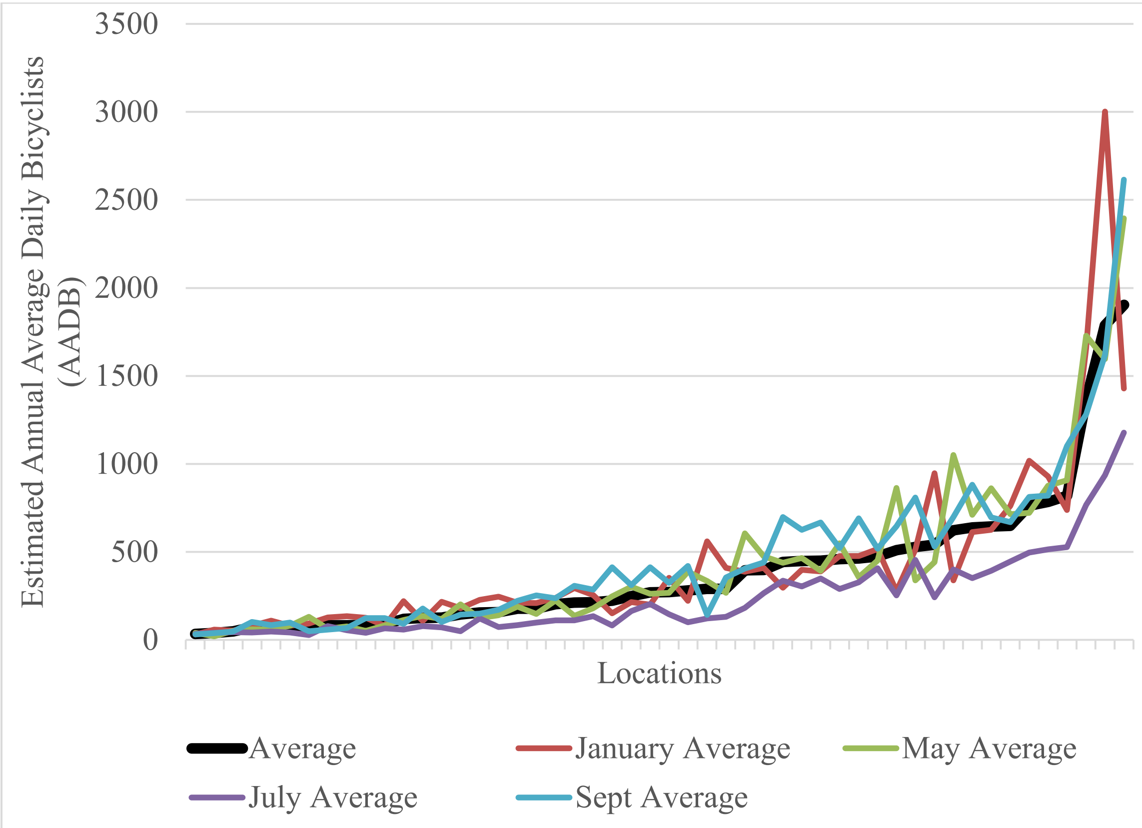

Figure 7 - Estimated AADB at 50 Sites in Seattle in 2012

The Olympia bicycle volume data consisted of at least one week of continuous counts per location. By multiplying by the monthly adjustment factor computed from the Seattle continuous count data, estimates of AADB were obtained for each of the 10 sites counted in July 2012. While applying Seattle factors to Olympia data is not the best practice, this illustrates how the method could be used if Olympia-specific factors were available. The resulting AADB estimates are shown in Figure 8. All of the Olympia sites have relatively low AADB estimates, with less than 200 bicyclists per day.

