# Institutionalizing Bicycle and Pedestrian Monitoring Programs in Three States: Progress and Challenges

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## ABSTRACT

Information about non-motorized traffic is needed to support planning and management of transportation systems. However, state transportation officials across the United States generally have not monitored non-motorized traffic, and most state agencies lack bicycle and pedestrian counts and other measures of traffic demand. This paper describes current efforts by the Colorado, Minnesota, and Oregon Departments of Transportation (DOTs) to establish non-motorized traffic monitoring programs. Using Federal Highway Administration (FHWA) principles for comprehensive traffic monitoring as a framework for assessment, this case study summarizes state approaches for initiating monitoring, agency collaboration with local governments, and the current scope of state DOT continuous and short-duration monitoring efforts. Agency protocols for data collection, analysis, and management, including development of factors for purposes such as estimating average daily bicyclists or bicycle miles traveled are also compared. Agency efforts to demonstrate the effectiveness of monitoring technologies also are described. The case study reveals similar objectives across states, both similarities and differences in approaches, differing rates of implementation, and similar problems in implementation. The paper summarizes lessons learned and identifies challenges state DOTs will face in institutionalizing non-motorized traffic monitoring programs.

## 1. Introduction

Information about use of streets, bike lanes, bicycle boulevards, sidewalks, and shared-use trails by bicyclists and pedestrians is needed to support planning and improve management of transportation systems. However, state and local transportation officials across the United States generally lack basic information such as bicycle and pedestrian traffic volumes and other measures of demand for facilities essential for evidence-based planning. This paper describes progress and challenges faced by three state departments of transportation (DOTs) – Colorado, Minnesota, and Oregon – in establishing non-motorized traffic monitoring programs. Following a brief, selective overview of the literature on traffic monitoring, we summarize new Federal Highway Administration (FHWA) guidelines for monitoring non-motorized traffic and present a short list of definitions of terms and concepts used in monitoring. Then, using the FHWA guidelines as a framework, we assess progress for each state. We summarize rationales for monitoring, collaboration with local governments, the current scope of state DOT continuous and short-duration monitoring, and protocols for data collection, analysis, and management, including development of factors for estimating average annual daily traffic or miles traveled. We conclude by discussing issues all state DOTs will face in institutionalizing non-motorized traffic monitoring programs.

## 2. Recent Progress in Monitoring Non-motorized Traffic

Over the past twenty years, as researchers have documented the potential benefits of bicycling and walking and advocates have pressed for more funding for bicycle and pedestrian facilities, governments at all levels have invested more in non-motorized infrastructure, often in collaboration with private, nonprofit organizations. Decision-makers often have made these investments following general planning processes, but without quantitative measures of demand for facilities. More recently, government officials have been under greater pressure to document the demand for facilities and benefits of investments. As a result, state and local governments across the United States are exploring strategies for monitoring of bicycle and pedestrian traffic.

While agency interest in monitoring bicycle and pedestrian traffic has grown, researchers have long recognized the need for consistent, comprehensive information about bicycle and pedestrian traffic. As early as the 1970s, researchers were exploring strategies for estimating pedestrian traffic by correlating counts of pedestrians with street classifications and adjacent land use (*1,2*)**.** In the following decades, researchers have continued to report methodological advances. Davis et al. (*3*), for example, published equations for estimating pedestrian crosswalk volumes from short (e.g., five, ten, 15, or 30 minute) duration counts.

Following passage of the Intermodal Surface Transportation Act in 1991 (ISTEA), interest in data about use of bicycle and pedestrian facilities grew. Hunter and Huang (*4*) collected bicycle and pedestrian counts from agencies across the United States (U.S.) and reported that daily bicycle and pedestrian traffic could be significant (i.e., between 1,000 and 2,000 cyclists per day). They concluded, however, the quality of the data was poor and they could not be used to make inferences about traffic at other locations. The U.S. Department of Transportation's (USDOT) Bureau of Transportation Statistics (BTS) came to a similar conclusion in a study released in 2000, describing the quality of existing information on the "number of bicyclists and pedestrians by facility or geographic region" as "poor" and the "priority for better data" as "high." (*5*, p. 45). At about the same time, Porter and Suhrbier (*6*) reported on the state of the practice for forecasting bicycle and pedestrian traffic, and the Federal Highway Administration (*7*) released the *Guidebook on Methods* *to Estimate Non-Motorized Traffic*. The FHWA did not address in detail, however, the challenges inherent in institutionalizing monitoring networks necessary to develop consistent estimates of average annual daily bicycle or pedestrian traffic or miles traveled.

During the past decade, the number of papers and reports describing technologies and methods for counting bicyclists and pedestrians, correlates of non-motorized traffic, and approaches to modeling has burgeoned. Researchers have described the strengths, potential, limitations, and tradeoffs among manual and automated methods of counting bicyclists and pedestrians (*8-16*). Nordback et al. (*17-18*) described general procedures for measuring error associated with automated bicycle counters. Miranda-Moreno et al. (*19*) proposed procedures for determining factor groups (e.g., utilitarian, mixed-utilitarian, mixed-recreational, and recreational) based on ratios of weekend-weekday daily traffic and morning and midday hourly traffic. Nordback et al. (*20*) demonstrated the magnitude of error in estimates of average annual daily traffic (AADT) associated with extrapolation of short duration counts of various lengths. Researchers also have developed statistical models for estimating bicycle and pedestrian traffic flows on urban networks (*13, 21-23*).

While this research has demonstrated different methods of monitoring, spatial and temporal variations in bicycle and pedestrian traffic, and factors that influence traffic volumes, it has not yet led to widespread institutionalization of monitoring programs. To date, most efforts have been launched by municipalities or regional governments, and most have involved manual counting of bicyclists and pedestrians, although a number of municipalities (e.g., San Francisco, San Diego) are launching ambitious monitoring programs that include automated, in-street monitoring of bicycles. Many (e.g., Minneapolis) have focused mainly on manual counts or engaged in limited monitoring of traffic on off-street, shared use paths (e.g., Columbus, OH, Indianapolis, IN).

