Institutionalizing Bicycle and Pedestrian Monitoring Programs in Three States

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Information about nonmotorized traffic is needed to support management of transportation systems. However, transportation officials across the United States generally have not monitored nonmotorized traffic, and most agencies lack bicycle and pedestrian counts. This paper describes current efforts by the Colorado, Minnesota, and Oregon Departments of Transportation (DOTs) to establish programs for monitoring nonmotorized traffic. With FHWA principles for traffic monitoring as a framework, this case study summarizes state approaches for initiating monitoring, agency collaboration with local governments, and 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 are described. This 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 that DOTs will face in institutionalizing the monitoring of nonmotorized traffic.

Information about the use of streets, sidewalks, and shared-use trails by bicyclists and pedestrians is needed to improve management of transportation systems. However, transportation officials across the United States generally lack basic information essential for planning, such as bicycle and pedestrian traffic volumes. This paper describes progress and challenges faced by departments of transportation (DOTs) of three states—Colorado, Minnesota, and Oregon—in establishing programs for monitoring nonmotorized traffic. Following a review of the literature on traffic monitoring, the authors summarize new FHWA guidelines for monitoring nonmotorized traffic and present a list of definitions of terms. Then, using the FHWA guidelines as a framework, they assess progress for each state. They summarize rationales for monitoring; collaboration with local governments; the scope of continuous and short-duration monitoring; and protocols for data collection, analysis, and management. They conclude by discussing issues all DOTs will face in institutionalizing programs for monitoring nonmotorized traffic.

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RECENT PROGRESS IN MONITORING OF NONMOTORIZED TRAFFIC

Over the past 20 years, governments at all levels have invested more in infrastructure for nonmotorized travel. Decision makers often have made these investments 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, managers are exploring strategies for monitoring of bicycle and pedestrian traffic.

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*). Researchers have since continued to report methodological advances. Davis et al., for example, published equations for estimating pedestrian crosswalk volumes from short (e.g., 5- to 30-min) counts (*3*).

Following passage of the Intermodal Surface Transportation Act in 1991, interest in bicycle and pedestrian data has grown. Hunter and Huang collected bicycle and pedestrian counts from agencies across the United States and reported volumes between 1,000 and 2,000 cyclists per day (*4*). They concluded, however, that the quality of the data was poor and could not be used to make inferences about traffic at other locations. The U.S. DOT's Bureau of Transportation Statistics came to a similar conclusion 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). Porter et al. reported on the state of the practice for forecasting bicycle and pedestrian traffic (*6*), and the FHWA released the *Guidebook on Methods to Estimate Non-Motorized Traffic* (*7*). The FHWA did not address, however, challenges in institutionalizing monitoring networks.

During the past decade, the number of studies describing technologies and methods for counting bicyclists and pedestrians has burgeoned. Researchers have described the strengths, limitations, and tradeoffs between manual and automated methods of counting (*8–15*). Nordback and Janson (*16*) and Nordback et al. (*17*) described general procedures for measuring error associated with automated bicycle counters. Miranda-Moreno et al. determined factor groups (e.g., utilitarian, recreational) on the basis of ratios of weekend–weekday daily traffic and morning and midday hourly traffic (*18*). Nordback et al. demonstrated the magnitude of error in estimates of average annual daily traffic (AADT) associated with extrapolation of short-duration counts of various lengths (*19*). Researchers also have estimated bicycle and pedestrian traffic flows on urban networks (*13, 20–22*).

While this research has demonstrated different methods of monitoring and spatial and temporal variations in traffic, it has not led to widespread institutionalization of monitoring. To date, most efforts have been by municipalities or regional governments, and most have involved manual counting, although a number of municipalities (e.g., San Francisco and San Diego, California) are launching ambitious monitoring programs that include automated, in-street monitoring of bicycles.

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, nationwide initiative launched in 2003 by the 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" (*23*). The voluntary NBPDP has raised awareness of the need for counting and engaging many communities but suffers from the lack of resources required for sustainability. In addition, researchers have demonstrated that estimates of AADT produced from 2-h short-duration counts, an NBPDP protocol, may have unacceptably high margins of error (*19*). These limitations notwithstanding, the NBPDP has helped build momentum for efforts to institutionalize monitoring.