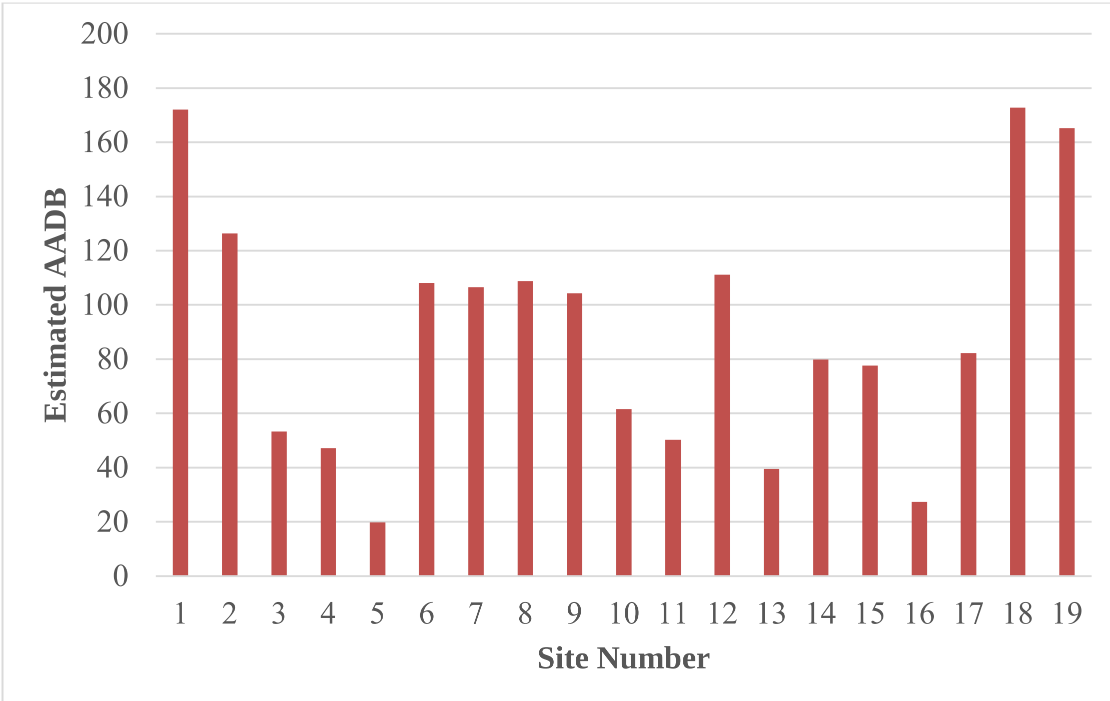

Figure 8 - Estimated AADB at 19 Sites in Olympia, Washington in 2012

To understand hourly, daily and monthly traffic patterns, the bicycle volumes per hour and per day were plotted as a percent of the annual average daily bicyclists (AADB). These patterns are discussed in the following three subsections.

Hourly Variation

To understand how bicyclist traffic varies over the hours of the day, data from Seattle and Olympia were plotted as a percent of AADB. No such data were available for pedestrians.

For the Fremont Bridge, the patterns were grouped by work days vs. weekend and summer vs. winter. Federal holidays were removed from the workdays. Because May through September have higher than average bicycle volumes at this site, these “summer” months were plotted separately. For convenience, “winter” months were defined as October through April. The resulting patterns are shown in Figure 9, which shows that workdays exhibit a strong commuter pattern with peaks from 8:00 AM to 9:00 AM and 5:00 PM to 6:00 PM, while weekends have lower volumes which peak at midday between 1:00 PM and 4:00 PM.

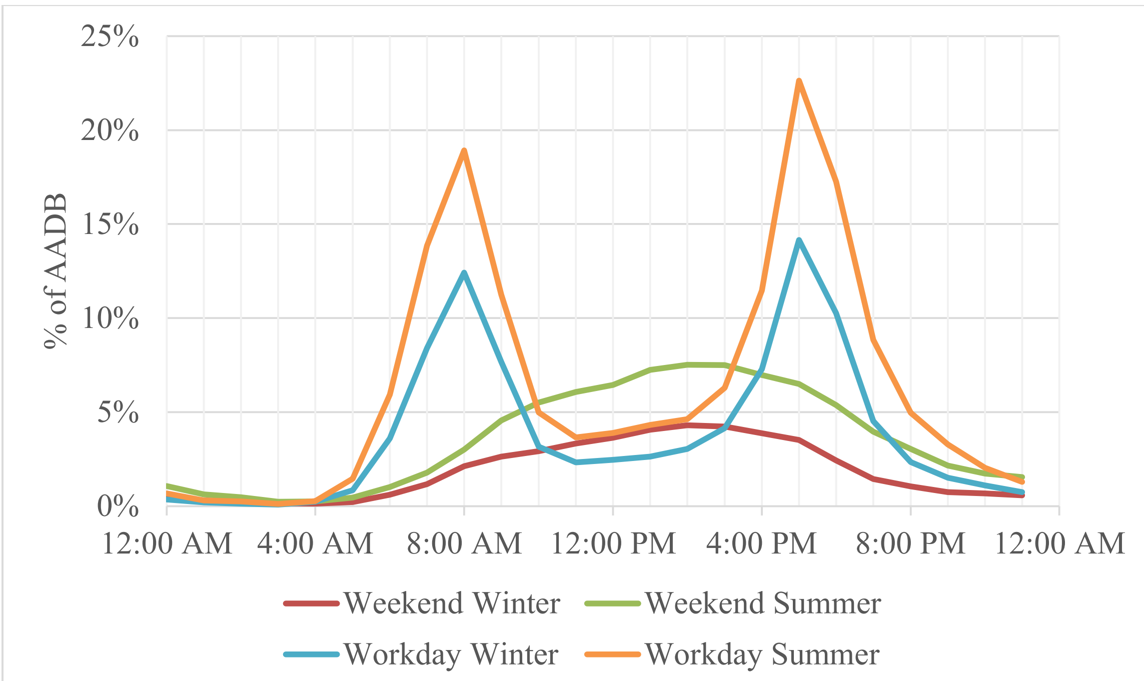

Figure 9 - Seattle Fremont Bridge Hourly Patterns in 2013

Data from the city of Olympia were also available to examine hourly patterns at the 19 locations where one week of bicycle counts were collected using pneumatic tube counters. Figure 10 shows the patterns for weekdays (Monday through Friday) at all 19 locations counted in June 2012. Most locations seem to show a morning (7 to 8 AM) and evening (5 to 6 PM) commute pattern, though at least one location has larger midday use and some locations have somewhat steady use throughout the day which would indicate mixed uses from recreational to utilitarian.