Perhaps the most significant, sustained effort to date to encourage bicycle and pedestrian monitoring has been the National Bicycle and Pedestrian Demonstration Project (NBPDP), a voluntary, nation-wide initiative launched in 2003 by the Institute of Transportation Engineers (ITE) Pedestrian and Bicycle Council and Alta Planning + Design, a private firm. The purpose of the NBPDP is to provide a “consistent model of data collection … for … planners, governments, and bicycle and pedestrian professionals” (*24*). The NBPDP has been successful in raising awareness of the need for counting and engaging many communities in counting, but, as a voluntary effort, has suffered from the lack of resources required for sustainability. In addition, researchers have demonstrated that estimates of AADT produced from two-hour short duration counts, a NBPDP protocol, may have unacceptably high margins of error (*20*). These limitations notwithstanding, the NBPDP has helped build momentum for efforts to institutionalize bicycle and pedestrian monitoring.

For a variety of reasons, including the absence of federal mandates and because most bicycle and pedestrian traffic occurs on local streets, no state DOTs have established comprehensive monitoring programs, although this is changing. Baker et al. (*25*) recently described state DOT participation in non-motorized traffic monitoring. They searched state DOT bicycle and pedestrian websites, classified state DOT bicycle and pedestrian programs according to evidence of programming, and surveyed agency staff from states with evidence of well-established programs.

Their review identified:

- 16 states with “abundant evidence” of a well-established bicycle and pedestrian program, including some with traffic monitoring and data collection programs;

- 18 states with some evidence of programs, but no evidence of non-motorized traffic monitoring; and
- 16 states with little or no evidence of a bicycle or pedestrian program.

Based on their follow-up survey, they concluded that three states – Colorado, Vermont, and Washington – have been leaders in supporting non-motorized traffic monitoring, although others, including Minnesota and Oregon, have commissioned studies to develop monitoring strategies. The Washington DOT collaborates with municipalities in conducting counts following the NBPDP methodology and publishes an annual summary of the counts (*26)*. The Washington DOT also is working with automated counters and beginning to integrate non-motorized and vehicular traffic counts. The Vermont DOT owns automated counters, provides technical guidance and assistance on counting, and loans the counters to local governments interested in monitoring non-motorized traffic (*27***)**. The Vermont DOT also works with organizations interesting in manual counting consistent with the NBPDP protocols. Vermont has analyzed counts taken throughout the state but concluded data remain inadequate to estimate BMT or PMT.

The FHWA has recently published an updated version of the Traffic Monitoring Guide (TMG) which includes a new chapter on monitoring non-motorized traffic (Chapter 4). This new chapter follows approaches used in motor vehicle monitoring and describes monitoring technologies, variability in non-motorized traffic, and steps in establishing permanent and short duration data programs (*28*). It includes a discussion of the relative advantages and disadvantages of automated and manual counts, noting, for example, that manual counts provide very limited information about temporal variation in non-motorized traffic. Chapter 4 also illustrates how factors derived from continuous monitoring data can be used to extrapolate short duration counts to obtain estimates of AADT. Key steps in managing permanent and short duration data monitoring programs are listed in Table 1. The FHWA also has indicated it will begin archiving non-motorized traffic data, although procedures and timelines for implementation have not been announced.

**Table 1. Key Steps in Institutionalizing Non-motorized Traffic Monitoring** – adapted from (*28)*

| *Permanent Data Management Program* | *Short-term Data Program* |
|---|---|
| 1. Review the existing permanent count program | 1. Select count locations (random and/or non-random) |
| 2. Develop an inventory of available permanent count locations and equipment | 2. Select type of count (segment and/or intersection) |
| 3. Determine the traffic patterns to be monitored | 3. Determine duration of counts |
| 4. Establish seasonal pattern groups | 4. Determine method of counting (automated and/or manual) |
| 5. Determine the appropriate number of permanent automated traffic recorder (ATR) locations | 5. Determine number of short-term counts |
| 6. Select specific count locations | 6. Evaluate counts (accuracy characteristics, variability) |
| 7. Compute monthly factors | 7. Apply factors (occlusion, time of day, day of week, monthly, seasonal) |
| 8. Develop seasonal factors | |

In sum, the last decade has witnessed significant progress in monitoring of bicycle and pedestrian traffic. Spurred on by local governments and voluntary initiatives, state and federal agencies are beginning efforts to establish non-motorized monitoring programs and integrate them with vehicular motorized monitoring programs.

## 3. Key Concepts and Definitions in Non-motorized Traffic Monitoring

While local, state, and federal governments are making significant progress in non-motorized traffic monitoring, the terms and concepts used to describe protocols or results have yet to be completely standardized. The lack of standard terminology is partly historical: transportation data collection and monitoring outputs have applications in a wide range of areas that range from travel survey and travel model validation to the estimation of accident rates and miles traveled. Over time, in different contexts, some commonly used terms such as screen-line counts have been used differently. Other terms historically used in vehicular traffic monitoring are being customized for non-motorized monitoring (e.g., vehicle miles traveled (VMT) vs. bicycle miles traveled (BMT). To ensure clarity, we adopt the following definitions in this study:

*ATRs:* automated *traffic recorders*. The word "automated" refers to the lack of human intervention during regular operation of the counting device.

*Continuous Count Program*: a program designed to collect count or traffic data that is representative of travel activity over a region or geographic area. The word "continuous" denotes the temporal granularity of the data (usually in hours, minutes or seconds) and the expected duration of the count without interruptions (at least a year). The backbone of this program is a system of ATRs that are typically used to determine travel patterns by purpose (e.g. recreational, commute) and variability over time (hourly, daily, or seasonal). Although these programs sometimes are referred to as permanent count programs, we use the term continuous because the sites are not always designed to be maintained in perpetuity.