For many 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. searched state DOT bicycle and pedestrian websites, classified bicycle and pedestrian programs according to evidence of programming, and surveyed agency staff from DOTs with well-established programs (*24*).

Their review identified the following:

- Sixteen states with abundant evidence of well-established bicycle and pedestrian programs, including some with traffic monitoring programs;
- Eighteen states with some evidence of programs but no evidence of monitoring; and
- Sixteen states with little or no evidence of programs (*24*).

Baker et al. concluded that three states—Colorado, Vermont, and Washington—have been leaders in monitoring nonmotorized traffic, although others, including Minnesota and Oregon, have commissioned studies to develop monitoring strategies. The Washington State DOT collaborates with municipalities in conducting counts by following the NBPDP methodology and publishes an annual summary of the counts (*25*); it is also working with automated counters. The Vermont Agency of Transportation owns automated counters, provides technical assistance with counting, and loans the counters to local governments (*26*). The Vermont Agency of Transportation also works with organizations on manual counts consistent with the NBPDP protocols and has analyzed counts taken throughout the state but concluded that data remain inadequate to estimate bicycle miles traveled (BMT).

The FHWA recently published an updated version of the *Traffic Monitoring Guide* (TMG), which includes a new chapter on monitoring nonmotorized traffic (*27*). This new chapter follows approaches used in motor vehicle monitoring and describes monitoring technologies, variability in nonmotorized traffic, and steps in establishing continuous and short-duration data programs (*27*).

The continuous data program will

1. Review the existing continuous count programs,
2. Develop an inventory of available continuous-monitoring sites and equipment,
3. Determine the traffic patterns to be monitored,
4. Establish seasonal pattern groups,
5. Determine the appropriate number of ATR locations,
6. Select specific count locations,
7. Compute monthly factors, and
8. Develop seasonal factors.

The short-term data program will

1. Select count locations (random or nonrandom),
2. Select type of count (segment or intersection),
3. Determine duration of counts,
4. Determine method of counting (automated or manual),
5. Determine number of counts,
6. Evaluate counts (accuracy characteristics and variability), and
7. Apply factors (occlusion, time of day, day of week, monthly, and seasonal).

The chapter also includes a discussion of the advantages and disadvantages of automated and manual counts, noting, for example, that manual counts provide limited information about temporal variation. The new chapter also illustrates how factors from continuous data can be used to extrapolate short-duration counts to obtain estimates of AADT.

KEY CONCEPTS AND DEFINITIONS IN MONITORING NONMOTORIZED TRAFFIC

While local, state, and federal governments are making progress, the terms used in monitoring have yet to be standardized. The lack of standard terminology is partly historical: transportation data have applications in areas that range from travel surveys and model validation to the estimation of accident rates and miles traveled. Over time, commonly used terms such as "screen-line counts" have been used differently. Other terms historically used in vehicular monitoring are being customized [e.g., vehicle miles traveled versus BMT]. To increase clarity, the authors adopt the following definitions:

Automated Traffic Recorder

In the term "automated traffic recorder" (ATR), "automated" refers to the absence of human intervention during operation of the counting device.

Continuous Count Program

A "continuous count program" is one designed to count traffic representative of travel activity over a region or geographic area. Here, "continuous" refers to 24-h counts from ATRs reported as time stamps or in bins (e.g., 15 min) for a minimum, uninterrupted duration of 1 year or more. These programs are used to determine travel patterns by purpose (e.g., recreation, commuting) and factors that reflect variability in temporal patterns. Although the TMG refers to these programs as permanent-count programs, the authors use the term "continuous" because some sites are not designed to be maintained perpetually.

Short Duration Count Program

A "short duration count program" is one conducted over a geographic study area to complement counts from ATRs and to increase the number of monitoring locations cost-effectively. Count durations usually range from 1 day to 1 month but may be as short as 2 h during peak periods (e.g., some NBPDP counts).

Segment Count

A "segment count" is any count of traffic crossing an imaginary line on a street, sidewalk, or path segment. Each segment count is representative of a continuous, homogeneous length of facility (e.g., same number and type of lanes, no major variation in volume).