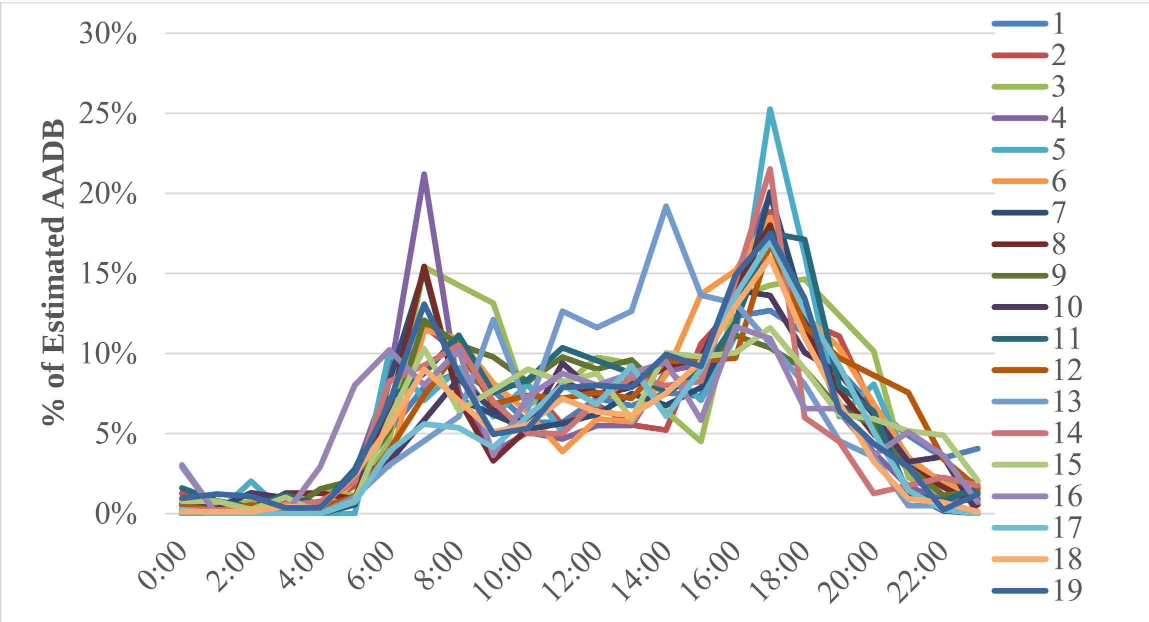

Figure 10 - Olympia June 2012 Hourly Weekday Patterns at 19 Locations

Figure 11 shows the patterns at the same locations on the weekends. As is common, there is much greater variability on the weekends.

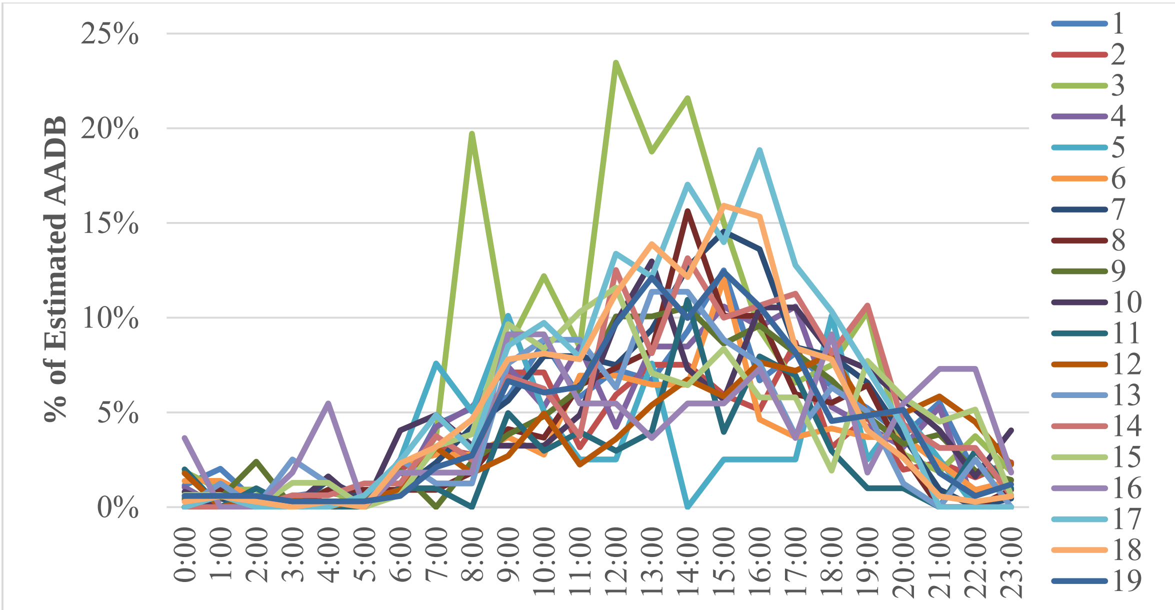

Figure 11 - Olympia June 2012 Hourly Weekend Patterns at 19 Locations

Daily Variation

Daily patterns over the week were examined in the two cities for which such data were available: Seattle and Olympia.

In Seattle average percent AADB by day of the week at the Fremont Bridge were plotted for 2013 (Figure 12). Because May through September have higher than average bicycle volumes at this site, these “summer” months were plotted separately. The daily pattern over the week seems similar for both seasons with lower counts on weekends than weekdays.