*Short Duration Count Program*: a program of counting over a region or geographic study area that is typically conducted to complement data from continuous ATRs and expand the number of counting locations in a cost-effective manner. Count durations usually range from one day to one month, although counts can be as short as two hours during peak times (e.g. some NBPDP counts).

*Segment Count*: any count on a road or path segment for which non-motorized traffic crossing an imaginary line across the facility is counted. Each segment count is representative of a continuous length of facility that is homogeneous (e.g. same number and type of lanes, no major traffic flows in or out of the segment).

*Screen-line Counts*: traditionally used in transportation modeling and traffic monitoring fields to validate regional travel models or origin-destination matrices. Screen-line counts are usually short duration and follow an imaginary line paralleling a major geographical barrier to an area of interest, such as a river or railway that reduces the number of crossings to be monitored. As an example of inconsistent use of terms in this field, we note that the term "screenline" is used by the NBPDP (*24*) and in Chapter 4 of the 2013 Traffic Monitoring Guide (*28*) to mean "segment count" as defined in this paper. We restrict the use of screenline to its historic, established meaning to eliminate confusion and because we think segment count better reflects the purpose for which counts are conducted on segments rather than at intersections.

*Intersection Counts*: counts that are taken at intersections or junctions where total counts and origin-destination (straight and turn movements) are typically recorded. Intersection short duration counts and additional OD data are commonly used for specific safety or signal timing studies.

## 4. Non-motorized Traffic Monitoring in Colorado, Minnesota, and Oregon

Because it is likely to evolve into the framework that all state DOT's follow, the approach in Chapter 4 of the FHWA's new edition of the TMG is useful for assessing initiatives to monitor bicycle and pedestrian traffic. We use this framework here to assess progress by state DOTs in Colorado, Minnesota, and Oregon to implement non-motorized traffic monitoring. We take a case study approach: our principal objective is to describe elements of these programs in a systematic way that informs the implementation of other monitoring initiatives. We selected these states because each has a long history of programming for bicyclists and pedestrians, is developing monitoring programs, and is collaborating with researchers at universities in program design and implementation. Because these states vary in their approaches and are at different stages in implementation, their comparison illustrates both the complexities of monitoring and the choices administrators must make in program development. Following discussions of background information about each state and institutional and other factors that have shaped their monitoring initiatives, we compare specific aspects of their programs using the FHWA framework.

The complexity of the challenge of establishing a statewide traffic monitoring network is partly a function of the complexity of the state. Among these three states, Minnesota and Colorado have comparable populations (i.e., 5.3 million and 5 million, respectively), while Oregon's population is smaller (3.8 million)(*29*). Colorado is the largest (104,000 square miles), and has 88,000 road miles, for an average road length per square mile of 0.85 (*30*). The comparable figures for Minnesota are 79,000 square miles, 137,000 miles of roadway, and 1.73 miles of road per square mile. Oregon has an area of 96,000 square miles, 59,000 miles of roadway, and 0.61 miles of roadway per square mile. Bicycle commute shares within states follow the same order as annual average temperature: Oregon: 48.4 F - 2.2% bicycle commuters; Colorado: 45.1 F - 1.3% bicycle commuters; Minnesota: 41.2 F - 0.7% bicycle commuters (*31-32)*. Overall, Minnesota has the largest network to monitor, but the Oregon network, on average, is less dense. The bicycle commuter rate in Oregon is nearly 70% higher than the rate in Colorado, and is triple the rate in Minnesota. The scope and challenge of monitoring programs will reflect these and other differences.

### *Colorado*

In 2009, CDOT adopted a new bicycle and pedestrian policy directive stating that transportation infrastructure should be provided for bicycle and pedestrian use "in a manner that is safe and reliable for all highway users," and that "*The needs of bicyclists and pedestrians shall be included in the planning, design, and operation of transportation facilities, as a matter of routine"* (*33*). This directive was codified by the state legislature in 2010 and is now part of the Colorado Revised Code (Colorado Revised Statutes 43-1-120). To meet this directive, CDOT recognized the need for additional data on bicycle and pedestrian use.

Accordingly, CDOT initiated a program in 2009 to collect continuous bicycle and pedestrian count data. Only two passive infrared counters then operated in the Denver metro area, but this soon grew to a total of 20 count locations, both on and off-street using infrared and inductive loop counters. CDOT also reached out to local jurisdictions to incorporate their continuous counts into the program. Two cities and four counties contributed data from 63 additional count stations, about half of which were passive infrared trail count stations which counted mixed-mode traffic; the rest were bicycle-only stations using inductive loops primarily on off-street paths, but also at on-street locations.

In addition, CDOT acquired six infrared mobile, short-duration counters in mid-2010 that since have been used on off-street paths throughout the state at locations requested by local jurisdictions. The mobile counters are usually placed for at least one week, and often over one month. CDOT does not collect or archive manual counts less than 24 hours in length (i.e., counts following NBPDP protocols) collected by local jurisdictions because estimating AADT from these short counts would lead to higher estimation error.

CDOT contracted with Texas Transportation Institute to provide guidance on the count program (*34*) and with the University of Colorado Denver to create a method to estimate annual average daily bicycle and pedestrian traffic at locations for which only short duration counts are available . CDOT has begun to implement many of the recommendations in the TTI report, including integration of non-motorized and motorized traffic monitoring data.