Screen-Line Count

A "screen-line count" is traditionally used in transportation modeling and traffic monitoring 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 (e.g., a river that limits crossings to a business district). In some contexts, screen-line counts are used to describe segment counts defined earlier [e.g., NBPDP (*23*) and TMG (*27*)]. Here, the authors restrict the use of screen-line count to its historical meaning.

Intersection Count

"Intersection counts" are those taken at intersections or junctions where both total traffic and straight and turn movements typically are recorded. Intersection short-duration counts are commonly used for specific safety or signal-timing studies.

MONITORING NONMOTORIZED TRAFFIC IN COLORADO, MINNESOTA, AND OREGON

Because all state DOTs are likely to follow the approach to monitoring outlined in Chapter 4 on traffic monitoring of nonmotorized traffic in the new edition of the TMG, the current authors use that approach as a framework to assess progress by state DOTs in Colorado, Minnesota, and Oregon in implementing the monitoring of nonmotorized traffic. The principal objective here is to describe elements of these programs in a way that informs the implementation of other monitoring initiatives. The authors 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, comparison of their programs illustrates both the complexities of monitoring and the choices administrators must make in program development.

The complexity of the challenge of establishing a statewide traffic monitoring network is partly a function of the complexity of the state. Of 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) (*28*). Colorado is the largest (104,000 mi^2) and has 88,000 mi of roadway, for an average road length per square mile of 0.85 (*29*). The comparable figures for Minnesota are 79,000 mi^2, 137,000 mi of roadway, and 1.73 mi of road per square mile. Oregon has an area of 96,000 mi^2, 59,000 mi of roadway, and 0.61 mi of roadway per square mile. Bicycle commute shares within these states follow the same order as annual average temperature: Oregon has an average temperature of 48.4°F and 2.2% bicycle commuters; Colorado an average temperature of 45.1°F and 1.3% bicycle commuters; and Minnesota an average temperature of 41.2°F and 0.7% bicycle commuters (*30, 31*). Overall, Minnesota has the largest network to monitor, but the Oregon network, on average, is less dense. The rate of bicycle commuting in Oregon is nearly 70% higher than the rate in Colorado and triple the rate in Minnesota.

Colorado

In 2009, the Colorado DOT adopted a new policy directive for bicycles and pedestrians 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 "[t]he needs of bicyclists and pedestrians shall be included in the planning, design, and operation of transportation facilities, as a matter of routine," which was codified by the state legislature in 2010 and is now part of the Colorado Revised Code (Colorado Revised Statutes 43-1-120). The Colorado DOT recognized that, to meet this directive, it needed additional data on bicycle and pedestrian use.

Accordingly, the Colorado DOT initiated a program in 2009 to collect continuous counts of bicycles and pedestrians. Only two counters then operated in the Denver, Colorado, metropolitan area, but this number soon grew to 20 count locations and used both inductive-loop and infrared counters on and off street. The Colorado DOT also engaged local jurisdictions: two cities and four counties contributed data from 63 additional count stations. The agency also acquired six more infrared, mobile, short-duration counters in mid-2010 that since have periodically traveled to various off-street paths at locations requested by local jurisdictions. The mobile counters are usually placed for 1 to 4 (or more) weeks. The Colorado DOT does not collect or archive manual counts of less than 24 h (i.e., counts following NBPDP protocols) because estimating AADT from these short counts would lead to higher estimation error.

The Colorado DOT contracted with the Texas A&M Transportation Institute (TTI) to provide guidance on the count program and with the University of Colorado–Denver to create methods to estimate annual average daily bicycle and pedestrian traffic from short-duration counts (*32*). The agency has begun to implement many of the recommendations in the TTI report, including integration of monitoring data on both nonmotorized and motorized traffic.

Minnesota

The Minnesota DOT has supported programs and research to foster biking and walking for years, but systematic efforts to institutionalize the monitoring of bicycling and walking began relatively recently. For example, the Minnesota DOT funded research to document the feasibility of estimating BMT through video monitoring (*33*) and to develop automated video classification of bicyclists and pedestrians (*14*). With the adoption of a long-range plan to develop multimodal systems (2050 Vision—Minnesota Go), policies to support Complete Streets, Safe Routes to Schools, and Toward Zero Deaths, and new performance measures, the Minnesota DOT's interest in monitoring bicycling and walking has grown. This interest in monitoring has been influenced by successful counting initiatives by the Minneapolis Department of Public Works and a nonprofit, Bike Walk Twin Cities, which began monitoring in 2007 by using NBPDP protocols.