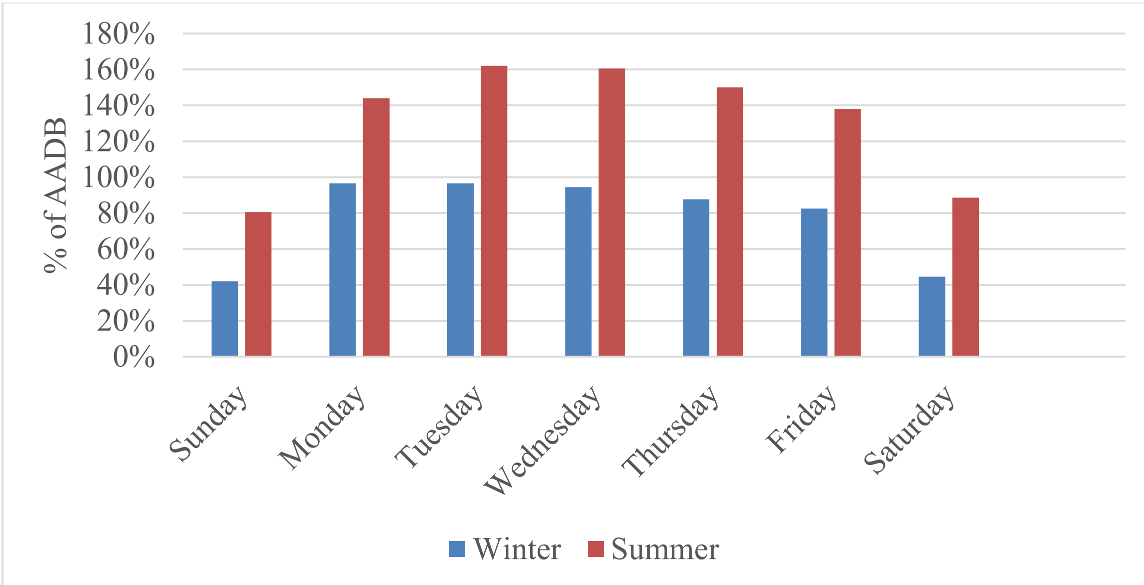

Figure 12 - Seattle Fremont Bridge Daily Patterns in 2013

Data from the city of Olympia were also available to examine hourly patterns at the 19 locations where one week of bicycle counts were collected using pneumatic tube counters. Figure 13 shows the patterns for days of the week at all 19 locations counted in June 2012. The patterns vary considerably by location with the locations having lower counts on weekends on average. Because each line represents only one week of data and volumes are relatively low (less than 200 bicyclists per day), there is high variability between sites.

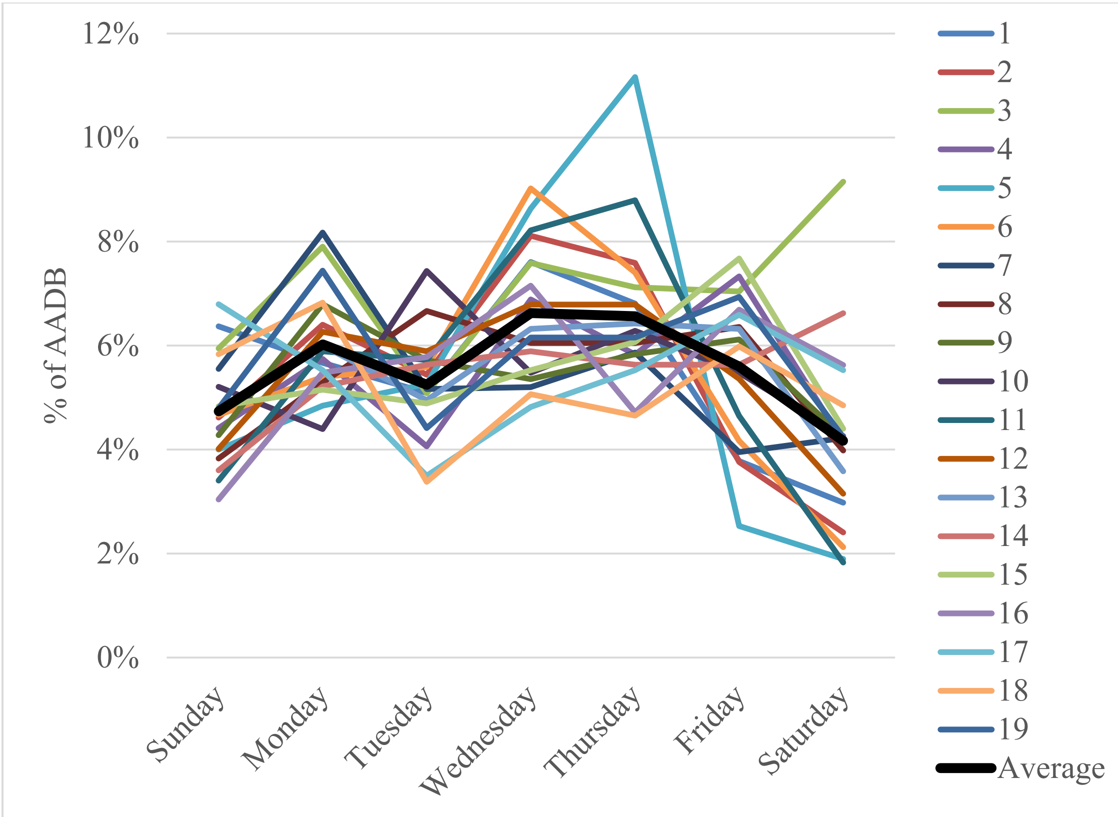

Figure 13 - Olympia June 2012 Daily Patterns at 19 Locations

Monthly Variation

Monthly variation was only available at one site, the Seattle Fremont Bridge (Figure 14). April through September have higher than average counts with peak average daily volumes in July.