*Minnesota*

The Minnesota Department of Transportation (MnDOT) has supported programs and research to foster biking and walking for years, but systematic efforts to institutionalize monitoring of bicycling and walking have begun relatively recently. For example, MnDOT funded research to document the feasibility of estimating bicycle miles traveled through video monitoring (*35*) and to develop automated video classification of bicyclists and pedestrians (*15*). With the adoption of a long range plan to develop multi-modal systems (*2050 Vision – Minnesota Go*), policies to support Complete Streets, Safe Routes to Schools, and Toward Zero Deaths, and new performance measures, MnDOT's interest in monitoring bicycling and walking has grown. MnDOT's interest in monitoring has been influenced by successful counting initiatives by the Minneapolis Department of Public Work (MDPW) and a nonprofit, Bike Walk Twin Cities, who began monitoring in 2007 using NBPDP protocols as part of their evaluation of the Non-motorized Transportation Pilot Program.

In 2011 and 2013, MnDOT funded projects at the University of Minnesota (UMN) to develop consistent methods for monitoring, provide training and support for local monitoring programs, and create a central repository for count data. The projects include field testing of protocols for manual counts, collection and analyses of continuous counts, and assessment of different commercially available monitoring technologies. Manual counts were taken in 44 municipalities in 2012 (*36*). Analyses of automated continuous counts with inductive loop detectors and active infrared monitors on shared-use paths have been completed. These analyses demonstrated the limitations of technologies, produced equations to correct for undercounting associated with occlusion, calculated hourly, daily, and monthly factors for estimating AADT, and illustrated procedures for calculating miles traveled on trail segments. While MnDOT is strongly encouraging counting, the agency has yet to make most key decisions including whether the state will assume responsibility for permanent reference locations or rely on location stations, how many and where permanent locations should be established, and the types of different factor groups that will be needed.

*Oregon*

Oregon has long supported the development of pedestrian and bicycle facilities. Oregon passed legislation in 1971 that requires ODOT, cities, and counties to include facilities for pedestrians and bicyclists wherever a road, street, or highway is built or rebuilt (ORS 366.514). The legislation requires that, in the long term, the amount to be expended by ODOT, cities or counties shall never in any one fiscal year be less than 1% of the total amount of the funds received by the highway fund (1). ORS 366.514 also allows for reasonable exemptions when the cost to provide walkways or bikeways would be excessive in relation to the need or probable use of the facilities. Although ODOT has funded facilities to foster biking and walking since the 1970's, and ODOT first installed continuous bicycle counters in the 1980s, the agency has only recently begun systematic efforts to institutionalize monitoring of bicycling and walking modes. For example, the ODOT Performance Dashboard contains one metric related to Bicycle Lanes and Sidewalks (% of urban state highway miles with bike lanes and pedestrian facilities in "fair" or better condition) but no metrics related to bicycle and pedestrian traffic or demand.

The 2011 ODOT Bicycle and Pedestrian Travel Assessment (PTA) recognized the need to enhance and implement bicycle and pedestrian data collection (*37*), and in 2012, ODOT funded a research project at Portland State University to design a statewide bicycle and pedestrian data collection program. The PTA and ODOT recommended that the research and data collection efforts concentrate on roadways, not trails, and on continuous counts from automated monitoring technologies. The statewide program will build on local monitoring efforts. The city of Portland Bureau of Transportation (PBOT) has been working to implement systems to count bicycle and pedestrian activity at intersections with advance controllers (2070 controllers). In addition, PBOT bicycle unit has been counting bicycle volumes on the key bridges in Portland since the 1990's. Portland Metro is on the leading edge of non-motorized transportation model development, and Metro has increased its efforts towards systematic counting of bicyclists and pedestrians. Counts are needed for the calibration of Metro's bicycle and pedestrian models but yet there are no counts in the Portland metropolitan region. Other MPOs and urban areas (e.g. Eugene and Salem) with a high percentage of bicyclists and pedestrians are also developing pedestrian and bicyclist counting capabilities.

*Progress in Establishing Permanent Data Management Programs*

Overall, each state has made progress in implementing the general steps in monitoring outlined in the FHWA's TMG (Tables 2 and 3), but no state has yet established a comprehensive program.

1. <u>Review existing programs.</u> CDOT, MnDOT, and ODOT each has reviewed non-motorized counting programs, retained consultants or sponsored research to develop plans, and begun to make decisions about the scope of programs it may develop. Colorado contracted with the Texas Transportation Institute to prepare a strategic plan for non-motorized monitoring (*34*), and collaborated with both local officials and university researchers at the University of Colorado Denver in program development (*38)*. MnDOT has reviewed past research, funded projects on methodologies for counting bicyclists and pedestrians and implementation of monitoring. ODOT similarly has reviewed programs and contracted for assistance in developing an integrated monitoring program including reference and short-duration monitoring sites.

Table 2. Status of permanent non-motorized traffic monitoring programs in Colorado, Minnesota, and Oregon.

