Monitoring Bicyclist and Pedestrian Travel and Behavior

DETAILS

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Monitoring Bicyclist and Pedestrian Travel and Behavior

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Monitoring Bicyclist and Pedestrian Travel and Behavior

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Bicycle and Pedestrian Data Joint Subcommittee
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Introduction

Bicycling and walking, or "active transportation," are fundamental modes of transportation, but methods to monitor the traffic of these modes have been slow to advance until the last decade or so. The purpose of this document is to chronicle the most recent advancements in techniques and technology of active transportation monitoring, but it is not meant to be an exhaustive review of the field. Though written for an audience of practicing engineers, urban planners, transportation researchers, this e-circular may also be of use to citizens or activists interested in developing high-quality data on bicycling and walking. More specifically, this e-circular addresses two key objectives:

1. Identify a selection of recent advancements in bicycle and pedestrian data monitoring pertaining to both traffic volumes and behavioral data and
2. Introduce a selection of ongoing projects expected to contribute to the field of bicycle and pedestrian data.

As a TRB e-circular, this document is intended to be immediately helpful to researchers and practitioners, but only for a relatively short shelf life. As such, it does not address a detailed chronology of the field, nor offer recommendations on next steps. This document focuses on where we are now.

RAPID ADVANCEMENTS IN PERFORMANCE MONITORING

Detailed information on passenger and freight vehicles are required by the FHWA (*1*) and other agencies, and a variety of solutions for monitoring traffic and travel behavior have been available for motorized modes for many years. Recently, researchers and practitioners in bicycling and walking transportation have leveraged knowledge and technology in the field of traffic monitoring towards active transportation modes. This upswing in research is shown in Figure 1, which shows the results of a search in Google Scholar for the terms "bicycle pedestrian traffic count", increasing from only about 50 related publications in 1990, to more than 1,600 in 2011. Citations in general have also increased during this period to some extent. The slight decline of citations in the year 2012 implies a first indication of a maturing field and an opportune moment to document the state of the practice and the latest science.

NATIONAL BASELINES

Two key national surveys provide a pulse on travel in the United States, but are limited at smaller geographies: the U.S. Census—American Community Survey (ACS) and the National Household Transportation Survey (NHTS). The NHTS began in 2001 as a combination of the American Travel Survey with the Nationwide Personal Transportation Survey. The NHTS is limited to a small sample of the nation, but offers a local add-on sampling for jurisdictions wishing to bolster the accuracy of results in their area. Conducted every 5 to 7 years, the NHTS provides information on all travel modes for all travel purposes. Its sample size of more than 150,000

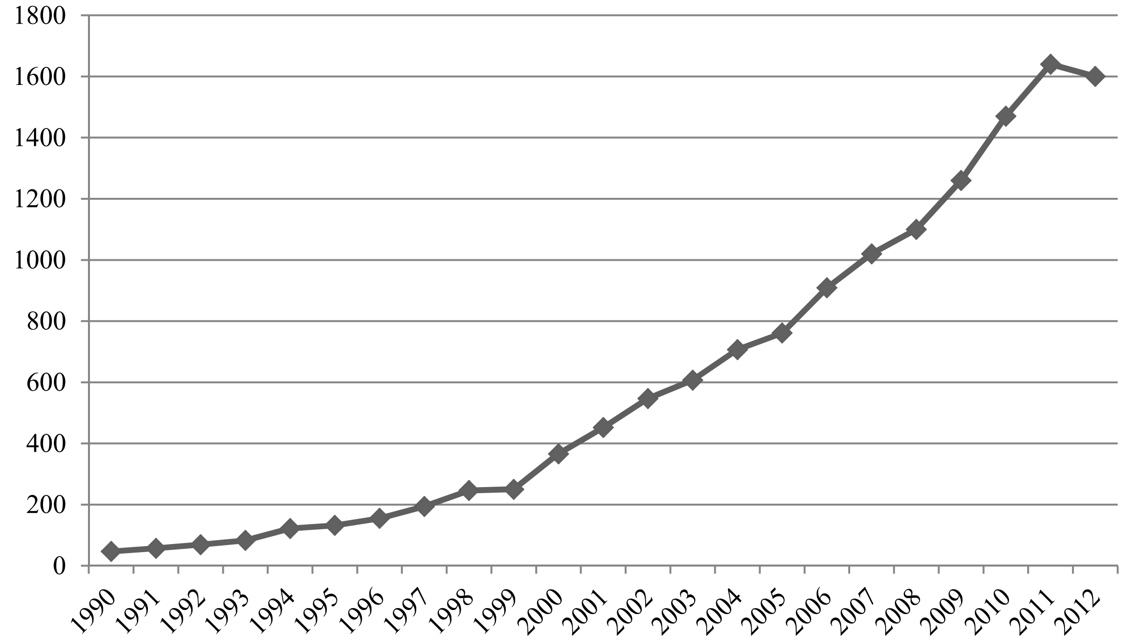

FIGURE 1 Research publications related to bicycle and pedestrian traffic counts. (Source: scholar.google.com.)