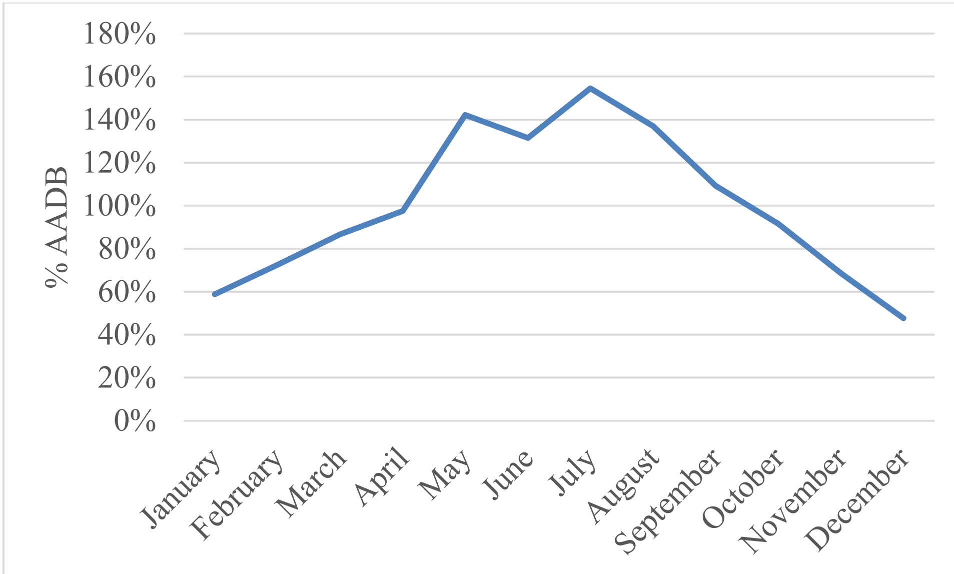

Figure 14 - Seattle Fremont Bridge Bicycle Traffic by Month in 2013

ANALYSIS OF GEOGRAPHIC DATA

A first step of implementing the count-based BMT/PMT estimation method is the estimation of the centerline miles in each of the 16 groups identified based on region, urbanity and facility type as summarized in Table 7.

Table 7 - Summary of Centerline Miles by Group

Region	Level of Urbanism	Road/Path Type	Total Miles
Coast Range	Urban	Arterial	409
	Urban	Collector	739
	Rural	Arterial	128
	Rural	Collector	13,062
Puget Lowlands	Urban	Arterial	4,042
	Urban	Collector	20,730
	Rural	Arterial	183
	Rural	Collector	15,380
Eastern Washington	Urban	Arterial	2,574
	Urban	Collector	7,140
	Rural	Arterial	1,448
	Rural	Collector	54,407
Cascades	Urban	Arterial	219
	Urban	Collector	352
	Rural	Arterial	576
	Rural	Collector	33,526
Total Centerline Miles in Washington State			**154,915**

Centerline miles were calculated using three street network layers provided by the Washington State Department of Transportation (WSDOT). For the most part, roads on all three layers were represented by a single polyline. However, highways and certain major arterials were represented by two lines, one for each direction of the roadway.

To avoid double counting highways for the purpose of determining centerline miles, all segments classified with a direction of decreasing (in relation to mileposts) were removed. Additionally, ramps, HOV Lanes, and other lanes that would result in double counting were also removed. Roads classified as couplets, spurs, and alternate route highways were included in the calculation of centerline miles.

The total number of centerline miles as determined using this methodology is significantly higher than the FHWA's estimate of 83,527 miles for the state (Federal Highway Administration 2008). The centerline miles for interstates, arterials, and collectors are all similar to the FHWA estimates. Thus, the difference between the two estimates is attributable to the centerline mileage for local access streets.

Regions

The state of Washington was divided into four regions: Eastern Washington, Cascades, Puget Lowland, and Coast Range. The four regions are a simplified version of Washington State Department of Transportation's Ecoregion map (WSDOT 2013) which was derived from the Level III ecoregions as defined by the U.S. Environmental Protection Agency (U.S. Environmental Protection Agency 2013). The Columbia Plateau, Northern Rockies, and the Blue Mountains were combined to form the Eastern Washington region. The North Cascades, Cascades, and Eastern Cascades Slopes and Foothills ecoregions were combined to form the Cascades region. The Willamette Valley ecoregion was consolidated into the Puget Lowland region. The fourth region was the Coast Range Region, which also included the portion of the North Cascades ecoregion in the Olympic Mountains.

Road Type

Each segment of road was classified into one of two categories using the Federal Functional Classification system for roadways. The first category contains interstates, other freeways, other principal arterials, and minor arterials. The second category contains major collectors, minor collectors, and local access roads.

Urban/Rural

Centerline miles were further categorized into urban and rural roads. Road segments were considered urban if they were contained in an Urbanized Area or Urban Cluster, as defined by the 2010 U.S. Census. All other roads were categorized as rural.

Classifying roads based on urban growth areas was also considered. However, the Federal Functional Classification system for urban and rural roads was found to be more in line with the method based on Census designations. The Federal Functional Classification could not be used for this urban/rural classification since local access streets were not classified.

CONCLUSIONS

This report presents recommended improvements for the State's Count Program so that it can better inform estimates of BMT and PMT. The report also outlines a method for estimating statewide BMT and PMT and identifies other methods for comparison. Additionally, the report documents the first steps toward creating such an estimate.