| **Steps in a Permanent Data Program** | **Colorado Department of Transportation (CDOT)** | **Minnesota Department of Transportation (MnDOT)** | **Oregon Department of Transportation (ODOT)** |
|---|---|---|---|
| 1. *Review existing continuous count program.* | • Review completed<br>• Consultants retained to prepare strategic plan<br>• Monitoring research ongoing | • Review completed<br>• Monitoring-related research ongoing | • Review completed<br>• Monitoring-related research ongoing |
| 2. *Develop inventory of automated continuous count locations and equipment* | • CDOT<br>  ○ 20 inductive loop or passive infrared<br>• Local jurisdictions (63 sites)<br>  ○ City of Boulder: 24 inductive loop counters<br>  ○ City of Denver: 1 video bicycle counter<br>  ○ Boulder County: 3 passive infrared<br>  ○ Douglas County: 12 passive infrared<br>  ○ Summit County: 6 passive infrared<br>  ○ Pitkin County: 17 passive infrared<br>• ± 50% of all sites count bicycles only<br>• ± 50% of all sites count mixed-mode traffic (i.e., bikes & peds combined)<br>• 45 sites have at least one complete year of data<br>• Segment counts only<br>• All locations purposefully sited (i.e., non-random) | • MnDOT<br>  ○ 0 automated monitors<br>• Local jurisdictions<br>  ○ Minneapolis DPW: 3 inductive loops on shared-use path<br>  ○ Three Rivers Park District: 7 passive infrared counters on shared-use paths<br>  ○ University of MN: 8 active infrared counters at six locations on combined and separated paths<br>• Segment counts only<br>• All locations purposefully sited (i.e., non-random) | • ODOT<br>  ○ 1 inductive loop on bicycle path<br>  ○ 20 intersections with 2070 controllers and loop detectors in the Portland metro area; more available in other cities but it is yet unknown how many intersections can provide useful bicycle data.<br>• City of Portland (PBOT)<br>  ○ tube counters on 3 bridges<br>  ○ 15 intersections with 2070 controllers and loop detectors<br>  ○ 1 inductive loop on shared-use path<br>• Metro & Tualatin Hills Parks<br>  ○ 43 passive infrared portable counters<br>  ○ 1 inductive loop/infrared combination counter for multiuse trail<br>  ○ Segment and intersection counts<br>  ○ All locations purposefully sited (i.e., non-random) |

Table 2. Status of permanent non-motorized traffic monitoring programs in Colorado, Minnesota, and Oregon, continued.

| | | | |
|---|---|---|---|
| 3. *Determine the traffic patterns to be monitored* | • CDOT and researchers have identified 4 patterns<br>○ Commute<br>○ Non-commute<br>○ Mountain non-commute<br>○ Mixed | • MnDOT has not officially identified patterns<br>• MnDOT research has identified 2 patterns<br>○ Mixed recreational<br>○ Mixed utilitarian | • ODOT has not officially identified patterns<br>• Research has so far identified 3 patterns<br>○ Bicycle utilitarian<br>○ Recreational<br>○ Mixed use patterns |
| *4. Establish seasonal pattern groups* | • CDOT and researchers have established 3 groups<br>○ Mountain non-commute<br>○ Front-Range non-commute<br>○ Commute | • Not yet established | • Not yet established. |
| *5. Determine the appropriate number of continuous ATR locations* | • Not yet determined<br>• Research indicates need for 7 ATRs per factor group. | • Not yet determined | • Not yet determined<br>• Number of ATRs will be based on population, weather, bicycle routes, and ODOT regions |
| *6. Select specific count locations* | • CDOT has added 12 new sites to account for geographic regions, volume, facility types, and use patterns (Stolz 2013) | • Not yet selected | • Not yet selected<br>• Focusing on data from 2070 controllers throughout state to count bicycles and pedestrian phases. |
| *7. Compute monthly factors (QA/QC)* | • Researchers have analyzed error rates for inductive loop counters (Nordback 2010 and 2011)<br>• CDOT and researchers have computed and validated day-of-week and monthly adjustment factors | • MnDOT has no standard factors<br>• Researchers have computed<br>○ Hourly occlusion adjustment factors for active infrared counters<br>○ Hourly, day-of-week, monthly, and day-of-year adjustment factors for mixed mode traffic | • ODOT has not yet computed standard factors<br>• PBOT has validated counts at some locations |
| *8. Develop seasonal factors* | • CDOT has developed and is using day-of-week and monthly factors | • MnDOT has not begun using non-motorized adjustment factors | • ODOT is working on a methodology to calculate seasonal factors |

Table 3. Status of short-duration non-motorized traffic monitoring programs in Colorado, Minnesota, and Oregon.

| Steps in a short duration program | Colorado | Minnesota | Oregon |
|---|---|---|---|
| 1. Select count locations (random vs. non-random) | • CDOT<br>o Sites chosen purposefully (non-random)<br>• Local jurisdictions<br>o Sites chosen purposefully (non-randomly) | • MnDOT<br>o No short-duration locations monitored<br>• Local jurisdictions<br>o Short-duration locations chosen purposefully (non-randomly) | • ODOT<br>o No short-duration locations monitored<br>• Local jurisdictions<br>o Short-duration locations chosen purposefully (non-randomly)<br>o METRO samples trails with passive infrared counters |
| 2. Select type of count (segment and/or intersection) | • CDOT<br>o Segment<br>• Local jurisdictions<br>o Manual segment and intersection counts<br>o Boulder County: segment | • MnDOT<br>o Focuses on segment counts<br>• Local jurisdictions<br>o Mainly segment counts | • ODOT<br>o No short-duration locations monitored<br>o Conducts intersection and segment counts as needed<br>• Local jurisdictions<br>o PBOT: both segment and intersection counts<br>o METRO: is planning screen-line counts to calibrate planning models |
| 3. Determine length of short-duration counts | • CDOT<br>o Recommends minimum length of 1 week; some counts over one month<br>o Does not use counts less than 24-hours<br>o On-street 48-hour bicycle tube counts planned<br>• Local jurisdictions<br>o Mostly 1 to 3 hour counts<br>o Boulder Co.: 24-hour to 1-week bike counts | • MnDOT<br>o Not determined minimum length; research underway<br>• Local jurisdictions<br>o Mostly 1 to 3 hour counts | • ODOT<br>o Not determined minimum length; research underway |

Table 3. Status of short-duration non-motorized traffic monitoring programs in Colorado, Minnesota, and Oregon, continued.