In 2011 and 2013, the Minnesota DOT funded projects at the University of Minnesota to develop consistent methods for monitoring, to provide training and support for local monitoring programs, and to 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 (*34*). 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 the Minnesota DOT is encouraging counting, it has yet to make most key decisions, including whether the state will assume responsibility for continuous count locations (or rely on local stations), determining counting locations, and selecting the types of factor groups to be monitored.

Oregon

Oregon has long supported the development of pedestrian and bicycle facilities. Oregon passed legislation in 1971 that requires the Oregon DOT, cities, and counties to include facilities for pedestrians and bicyclists wherever a road, street, or highway is built or rebuilt (Oregon Revised Statutes 366.514). The legislation requires that, in the long term, the amount expended to be at least 1% of the total amount of the funds received by the highway fund in any fiscal year (*1*). Oregon Revised Statutes 366.514 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 the Oregon DOT has funded facilities to foster biking and walking since the 1970s and first installed continuous bicycle counters in the 1980s, the agency has only recently begun systematic efforts to institutionalize monitoring. For example, the Oregon DOT Performance Dashboard contains one metric related to bicycle lanes and sidewalks (percentage 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.

The 2011 Oregon DOT Bicycle and Pedestrian Travel Assessment (PTA) recognized the need to enhance and implement collection of bicycle and pedestrian data (*35*), and in 2012, the Oregon DOT funded a research project at Portland State University for the design of a statewide program to collect bicycle and pedestrian data. The PTA and the Oregon DOT recommended that efforts concentrate on roadways, not trails, and on continuous counts from ATRs. The statewide program will build on local monitoring efforts. The city of Portland Bureau of Transportation (PBOT) has been implementing systems to count bicycle and pedestrian activity at intersections with advanced controllers (Model 2070 controllers). In addition, PBOT's bicycle unit has been counting bicycle volumes on the key bridges in Portland since the 1990s. Portland Metro, a regional planning agency, has also begun counting bicyclists and pedestrians to calibrate its bicycle and pedestrian models. Other metropolitan planning organizations and urban areas (e.g., Eugene and Salem; Oregon) with a high percentage of bicyclists and pedestrians are also developing capabilities for counting pedestrian and bicyclist.

Progress in Establishing Continuous Data Management Programs

Overall, each of the three states has made progress in implementing the general steps in monitoring outlined in the FHWA's TMG (see Tables 1 and 2), but no state has yet established a comprehensive program (*27*). This discussion summarizes that progress on various steps of the process.

1. Review existing programs. Each DOT—Colorado, Minnesota, and Oregon—has reviewed programs for nonmotorized counting, retained consultants, or sponsored research to develop plans. Colorado contracted with the TTI to prepare a strategic plan for nonmotorized monitoring (*32*) and collaborated with both local officials and university researchers at the University of Colorado–Denver in program development (*36*). The Minnesota DOT has reviewed past research and funded projects on methodologies for counting bicyclists and pedestrians and for implementation of monitoring. Oregon DOT similarly has reviewed programs and contracted for assistance in developing an integrated monitoring program, including continuous and short-duration monitoring sites.
2. Develop inventory of continuous-monitoring sites. Each DOT has inventoried continuous-monitoring sites: Colorado has more sites than either Oregon or Minnesota, but, in each state, more sites are maintained by local jurisdictions than by the state DOT. The Colorado DOT now maintains 20 monitoring sites. Local jurisdictions maintain at least 63 more continuous count locations; approximately two-thirds of these are in the Denver metropolitan area. All the sites conduct segment counts by 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. The Oregon DOT maintains one loop counter on a shared-use path and is trying to collect continuous counts at 20 intersections by using Model 2070 traffic controllers. PBOT maintains at least 19 ATRs, including pneumatic tubes, to count bikes on bridges, one inductive loop on a shared-use path, and 15 intersection counters. Portland Metro has another 43 counters (mainly passive infrared—and one that combines infrared and inductive-loop technologies to count bicyclists and pedestrians separately) that it uses to monitor traffic on shared-use and pedestrian-only trails. Minnesota has fewer continuous-monitoring sites: the Minnesota DOT currently does not operate any reference sites. Local agencies in Minneapolis maintain three inductive-loop and eight active infrared counters on shared-use paths at six sites. The Three Rivers Park District maintains seven infrared counters.
3. Determine traffic patterns to be monitored. Each DOT is analyzing patterns of nonmotorized traffic, but only the Colorado DOT has formally detailed specify patterns to be monitored (i.e., commute, noncommute, mountain noncommute, and mixed). The mountain noncommute category recognizes geographic differences in patterns across the state. Research sponsored by the Oregon DOT has identified three patterns—bicycle utilitarian, recreational, and mixed—and the Minnesota DOT has, following Miranda-Moreno et al. (*18*), identified mixed-utilitarian and mixed-recreational patterns on shared-use paths. The Minnesota DOT has also documented differences in modal patterns on shared-use paths.
4. Establish seasonal-pattern groups. The Colorado DOT is the only agency to have established seasonal-pattern groups. The three Colorado DOT groups reflect geographic differences in the state: mountain noncommute, front-range noncommute, and commute. Both the Minnesota and the Oregon DOTs are engaged in research to identify seasonal-pattern groups.