households across the United States can be very useful for nationwide statistics, but poses significant challenges in use for local bicycle and pedestrian studies (*2*).

In 1960, the U.S. Census started tabulating commute mode with the question: "How did this person get to work last week?" (*3*). The question wording and commute mode options have changed slightly over the years, and the ACS took over responsibility for journey-to-work from the decennial census following the year 2000, the last year for the long-form questionnaire (*4*). This change from full census tabulation to the sampling of the ACS decreased the absolute accuracy of the commute mode question, but increased its frequency. The modern ACS provides the most publicly accessible snapshot of commute mode data in the United States on an annual basis, but it has several problems for analysis of bicycling and walking. First, the ACS only asks about one trip purpose: the journey to work. In most places, more trips are taken as a pedestrian or bicyclist for other purposes as a whole, such as school, social, shopping and recreational purposes. The modern ACS question asks "How did this person usually get to work last week?" which means that any mode other than a respondent's predominant mode is not recorded at all. Also, the margins of error for smaller populations for a single year are rather large, limiting the usefulness of the data for many analyses. However, efforts such as the Census Transportation Planning Package add value to ACS data by offering cross-tabulations of journey-to-work with flow and demographic data.

GOING BEYOND THE AMERICAN COMMUNITY SURVEY

As discussed in this report, there are many other data sources and analytical techniques to quantify bicycling and walking than ACS data. In the year 2000, the Bureau of Transportation Statistics commissioned "Bicycle and Pedestrian Data: Sources, Needs and Gaps" (*5*), which set the stage for several data priorities, some of which have not been met in the 13 years since. In 2005, Schneider et al. published a detailed report of traffic monitoring and surveying techniques (*6*), following up with 29 case studies in bicycle and pedestrian data collection (*7*). Additional research made several advancements in the years since, with new providers offering additional equipment choices to a growing number of organizations interested in monitoring active transportation.

The past year (2013) has brought a major revision of FHWA's Traffic Monitoring Guide (TMG). The TMG is available free of charge at http://www.fhwa.dot.gov/policyinformation/tmguide/ and includes for the first time a chapter on monitoring bicycling and walking (Chapter 4: Traffic Monitoring for Non-Motorized Traffic). Additionally, Chapter 7 of the TMG specifies a data format for nonmotorized traffic data, which will allow it to be added to the Travel Monitoring Analysis System (TMAS). Readers interested in bicycle and pedestrian counting will find many helpful resources in the TMG. For those setting up or maintaining bicycle and pedestrian count program, the Initiative for Bicycle and Pedestrian Innovation provides an online resource based on Chapter 4 of the TMG (http://www.pdx.edu/ibpi/guide-to-bicycle-pedestrian-count-programs). Another major publication in the field is in draft as of this writing is NCHRP 07-19: Methods and Technologies for Collecting Pedestrian and Bicycle Volume Data, and should be published by June 2014. Authors make much use of both the TMG and NCHRP 07-19 for this e-circular, and readers are encouraged to review these for further background.

This e-circular is organized to enable a quick reference to methods. It begins with a review of traffic counting techniques for bicycling and walking (where and how much), then moves on to cover methods to understand travel behavior (who and why). A section on archiving and sharing data contains information on storing data and making it available for use. Some of the very latest innovations in the field incorporate a combination of traffic counting, travel behavior, and archiving and data sharing in more comprehensive techniques, and the authors attempt to group them in the category that dominates documentation of the methods. The next section covers research that is underway, or is suggested for the future. This e-circular concludes with a summary of the policy implications of bicycling and walking, and what it may mean to the future of transportation.

Traffic Counting

For a long time, the selection of count methodology for active transportation was a nonissue. Lack of funds as much as suitable technology left manual counts as the only option. These counts initially served the simple purpose of having a raw number behind active transportation (in particular, cycling), often in the context of advocacy efforts. With ongoing promotion of active transportation, increasing count timelines, tracking growth, and a focus on success of measures and policies, comparability of data over time has received more attention.