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| 4. Determine method of counting (automated vs. manual) | • CDOT<br>   o Agency policy to only collect and archive short-duration counts taken with portable, automated monitors<br>   o Most data from infrared monitors<br>• Local jurisdictions<br>   o Boulder County: pneumatic tube counters which classify motor vehicles and cyclists | • MnDOT<br>   o Encourages local jurisdictions to do both automated and manual short-duration counts<br>• Local jurisdictions mainly do 2-hour manual field counts following NBPDP protocols<br>   o 44 municipalities completed manual field counts at more than 550 locations in 2012<br>   o Three Rivers Park District samples trails with Fpassive infrared counters | • ODOT<br>   o Encourages only the utilization of automatic counters; does not support manual segment counts<br>   o METRO heavily relies on manual counts |
| 5. Determine number of counts | • CDOT<br>   o No guidance on number of sites needed to characterize networks<br>   o ± 30 sites monitored<br>• Local jurisdictions<br>   o Boulder County: 150 locations planned in 2013 | • MnDOT<br>   o No guidance on number of sites needed to characterize networks<br>   o Research illustrates number of sites needed to estimate miles traveled with different levels of confidence<br>• Local jurisdictions<br>   o 44 municipalities completed manual field counts at more than 550 locations in 2012 (more than 400 locations in Minneapolis)<br>   o Research ongoing to sample 78 mile trail network in Minneapolis | • ODOT<br>   o No guidance on number of sites needed to characterize networks |

Table 3. Status of short-duration non-motorized traffic monitoring programs in Colorado, Minnesota, and Oregon, continued.

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|---|---|---|---|
| 6. Evaluate counts (accuracy characteristics, variability) | • CDOT<br>  ○ No agency guidance on QA-QC adopted<br>  ○ Related research published and ongoing<br>• Local jurisdictions<br>  Boulder County: assessed accuracy of pneumatic tube counters for bicycle counting (Hyde-Wright et al 2013) | • MnDOT<br>  ○ No agency guidance on QA-AC adopted<br>  ○ Related research ongoing: testing commercial technologies to assess accuracy of counts | • ODOT<br>  ○ No agency guidance on QA-AC adopted<br>  ○ Isolated efforts to validate counts using different technologies.<br>  ○ Research to provide guidelines ongoing |
| 7. Apply factors (occlusion, time of day, day of week, monthly, seasonal) | • CDOT<br>  ○ Computations are underway | • MnDOT<br>  ○ Research documents general approach for applying factors and estimating miles traveled on multiuse trails<br>• Local jurisdictions<br>  ○ Minneapolis has protocols for extrapolating 12 hour manual counts | • ODOT<br>  ○ Research to provide guidelines ongoing |

2. Develop inventory of continuous reference monitoring sites. Each state agency has completed an inventory of continuous monitoring sites. The number of continuous reference sites varies, with more sites in Colorado than Oregon and Minnesota, respectively, and, across states, more sites maintained by local jurisdictions than their respective state DOT. CDOT now maintains 20 monitoring sites. Local jurisdictions maintain at least 63 more permanent locations; approximately two-thirds of these are in the Denver metro area known as the Front-Range of the Rocky Mountains. All the sites conduct segment counts using inductive loops to count bicycles (on-street or on shared-use paths) or infrared counters to count mixed-mode traffic (i.e., undifferentiated bicyclists and pedestrians) on shared-use paths, except one site where video detection cameras count bicycles in bike lanes. In Oregon, ODOT maintains one permanent loop counter on a shared-use path and is trying to collect permanent counts at 20 intersections using 2070 traffic controllers. The Portland Bureau of Transportation (PBOT) maintains at least 19 permanent sites including pneumatic tubes to count bikes on bridges, one inductive loop on a shared use path, and 15 intersection counters. Portland METRO, a regional planning agency, has another 43 counters (mainly passive infrared and one which combines infrared and inductive loop technologies to count both bicyclists and pedestrians separately) that it uses to monitor traffic on shared-use and pedestrian-only trails. There are fewer permanent reference sites in Minnesota: MnDOT currently does not operate any reference sites. Local agencies in Minneapolis maintain 3 inductive loop and 8 active infrared counters on shared-use paths at 6 sites. The Three Rivers Park District maintains 7 infrared counters. Each of the sites in each state has been purposely located; no DOT has located sites using randomized sampling techniques.

3. Determine traffic patterns to be monitored. Each DOT is analyzing non-motorized traffic patterns, but only CDOT has formally specified specific patterns to be monitored (i.e., commute, non-commute, mountain non-commute, and mixed). The mountain non-commute recognizes geographic differences in patterns across the state. Research sponsored by ODOT has identified 3 patterns: bicycle utilitarian, recreational, and mixed, and MnDOT has, following Miranda-Moreno et al. (2013), identified mixed utilitarian and mixed recreational patterns on shared-use paths. MnDOT also has documented differences in modal patterns on shared-use path (e.g., bicyclists vary more in response to weather than pedestrians).

4. Establish seasonal pattern groups. CDOT is the only agency to have established seasonal pattern groups. The three CDOT groups reflect geographic differences in the state: mountain non-commute, front-range non-commute, and commute. Both MnDOT and ODOT are engaged in research to identify seasonal pattern groups.

5. Determine number of automated continuous reference sites. No state DOT has yet determined the number of continuously monitored reference sites needed to reflect the patterns within its state. CDOT-sponsored research indicates a minimum of seven reference sites are needed per factor group. ODOT believes the number of sites will be a function of geographic differences across the state, corresponding weather patterns, population characteristics, and bicycle route characteristics.

6. Select specific count locations. Because selection of monitoring locations follows determination of the number of locations needed, none of the state agencies has identified specific locations. When CDOT recently established 12 new count stations, non-motorized traffic volume, geographic regions, facility types, and user patterns were considered (Stolz, 2013). ODOT is focusing on counting at intersections using existing controller technologies because this approach will provide information without the cost of new equipment. MnDOT will be testing new

technologies and deploy them at locations chosen by local jurisdictions that eventually will operate them.

7. Compute monthly factors (*QA/QC*). Each DOT is working on quality assurance / quality control and computation of monthly factors. CDOT has computed day-of-week and monthly adjustment factors and is using them to estimate annual average daily traffic. MnDOT research has measured error in inductive loop and active infrared counters, computed hourly adjustment equations to correct undercounts associated with occlusion, and illustrated hourly, day-of-week, and monthly adjustment factors. ODOT has not yet standardized procedures for computing factors but is developing a methodology. PBOT has validated counts taken using automated counters and is developing factors.