This report proposes a sampled-based method to calculate BMT and PMT using pedestrian and bicycle counts collected in the state of Washington. In order to use the method, improvements to the State's Count Program need to be made. Recommended improvements are detailed in this report and include expanding the program geographically and installing permanent automated bicycle and pedestrian counters to complement the existing short duration count program. The method to estimate BMT and PMT relies on the assumption of a stratified random sample drawn from the set of all roads and paths divided into 16 groups. These groups are based on three spatial attributes, which were gathered from a review of the literature. The attributes by which the groups are divided are

- Level of urbanism (2 categories): Urban and Rural
- Facility type (2 categories): Highway/Arterial and Other
- By geographic and climatic regions (4 regions): Coast Range, Puget Lowland, Cascades, Eastern Washington

This report describes the first steps being taken toward the goal of computing this metric. Count data from Seattle, Olympia, and the State's Count Program have been gathered. Seasonal adjustment, daily, and hourly adjustment factors have been computed based on one year of count data collected from the Fremont Bridge in Seattle. The short duration count sites have been grouped by the attributes described above, though most fall into just two groups: Puget Lowland Urban Arterial/Highway and Puget Lowland Urban Local/Collector/Path. While the Eastern Washington Urban Arterial/Highway and Eastern Washington Local/Collector/Path groups are also represented, no counts are available in most of the other groups. The roads in the state have also been divided into these 16 groups in order to compute total centerline miles for each group. This report outlines a method that could be used to compute BMT and PMT for the state and identifies both the data available for such a computation as well as the data gaps.

RECOMMENDATIONS

This report provides recommendations to the state regarding two improvements to the State's Count Program for future years and for the continuation of the project in Phase III.

RECOMMENDATIONS FOR THE STATE'S COUNT PROGRAM

The recommendations for the State's Count Program were divided into two sets: those that can be implemented in the coming years and those that can be implemented in the coming decades.

Recommendations for the coming years:

- Gradually, expand count sites into rural areas and both urban and rural areas in mountain areas.
- For each of the 16 sampling groups identified, install at least one permanent counter with separate automated bicycle and pedestrian counts.
- For sampling groups for which a permanent count site is available, allow short duration counts any Tuesday, Wednesday, or Thursday, May through October in order to increase the locations where counting is performed.

Recommendations for the next twenty years:

- For each sampling group, at least seven permanent bicycle and pedestrian counters are desired. Bicyclists and pedestrians should be counted separately.
- Count for at least seven days, 24 hours per day, at each short duration count location.

- At least 150 short duration count locations per sampling group would be beneficial to the accuracy of estimating bicycle and pedestrian miles traveled.
- Short duration count locations should be selected at random from each sampling group, even though this means counting at new sites some of which may have low volumes of cyclists and/or pedestrians.

RECOMMENDATIONS FOR PHASE III

We have two recommendations for the continuation of the project into Phase III:

1. Methods. This report outlined methods to be used for first rough estimates of bicycle and pedestrian miles traveled in the state: survey-based, count-based, and a sketch planning tool or, if possible, an aggregate demand model. Because of the large uncertainties present, we recommend that all three approaches be employed in the next phase of work with special attention to the count-based approach. Focusing on all three will allow us to compare the pros and cons of the estimation methods as well as to evaluate the magnitudes predicted including quantifying the error for each. It will not be possible, given the data available, to compute an accurate estimate, but if we can bound the estimate within one or two orders of magnitude based on the multiple methods, this would be a contribution to the field and to the State's understanding of non-motorized travel.
2. Pilot City. In order to test the methods, we recommend that in addition to the statewide estimates above, if possible within budget, a pilot city be

identified. The city should have a relatively high quantity of both survey and count data on bicycling and walking. If time and budget allow, applying the methods to the pilot city will better allow us to compare the methods and assess their pros and cons.

ACKNOWLEDGMENTS

The project team is grateful for the assistance of WSDOT staff, especially Paula Reeves, Ian Macek, Ed Spilker, Kathy Lindquist, and Charlotte Claybrooke, who each provided useful input, data and guidance. The team is also grateful for the efforts of the City of Seattle (Craig Moore and Rafael Zuniga) and City of Olympia (John Lindsay and Michelle Swanson), who have been collecting bicycle and pedestrian counts beyond the State's Count Program. We would also like to thank the National Institute of Transportation and Communities (NITC) at the Oregon Transportation Research and Education Consortium (OTREC) for funding for Phase III of the project. We look forward to continuing the work to the next phase.

REFERENCES

Barnes, Gary, and Kevin Krizek. 2005. "Estimating Bicycling Demand." *Transportation Research Record: Journal of the Transportation Research Board* no. 1939 (-1):45-51.

Cascade Bicycle Club. 2013. Washington State Bicycle and Pedsetrian Documentation Project 2012: A summary report to the Washington State Department of Transportation. WSDOT.

Davis, G., and T. Wicklatz. 2001. Sample based estimation of bicycle miles of travel (BMT). Minnesota Department of Transportation.

Dill, Jennifer, and Kim Voros. 2007. "Factors Affecting Bicycling Demand: Initial Survey Findings from the Portland, Oregon, Region." *Transportation Research Record: Journal of the Transportation Research Board* no. 2031 (-1):9-17. doi: 10.3141/2031-02.

Dowds, Johanthan, and James Sullivan. 2012. Applying a Vehicle-miles of Travel Calculation Methodology to a County-wide Calculation of Bicycle and Pedestrian Miles of Travel. In *Transportation Research Board Annual Meeting*. Washington, DC: The Transportation Research Board of the National Academies.