TABLE 1 Status of Continuous Programs for Monitoring Nonmotorized Traffic in Colorado, Minnesota, and Oregon

Continuous Count Program	Colorado	Minnesota	Oregon
1. Review existing continuous count program	Review completed Consultants retained to prepare strategic plan Monitoring research ongoing	Review completed Monitoring-related research ongoing	Review completed Monitoring-related research ongoing
2. Develop inventory of automated continuous count locations and equipment	Colorado DOT 20 inductive loop or passive infrared Local jurisdictions (63 sites) City of Boulder: 24 inductive loop counters City of Denver: one video bicycle counter Boulder County: three passive infrared Douglas County: 12 passive infrared Summit County: six passive infrared Pitkin County: 17 passive infrared ±50% of all sites count bicycles only ±50% of all sites count mixed-mode traffic (i.e., bikes and pedestrians combined) 45 sites have at least one complete year of data Segment counts only All locations purposefully sited (i.e., nonrandom)	Minnesota DOT No automated monitors Local jurisdictions Minneapolis DPW: three inductive loops on shared-use path Three Rivers Park District: seven passive infrared counters on shared-use paths University of Minnesota: eight active infrared counters at six locations on combined and separated paths Segment counts only All locations purposefully sited (i.e., nonrandom)	Oregon DOT One inductive loop on bicycle path 20 intersections with 2,070 controllers and loop detectors in the Portland metro area; more avail able in other cities but it is yet unknown how many intersections can provide useful bicycle data PBOT Tube counters on three bridges 15 intersections with 2,070 controllers and loop detectors 1 inductive loop–on shared-use path Metro and Tualatin Hills Parks 43 passive infrared portable counters One inductive loop–infrared combination counter for multiuse trail Segment and intersection counts All locations purposefully sited (i.e., nonrandom)
3. Determine the traffic patterns to be monitored	Colorado DOT and researchers have identified four patterns Commute Noncommute Mountain noncommute Mixed	Minnesota DOT has not officially identified patterns Minnesota DOT research has identified two patterns Mixed recreational Mixed utilitarian	Oregon DOT has not officially identified patterns Research has so far identified three patterns Bicycle utilitarian Recreational Mixed-use patterns
4. Establish seasonal pattern groups	Colorado DOT and researchers have established three groups Mountain noncommute Front range noncommute Commute	Not yet established	Not yet established
5. Determine the appropriate number of continuous ATR locations	Not yet determined Research indicates need for seven ATRs per factor group.	Not yet determined	Not yet determined Number of ATRs will be based on population, weather, bicycle routes, and Oregon DOT regions
6. Select specific count locations	Colorado DOT has added 12 new sites to account for geographic regions, volume, facility types, and use patterns [Stoltz (*36*)]	Not yet selected	Not yet selected Focusing on data from 2,070 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 (*16*, *17*)] Colorado DOT and researchers have computed and validated day-of-week and monthly adjustment factors	Minnesota DOT has no standard factors Researchers have computed Hourly occlusion adjustment factors for active infrared counters Hourly, day-of-week, monthly, and day-of-year adjustment factors for mixed-mode traffic	Oregon DOT has not yet computed standard factors PBOT has validated counts at some locations
8. Develop seasonal factors	Colorado DOT has developed and is using day-of-week and monthly factors	Minnesota DOT has not begun using nonmotorized adjustment factors	Oregon DOT is working on a methodology to calculate seasonal factors

NOTE: QA/QC = quality assurance/quality control; DPW = Department of Public Works.