8. Develop seasonal factors. CDOT is the only state agency that is in the process of integrating non-motorized counts into its traffic monitoring database and routinely applying seasonal and other adjustment factors.

*Progress in Establishing Short-duration Monitoring Programs*

1. Select count locations. Only one DOT has implemented a short-duration count program, although each is aware of initiatives launched by local jurisdictions. CDOT operates portable passive infrared counters that rotate by request of local jurisdictions and collect data for at least one week at each site. Boulder County has an on-street count program that uses pneumatic tube counters to count bicycles and motor vehicles simultaneously at 150 sites (*39*). All local count locations have been chosen purposefully. Many short-duration counts have been taken on shared-use paths. In Oregon and Minnesota, regional and local agencies use passive infrared monitors to take short duration counts on shared-use paths.

2. Select type of counts (segment, intersection). Each DOT is focused primarily on encouraging segment counts as a basis for estimating non-motorized traffic volumes, although local agencies also complete intersection counts as needed, depending on priorities and the availability of technology. In Oregon, PBOT is developing procedures for both segment counts at key bridges and for counts from controllers at intersections, in part because the technologies at the intersection exist and can yield information about relative volumes, if not exact counts.

3. Determine length of short duration counts. The three DOTs diverge somewhat in their perspectives and policies on the length of short-duration counts. Based on research findings, CDOT recommends that short duration counts be at least one week long. CDOT discourages counts less than 24 hours because of error that results when the counts are extrapolated to obtain AADT. Neither ODOT nor MnDOT have established formal guidelines for the length of short-duration counts.

4. Determine method of counting (automated or manual). Each DOT considers automated counts essential for integration of non-motorized and motor vehicle counts, but manual counts tend to be more common among local jurisdictions in each state, and the number of sites where manual counts occur is greater. CDOT, MnDOT, and ODOT have different perspectives on manual counts, with CDOT establishing a policy to only archive automated counts, and MnDOT encouraging local jurisdictions to undertake both automated counts and counts following the NBPDP protocols. One reason MnDOT encourages manual counts is that they can provide information about user attributes not available from automated counts such as gender or helmet use. ODOT is interested primarily in

automated counts but METRO and other local agencies organize volunteers to complete manual counts.

5. Determine number of counts. None of the state DOTs has issued guidance concerning the number short-duration counts needed to characterize traffic volumes on transportation networks, and none has specified protocols for determining the number required to characterize different sizes of networks. MnDOT previously sponsored research that illustrated an approach to a probability-based estimates of bicycle miles traveled. (Davis 2001) demonstrated that for 16 factor groups (4 road types stratified by 4 population density categories), 33 observations per stratum would be needed to estimate bicycle miles traveled in a three county area within 18% of the true value with 68% confidence. No public agencies in Minnesota have implemented programs based on this guidance, however. In each state, counts taken following NBPDP-type protocols are being used principally to illustrate the order of magnitude of traffic volumes, not to estimate AADT.

6. Evaluate counts (accuracy, characteristics, variability). CDOT, MnDOT, and ODOT each recognizes the importance of evaluation of the quality of short duration counts, but only CDOT has begun to standardize procedures for assessing data quality. CDOT's strategic plan for monitoring outlines heuristics for identification of outliers and discusses approaches to inspection and validation of suspect daily counts. CDOT traffic monitoring database software includes sets of heuristics that can be run to check for bad data. CDOT also has participated in studies of the accuracy of automated counters. MnDOT-sponsored research has identified the problem of systematic counter error and is now validating commercially available technologies, including portable counters. ODOT has not established technical guidance, but local agencies have completed some validation of counters.

7. Apply factors (occlusion, time of day, day of week, monthly, seasonal). CDOT has made greater progress than MnDOT or ODOT in development and application of factors for extrapolation of short duration counts to estimates of AADT. CDOT traffic monitoring software is being used to derive and apply factors for the factor groups, and estimates of AADT are being produced for some sites. MnDOT research has illustrated methods for estimating AADT and miles traveled on segments of networks, but neither MnDOT nor any local agency is routinely generating estimates of AADT. Similarly, in Oregon, ODOT and local jurisdictions have not published standard procedures for applying adjustment factors, but efforts are underway to develop them.

## 5. Common Challenges and Evolving Programs

CDOT, MnDOT, and ODOT share common challenges in developing non-motorized traffic monitoring programs, and they are at different stages in implementation. CDOT has done most to institutionalize monitoring, making progress on most of the steps of permanent and short duration monitoring. CDOT has established state-operated continuous monitoring sites, initiated a short-duration count program, developed factors for extrapolation of short-duration counts, begun to integrate non-motorized counts with vehicular counts in a common database, and is encouraging and collaborating with local monitoring initiatives.

MnDOT and ODOT, in comparison, are not as far along, but each has made progress consistent with the TMG framework. MnDOT has inventoried programs, supported research to identify factor groups and develop factors, posted standard procedures for manual counts, and is testing commercially-available monitoring devices, collaborating with local initiatives, and exploring integration of non-motorized counts into its traffic monitoring database. MnDOT has not, however, made the policy decision to establish state-operated permanent or short-duration monitoring sites. ODOT is inventorying monitoring programs, operates one site and is collecting and analyzing data from controllers at intersections, supporting research to identify factor groups and compute factors, and is collaborating with local initiatives. Neither MnDOT nor ODOT has yet adopted general protocols for the collection, cleaning, and factoring of continuous or short duration data.