Federal Highway Administration. 1993. Case Study No. 15, The Environmental Benefits of Bicycling and Walking. In *National Bicycling and Walking Study*. Washington, D.C.: U.S. Department of Transportation.

———. 2014. *State Statistical Abstracts, Washington*. U.S. Department of Transportation 2008 [cited March 20, 2014 2014]. Available from http://www.fhwa.dot.gov/policyinformation/statistics/abstracts/wa.cfm.

———. 2012. Report to the U.S. Congress on the Outcomes of the Nonmotorized Transportation Pilot Program SAFETEA-LU Section 1807. Washington, D.C.: U.S. Department of Transportation.

———. 2013a. Highway Performance Monitoring System Field Manual. edited by U.S. Department of Transportation. Washington, D.C.

———. 2013b. Traffic Monitoring Guide. Washington, DC: U.S. Department of Transportation.

Frank, Lawrence D., Michael J. Greenwald, Sarah Kavage, and Andrew Devlin. 2011. An Assessment of Urban Form and Pedestrian and Transit Improvements as an Integrated GHG Reduction Strategy.

Griswold, Julia B., Aditya Medury, and Robert J. Schneider. 2011. Pilot Models for Estimating Bicycle Intersection Volumes. In *Transportation Research Board Annual Meeting*. Washington, DC.

Hankey, Steve, Greg Lindsey, Xize Wang, Jason Borah, Kristopher Hoff, Brad Utecht, and Zhiyi Xu. 2012. "Estimating use of non-motorized infrastructure: Models of bicycle and pedestrian traffic in Minneapolis, MN." *Landscape and Urban Planning* no. 107 (3):307-316. doi: http://dx.doi.org/10.1016/j.landurbplan.2012.06.005.

Jones, Michael G., Sherry Ryan, Jennifer Donlon, Lauren Ledbetter, David R. Ragland, and Lindsay Arnold. 2010. Seamless Travel: Measuring Bicycle and Pedestrian Activity in San Diego County and its Relationship to Land Use, Transportation, Safety, and Facility Type. Berkley, California: Institute of Transportation Studies, UC Berkeley Safe Transportation Research & Education Center, University of California,.

Krizek, Kevin J., Gary Barnes, Gavin Poindexter, Paul Mogush, Kristin Thompson, David Levinson, Nebiyou Tilahun, David Loutzenheiser, Don Kidston, William Hunter, Dwayne Tharpe, Zoe Gillenwater, and Richard Killingsworth. 2005. NCHRP Project 7-14 Guidelines for Analysis of Investments in Bicycle Facilities. In *National Co-operative Highway Research Program*.

Kumapley, Robert K., and Jon D. Fricker. 1996. "Review of Methods for Estimating Vehicle Miles Traveled." *Transportation Research Record* no. 1551 (Innovative Transportation Data Management , Survey Methods, and Geographic Information Systems):59-66.

Kuzmyak, Richard. 2014 forthcoming. NCHRP 08-78 Estimating Bicycling and Walking for Planning and Project Development. Washington, D.C.: National Cooperative Highway Research Program.

Landis, B. 1996. *Pro Bike/Pro Walk 96 Resource Book*. Edited by J. Toole, *Ninth international conference on bicycle and pedestrian programs: Using the latent demand score model to estimate use*. Portland: Bicycle Federation.

Lindsey, Greg, Steve Hankey, Xize Wang, and Junzhou Chen. 2013. The Minnesota Bicycle and Pedestrian Counting Initiative: Methodologies for Non-motorized Traffic Monitoring.

Lindsey, Greg, Jeff Wilson, Elena Rubchinskaya, Jihui Yang, and Yuling Han. 2007. "Estimating urban trail traffic: Methods for existing and proposed trails." *Landscape and Urban Planning* no. 81 (4):299-315. doi: DOI: 10.1016/j.landurbplan.2007.01.004.

Lindsey, John. 2013. City of Olympia Bicycle Count Program - Overview. edited by Krista Nordback. Olypmia, WA: City of Olympia.

Liu, Feng, John Evans, and Thomas Rossi. 2012. "Recent Practices in Regional Modeling of Nonmotorized Travel." *Transportation Research Record: Journal of the Transportation Research Board* no. 2303 (-1):1-8. doi: 10.3141/2303-01.

McCahill, Chris, and Norman Garrick. 2008. "The Applicability of Space Syntax to Bicycle Facility Planning." *Transportation Research Record: Journal of the Transportation Research Board* no. 2074 (-1):46-51. doi: 10.3141/2074-06.

McDaniel, Stephen, Michael B. Lowry, and Michael Dixon. 2014. Using Origin-Destination Centrality to Estimate Directional Bicycle Volumes. In *93rd Annual Meeting of the Transportation Research Board*. Washington, D.C.: National Academies.

Minnesota Department of Transportation. 2013. Minnesota Statewide Bicycle Planning Study.

Miranda-Moreno, Luis F., Patrick Morency, and Ahmed M. El-Geneidy. 2011. "The link between built environment, pedestrian activity and pedestrian–vehicle collision occurrence at signalized intersections." *Accident Analysis & Prevention* no. 43 (5):1624-1634. doi: http://dx.doi.org/10.1016/j.aap.2011.02.005.

Miranda-Moreno, Luis, and David Fernandes. 2011. "Modeling of Pedestrian Activity at Signalized Intersections: Land Use, Urban Form, Weather, and Spatiotemporal

Patterns." *Transportation Research Record: Journal of the Transportation Research Board* no. Pedestrians 2011 (2264):74-82.