TABLE 2 Status of Short-Duration Programs for Monitoring Nonmotorized Traffic in Colorado, Minnesota, and Oregon

Short Duration Program	Colorado	Minnesota	Oregon
1. Select count locations (random or nonrandom)	Colorado DOT Sites chosen purposefully (nonrandom) Local jurisdictions Sites chosen purposefully (nonrandom)	Minnesota DOT No short-duration locations monitored Local jurisdictions Short-duration locations chosen purposefully (nonrandom)	Oregon DOT No short-duration locations monitored Local jurisdictions Short-duration locations chosen purposefully (nonrandom) Metro samples trails with passive infrared counters
2. Select type of count (segment or intersection)	Colorado DOT Segment Local jurisdictions Manual segment and intersection counts Boulder County: segment	Minnesota DOT Focuses on segment counts Local jurisdictions Mainly segment counts	Oregon DOT No short-duration locations monitored Conducts intersection and segment counts as needed Local jurisdictions PBOT: both segment and intersection counts Metro: is planning screen-line counts to calibrate planning models
3. Determine length of short-duration counts	Colorado DOT Recommends minimum length of 1 week; some counts over one month Does not use counts less than 24 h On-street 48-h bicycle tube counts planned Local jurisdictions Mostly 1- to 3-h counts Boulder County: 24-h to 1-week bike counts	Minnesota DOT Not determined minimum length; research underway Local jurisdictions Mostly 1- to 3-h counts	Oregon DOT Not determined minimum length; research underway
4. Determine method of counting (automated or manual)	Colorado DOT Agency policy to only collect and archive short-duration counts taken with portable, automated monitors Most data from infrared monitors Local jurisdictions Boulder County: pneumatic tube counters which classify motor vehicles and cyclists	Minnesota DOT Encourages local jurisdictions to do both automated and manual short-duration counts Local jurisdictions mainly do 2-hour manual field counts following NBPDP protocols 44 municipalities completed manual field counts at more than 550 locations in 2012 Three Rivers Park District samples trails with passive infrared counters	Oregon DOT Encourages only the utilization of automatic counters; does not support manual segment counts Metro heavily relies on manual counts
5. Determine number of counts	Colorado DOT No guidance on number of sites needed to characterize networks ±30 sites monitored Local jurisdictions Boulder County: 150 locations planned in 2013	Minnesota DOT No guidance on number of sites needed to characterize networks Research illustrates number of sites needed to estimate miles traveled with different levels of confidence Local jurisdictions 44 municipalities completed manual field counts at more than 550 locations in 2012 (more than 400 locations in Minneapolis) Research ongoing to sample 78-mi trail network in Minneapolis	Oregon DOT No guidance on number of sites needed to characterize networks
6. Evaluate counts (accuracy characteristics, variability)	Colorado DOT No agency guidance on QA/QC adopted Related research published and ongoing Local jurisdictions Boulder County: assessed accuracy of pneumatic tube counters for bicycle counting	Minnesota DOT No agency guidance on QA/AC adopted Related research ongoing: testing commercial technologies to assess accuracy of counts	Oregon DOT No agency guidance on QA/AC adopted Isolated efforts to validate counts using different technologies Research to provide guidelines ongoing
7. Apply factors (occlusion, time of day, day of week, monthly, seasonal)	Colorado DOT Computations are underway	Minnesota DOT Research documents general approach for applying factors and estimating miles traveled on multiuse trails Local jurisdictions Minneapolis has protocols for extrapolating 12-h manual counts	Oregon DOT Research to provide guidelines ongoing

5. Determine the number of ATR locations. No DOT has determined the number of continuous-monitoring sites needed to reflect the patterns within its state. The Colorado DOT research indicates a minimum of seven continuous sites are needed per factor group. The Oregon DOT believes the number of sites will be a function of geographic differences across the state that correspond to weather patterns, population characteristics, and bicycle route characteristics.