Within each state, local initiatives have preceded and informed development of state initiatives. In Colorado, monitoring programs in Boulder and Denver inform the CDOT initiative. In Minnesota, counting programs administered by the Minneapolis DPW and the nonprofit Bike Walk Twin Cities shaped the MnDOT initiative, and in Oregon, work by PBOT and METRO is informing ODOT initiatives. This collaboration between local "early adopters" and state DOTs is important in developing more comprehensive programs that serve other local jurisdictions that have not initiated monitoring programs.

Another similarity across states involves the deployment of different types of automated counters on different types of infrastructure over time. In each state, early monitoring initiatives focused on use of inductive loop detectors or infrared monitors on off-street, shared-use paths to monitor, respectively, bicycles or mixed-mode traffic. Each state has documented examples of failure of these first-generation technologies. As programs have evolved, states have begun to deploy newer technologies, including integrated infrared and inductive loop monitors that provide mode splits on shared-use paths, and inductive loops in streets that distinguish bicycles from motor vehicles. While these newer technologies now are being deployed, few validation studies and monitoring results have been reported. Least is known about pedestrian traffic on sidewalks: fewer technologies for counting pedestrians are available, the conditions on sidewalks that affect installation are both more variable and limiting, and pedestrian traffic itself may vary more spatially in response to socio-demographics and characteristics of the built environment. Stated another way, state and local agencies now know most about non-motorized traffic patterns on the infrastructure that is easiest to monitor (i.e., shared-use paths) and the least about patterns on infrastructure where most non-motorized traffic occurs (i.e., sidewalks). None of these three state agencies have made significant progress in monitoring or characterizing pedestrian traffic.

While there are many similarities across these initiatives, each has distinctive elements. CDOT has made the most important decision in institutionalizing a statewide monitoring program, namely, the decision to operate and support both continuous and short duration monitoring locations. ODOT is operating a site, but MnDOT has not yet made a decision to implement its own monitoring network. MnDOT, in contrast to CDOT and ODOT, has made the decision to support manual field counts, releasing its own version of NBPDP-style protocols and encouraging municipalities to participate. MnDOT recognizes that automated continuous and short duration monitoring is essential, but supports the two-hour counts as well because Minneapolis and other jurisdictions have established programs, the jurisdictions are collecting data on gender and helmet use that cannot be obtained from automated counts,  and staff believe that engaging jurisdictions in manual counts helps build support for automated monitoring. ODOT, like CDOT, is focused on automated, continuous monitoring, but is developing methods for capitalizing on existing infrastructure that can be adapted to provide measures of traffic volumes, specifically inductive loops and 2070 controllers at intersections. This strategy has the potential to provide useful information without the added cost of establishing new monitoring sites.

Each of the state DOTs has begun identification of factor groups and development of factors for estimating AADT from short duration counts. While each state has recognized the need to distinguish utilitarian or commuter-related traffic patterns from recreational based patterns, they have not specified the criteria for categorizing has not been specified, and the language used to describe patterns varies. Each state DOT also has recognized the need to develop factors specific to geographic region and by mode, but only CDOT has specified geographically based factor groups.

The fact that CDOT, MnDOT, and ODOT are at different stages in the implementation of non-motorized traffic monitoring programs is not surprising: differences in both the scope and rate of implementation are to be expected because states differ in needs, priorities, and the availability of resources. What is useful about this study is the degree to which these three DOTs share challenges and are responding in similar ways, yet customizing their programs to meet particular needs. Other states can learn from the progress these states have made. More generally, these similarities and differences in approaches illustrate the range and types of decisions other state DOTs will need to make to implement monitoring.

## 6. Progress in Monitoring but Miles to Go

Across the U.S., non-motorized traffic monitoring is in the early stages of development and implementation. Increasing numbers of local agencies in municipalities have launched monitoring programs, and state DOTs are in varying stages of exploring or beginning monitoring programs. The FHWA is beginning new initiatives to institutionalize non-motorized traffic monitoring, including, for the first time, issuance of guidance for non-motorized traffic monitoring. Chapter 4 of the FHWA's TMG recommends networks of more or less permanent, continuous reference monitoring sites and larger numbers of short duration monitoring sites. No state or municipality yet has established comprehensive programs consistent with this guidance that approach the scale of programs for monitoring vehicular traffic. Similarly, no state or municipality yet has the capacity to routinely report AADTs or bicycle or pedestrian miles traveled, the analogue to vehicular miles traveled that informs transportation planning. But state DOTs are making progress, especially in monitoring bicycle traffic.

As this study has illustrated, the key policy question each state DOT faces is whether to initiate a comprehensive program that includes both continuous and short-duration counts designed to lead to estimates of AADT and miles traveled on travel networks. Other considerations – such as the development of QA/QC procedures or determination of factor groups and procedures for factoring – flow from this decision. The Colorado, Oregon, and Minnesota DOTs are in the vanguard of the national monitoring movement, and each has answered this key question differently. As a result, their progress in both technical areas (e.g., factoring) and programmatic areas (e.g., development of performance indicators) varies.

This study also has illustrated where additional research is needed. Neither the FHWA nor these three states have developed general protocols for determining the number of continuous and short-duration monitoring locations needed to characterize traffic flows on a network. Guidance is not available, for example, for assessing variation in traffic flows and determining the length of road segments that can be characterized with a short-duration count. New guidance in the design of monitoring networks would be beneficial. Although researchers have made progress in determining minimum lengths of time for short-duration monitoring and factor groups, additional research still is needed. Concerted efforts by both researchers and practitioners to standardize terms used in non-motorized traffic monitoring also would be useful.

Finally, we have not explored the question of resources required to establish and operate monitoring programs, but it is clear that the need for resources will be substantial. A useful follow-up study could focus on the costs associated with different strategies to institutionalize monitoring. Information from other states that have launched initiatives, including Vermont and Washington, would be useful. State DOTs can gain efficiencies in implementation by learning from their peers about successes and problems in implementation.

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