Molino, John A., Jason F. Kennedy, Patches L. Johnson, Pascal A. Beuse, Amanda K. Emo, and Ann Do. 2009. "Pedestrian and bicyclist exposure to risk: Methodology for estimation in an urban environment." *Transportation Research Record* (Compendex):145-156.

Moudon, Anne Vernez, and Orion Stewart. 2013. Tools for Estimating VMT Reductions from Built Environment Changes. Olympia, Washington: Washington State Department of Transportation.

Nordback, K., W. Marshall, B. Janson, and Elizabeth Stolz. 2013. "Estimating Annual Average Daily Bicyclists: Error and Accuracy." *Transportation Research Record*.

Nordback, Krista L. 2012. *Estimating Annual Average Daily Bicyclists and Analyzing Cyclist Safety at Urban Intersections*, Department of Civil Engineering, University of Colorado Denver, Denver.

Nordback, Krista, Wesley E. Marshall, and Bruce N. Janson. 2013. Development of Estimation Methodology for Bicycle and Pedestrian Volumes Based on Existing Counts. Denver, CO: Colorado Department of Transportation (CDOT).

Piatkowski, Daniel. 2013. *Identifying Impacts of Interventions Aimed at Promoting Walking and Bicycling; Directions for Increasing Non-Motorized Transportation in US Cities*, Department of Planning and Design, University of Colorado Denver, Denver, Colorado.

Pratt, Richard H., John E. Evans, Herbert S. Levinson, Shawn M. Turner, Chawn Yaw Jeng, and Daniel Nabors. 2012. Pedestrian and Bicycle Facilities: Traveler Response to Transportation System Changes. In *Transit Cooperative Research Program*, edited by Transportation Research Board of the National Academies. Washington, D.C.: U.S. Department of Transportation, Federal Transit Administration.

Pulugurtha, Srinivas, and Sudha Repaka. 2008. "Assessment of Models to Measure Pedestrian Activity at Signalized Intersections." *Transportation Research Record: Journal of the Transportation Research Board* no. 2073 (-1):39-48. doi: 10.3141/2073-05.

Pulugurtha, Srinivas S., and Venkata R. Sambhara. 2011. "Pedestrian crash estimation models for signalized intersections." *Accident Analysis & Prevention* no. 43 (1):439-446. doi: http://dx.doi.org/10.1016/j.aap.2010.09.014.

Results Washington. 2014. *Measure Results*. State of Washington 2014 [cited May 8, 2014 2014]. Available from http://www.results.wa.gov/what-we-do/measure-results.

Rodríguez, Daniel A., and Joonwon Joo. 2004. "The relationship between non-motorized mode choice and the local physical environment." *Transportation Research Part D: Transport and Environment* no. 9 (2):151-173. doi: http://dx.doi.org/10.1016/j.trd.2003.11.001.

Schneider, Robert J., Todd Henry, Meghan F. Mitman, Laura Stonehill, and Jesse Koehler. 2012. "Development and Application of the San Francisco Pedestrian Intersection Volume Model." *Transportation Research Record*.

Seattle Department of Transportation. *Bicycle Data*. City of Seattle 2013a [cited December 11, 2013. Available from http://www.seattle.gov/transportation/bikedata.htm.

———. *Seattle's Bicycle Counters*. City of Seattle 2013b [cited December 13, 2013. Available from http://www.seattle.gov/transportation/bikecounter.htm.

Singleton, Patrick A, and Kelly J Clifton. 2013. Pedestrians in Regional Travel Demand Forecasting Models: State of the Practice. In *Transportation Research Board 92nd Annual Meeting*. Washington, D.C.: Transportation Research Board of the National Academies.

U.S. Environmental Protection Agency. 2013. Level III ecoregions of the continental United States. Corvallis, Oregon: U.S. EPA - National Health and Environment Effects Research Laboratory.

Wang, X., G. Lindsey, S. Hankey, and K. Hoff. 2013. "Estimating Mixed-Mode Urban Trail Traffic Using Negative Binomial Regression Models." *Journal of Urban Planning and Development*:04013006. doi: doi:10.1061/(ASCE)UP.1943-5444.0000157.

Washington State Department of Ecology. 2003. Washington State Annual Average Precipitation. GIS Technical Services.

———. 2007. Washington State Average Annual Temperatures. GIS Technical Services.

Washington State Department of Transportation. 2013. *Washington State Bicycle and Pedstrian Documentation Project*. WSDOT 2013 [cited December 13, 2013 2013]. Available from http://www.wsdot.wa.gov/bike/count.htm.

WSDOT. 2013. Map of Washington State Eco-regions. Washington State: Department of Transportation.

APPENDIX A

Text of Email Sent to State Lists

APPENDIX A
TEXT OF EMAIL SENT TO STATE LISTS

Below is the text of the email sent to state lists by WSDOT staff in order to solicit additional count data:

“Do you count bicyclists and pedestrians? The Washington State Department of Transportation (WSDOT) is studying how to roughly estimate bicycle and pedestrian miles traveled. To assist with this estimation, WSDOT would like to gather any additional bicycle and pedestrian count data that are collected within the state. Outside of the annual WSDOT Bicycle and Pedestrian Documentation Program count in September/October, does your agency or one you know counts bicyclists and pedestrians?

“If so, please contact Krista Nordback (nordback@pdx.edu) who is working on the project for WSDOT. Both automated and manual counts are welcomed. Thank you!”