6. Select specific count locations. Because selection of monitoring locations follows the determination of the number of locations needed, none of the state agencies has identified specific locations. When the Colorado DOT recently established 12 new count stations, volume of nonmotorized traffic, geographic regions, facility types, and user patterns were considered (*36*). The Oregon DOT is focusing on counting at intersections by using existing controller technologies because this approach will provide information without the cost of new equipment. The Minnesota DOT will test new technologies and deploy them at locations chosen by local jurisdictions.

7. Compute monthly factors [quality assurance/quality control (QA/QC)]. Each DOT is working on QA/QC and computation of monthly factors. The Colorado DOT has computed day-of-week and monthly adjustment factors and is using them to estimate AADT. The Minnesota DOT 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. The Oregon DOT has not yet standardized procedures for computing factors but is developing a methodology. PBOT has validated counts taken by using automated counters and is developing factors.

8. Develop seasonal factors. Only the Colorado DOT is integrating nonmotorized counts into its traffic monitoring database and routinely applying seasonal and other adjustment factors.

Progress in Establishing Short-Duration Monitoring Programs

The following items cover various elements to show the progress that the three subject states are making in short-duration monitoring:

1. Select count locations. Only one DOT has implemented a program of short-duration counts, although each is aware of initiatives launched by local jurisdictions. The Colorado DOT operates portable, passive infrared counters that move from one site to another at the request of local jurisdictions and collect data for at least 1 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 (*37*). 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 or intersection). Each DOT is focused primarily on encouraging segment counts as a basis for estimating volumes of nonmotorized traffic, although local agencies also complete intersection counts as needed; these depend 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.

3. Determine duration of counts. The three DOTs diverge somewhat in their perspectives and policies on the length of short-duration counts. On the basis of research findings, the Colorado DOT recommends that short-duration counts be at least 1 week long. The agency discourages counts less than 24 h because of error that results when the counts are extrapolated to obtain AADT. Neither the Oregon nor Minnesota DOT has established formal guidelines for the length of short-duration counts.

4. Determine method of counting (automated or manual). Each state DOT considers automated counts essential for integration of counts of nonmotorized and motor vehicles, but manual counts tend to be more common among local jurisdictions, and the number of sites where manual counts occur is greater. The three DOTS have different perspectives on manual counts, with the Colorado DOT establishing a policy to archive only automated counts, and the Minnesota DOT encouraging local jurisdictions to undertake both automated counts and counts that follow NBPDP protocols. The Minnesota DOT encourages manual counts because they can provide information about user attributes, such as gender, not available from automated counts. The Oregon DOT is interested primarily in automated counts but Portland Metro and other local agencies organize volunteers to complete manual counts.

5. Determine number of counts. No DOT has issued guidance concerning the number of 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. The Minnesota DOT previously sponsored research that illustrated an approach to probability-based estimates of BMT. Davis and Wicklatz demonstrated that, for 16 factor groups (four road types stratified by four categories of population density), 33 observations per stratum would be needed to estimate BMT in a three-county area within 18% of the true value with 68% confidence (*33*). No public agency in Minnesota has implemented programs based on this guidance, however.

6. Evaluate counts (accuracy, characteristics, and variability). Each of the three DOTs recognizes the importance of evaluation of the quality of short-duration counts, but only the Colorado DOT has begun to standardize procedures for assessing data quality. Its strategic plan for monitoring outlines heuristics for identification of outliers and discusses approaches to inspection and validation of suspect daily counts. The Colorado DOT has also studied the accuracy of automated counters. The Minnesota DOT has identified the problem of systematic counter error and is now validating commercially available technologies. The Oregon DOT has not established technical guidance, but local agencies have validated some counters.

7. Apply factors (occlusion, time of day, day of week, monthly, and seasonal). The Colorado DOT has made greater progress than the other two agencies in development and application of factors for extrapolation of short-duration counts to estimates of AADT. That DOT's 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. The Minnesota DOT research has illustrated methods for estimating AADT and miles traveled on segments of networks, but neither it nor any local agency is routinely generating estimates of AADT. Similarly, the Oregon DOT and local jurisdictions have not published standard procedures for applying adjustment factors.

COMMON CHALLENGES AND EVOLVING PROGRAMS

The three DOTs share common challenges in developing programs for monitoring of nonmotorized traffic, and they are at different stages in implementation. The Colorado DOT has done most to institutionalize monitoring, making progress on most of the steps of continuous and short-duration monitoring; it has established state-operated continuous-monitoring sites, initiated a program of short-duration counts, developed factors for extrapolation of short-duration counts, begun to integrate nonmotorized counts with vehicular counts in a common database, and is encouraging and collaborating with local monitoring initiatives.

The Minnesota and Oregon DOTs, in comparison, are not so far along, but each has made progress consistent with the TMG framework. The Minnesota agency 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. The Minnesota DOT has not, however, made the policy decision to establish state-operated sites for continuous or short-duration monitoring. The Oregon DOT is inventorying monitoring programs, operating one site, analyzing data from controllers at intersections, supporting research to identify factor groups and compute factors, and collaborating with local initiatives. Neither the Minnesota nor the Oregon DOT 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 state DOT initiative. In Minnesota, counting programs administered by the Minneapolis Department of Public Works and the nonprofit Bike Walk Twin Cities shaped the state DOT initiative, and in Oregon, work by PBOT and Portland Metro is informing Oregon DOT initiatives. This collaboration between local early adopters and state DOTs is important in developing more comprehensive programs to serve other local jurisdictions that have not initiated monitoring programs.

Another similarity across the three 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 the 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 that distinguish bicycles from motor vehicles in streets. Although these newer technologies 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 sociodemographics and characteristics of the built environment. Stated another way, state and local agencies now know most about patterns of the nonmotorized traffic on the infrastructure that is easiest to monitor (i.e., shared-use paths) and the least about patterns on the infrastructure where most nonmotorized traffic occurs (i.e., sidewalks). No DOT has made significant progress in monitoring or characterizing pedestrian traffic.

Each state's program has distinctive elements. The Colorado DOT has made the most important decision in institutionalizing a statewide monitoring program: to operate locations of both continuous and short-duration monitoring. The Oregon DOT is operating a site, but the Minnesota agency has not yet made a decision to implement its own monitoring network. It, in contrast to the DOTs in Colorado and Oregon, has made the decision to support manual field counts, releasing its own version of the NBPDP-style protocols. The Minnesota DOT recognizes that both continuous and short-duration monitoring is essential but also supports the 2-h counts because Minneapolis and other jurisdictions have established programs, local jurisdictions are collecting data that cannot be obtained from automated counts, and staff believes that engaging jurisdictions in manual counts helps build support for automated monitoring. The Oregon DOT, like Colorado's, 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. This strategy has the potential to provide useful information without the costs of establishing new monitoring sites.

Each DOT is identifying factor groups and developing factors for estimating AADT from short-duration counts. Each state has also recognized the need to distinguish utilitarian and recreational traffic patterns but has not specified criteria for categorizing, and the language used to describe patterns varies. Only the Colorado DOT has specified geographically based factor groups.

The fact that the three agencies are at different stages in the implementation of programs for monitoring of nonmotorized traffic is not surprising: differences in both the scope and the 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.

PROGRESS IN MONITORING BUT MILES TO GO

Across the United States, monitoring of nonmotorized traffic is in the early stages of implementation. Increasing numbers of local agencies have launched monitoring programs, and state DOTs are in varying stages of exploring or beginning monitoring programs. The FHWA has launched new initiatives to institutionalize monitoring of nonmotorized traffic, including, for the first time, issuance of technical guidance in the TMG. No state or municipality, however, has established monitoring programs that approach the scale of programs for vehicular traffic. Similarly, no state or municipality yet has the capacity for routine reporting of AADT or bicycle or pedestrian miles traveled. But 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 has also illustrated where additional research is needed. Neither the FHWA nor these three states have developed general protocols for determining the number of locations for continuous and short-duration monitoring 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 times for short-duration monitoring and factor groups, additional research is still needed. Concerted efforts by both researchers and practitioners to standardize terms used in monitoring of nonmotorized traffic also would be useful.

Finally, the authors have not explored the question of resources required to operate monitoring programs, but clearly they will be substantial. A useful follow-up study could focus on the costs associated with different strategies to institutionalize monitoring. State DOTs can gain efficiencies in implementation by learning from their peers about successes and problems in implementation.

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