UNDERSTANDING NEEDS FOR ACTIVE TRANSPORTATION COUNTS

Count technology has evolved to provide a range of options, and active transportation receives increased attention and funding to justify more differentiated considerations of bicycling and walking counts. In many ways active transportation counting can learn and copy from motorized transportation; however, there remain several factors that require adaptations of motorized approaches to active transportation.

When determining the purpose of counting active transportation, two dimensions need to be distinguished:

- Is the purpose to learn about active transportation volumes as they change over time (e.g., from year to year, day to day, between hours of the day, or with the weather)?
- Is the purpose to learn about how much active transportation occurs where (e.g., on certain facilities, types of roads, neighborhoods, or by frequency of accidents)?

The first purpose, capturing temporal variability of active transportation, requires as long count periods as possible, ideally continuous counts. The number of count locations is less important, because often the relevant patterns across time correlate significantly (within reasonable distance).

The second purpose, capturing spatial variability of active transportation, is, at least in theory, about counting at as many locations as possible. This typically comes at the price of using techniques with shorter count periods, hence resulting in greater vulnerability to the influence of temporal variations of bicycling and walking.

Identifying count needs therefore means clarifying the questions of interest, and based on these, the balance between capturing temporal and spatial variation. For example, tracking the success of a long-term program is clearly a question of temporal variation—changes from year to year, ideally independent of seasonal influences—and best served with a continuous counter. The same is true for determining maximum capacity requirements of facilities, or the influence of weather. It also needs to be pointed out that short-term counts, even if conducted at many locations, are not very informative about changes over time, because short-term variations of active transportation typically outweigh long-term changes significantly.

Using counts for the purpose of capturing spatial variation of active transportation is by far the more challenging task, but understanding spatial variation of active transportation is crucial for many pressing questions in research and planning, such as addressing safety issues and improving infrastructure and other measures. Differences in active transportation across space—between neighborhoods, different facilities, from road to road—vary due to numerous factors. Many of these factors are hard to quantify or even identify, and can therefore rarely be reflected properly when selecting count locations. [Note: This does not apply to comparisons between cities, states, etc. Instead, it is based on population-based surveys that provide representative estimates of active transportation across fairly large areas (i.e., those of low spatial resolution).]

As a consequence, count data would need to stem from many randomly selected locations. Gaps could be filled in a variety of ways. Work in Vermont and Minnesota has simplified the problem by grouping like facilities to allow the computation of bicycle and pedestrian miles traveled (*8*, *9*). However, gaps between locations would need to be filled by fairly sophisticated spatial models. NCHRP 08-78: Estimating Bicycling and Walking for Planning and Project Development aims to address this to some extent by including land use and other spatial variables (*10*). Recent research from the University of Idaho uses a geographic information system (GIS) -based tool to estimate bicycle volumes using origin–destination centrality (*11*). Others are also working this problem with various approaches (*12–14*). Such efforts are hampered due to the lack of data. However, several technology developments will likely improve the feasibility of such models in the future.

The various counting methods and technologies available can be grouped into three general categories: short-term counts taken manually (that can use paper and pencil or smartphones); portable counters that can be left in place for a few days; and permanent stations that are embedded on an active transportation route and provide continuous data (Figure 2). Although much more research is desirable for refining the state of the practice in suiting all the needs of practitioners and researchers, recent guidance documents are beginning to standardize good practices.

NEW GUIDANCE ON ACTIVE TRANSPORTATION TRAFFIC COUNTS

Though techniques for counting bicycles and pedestrians have been available for several years, the practice is now becoming more common. The revised FHWA TMG dedicates a chapter on Traffic Monitoring for Non-Motorized Traffic (*15*), which provides a valuable review of existing techniques and guidance for implementation. This chapter includes a detailed data dictionary of recommended attributes that enable the development of new standard forms and computer software. Also, it provides guidance on choosing methods for bicycle and pedestrian counts, summarized in the Simplified Flowchart for Selecting Non-Motorized Count Equipment (Figure 3).

This chart simplifies the process of reviewing techniques for collecting bicycle and pedestrian volume data by identifying methods organized by transportation mode and duration of counting. It is a starting place for reviewing technologies, but practitioners will need to look at more specifics to suite their particular needs.

The guide recommends a system of many short and relatively sparse long-term counters. The long-term, permanent, automated count sites record 24-h per day, 365 days per year, thus providing information on temporal variation. From these data, hourly, daily, and monthly expansion factors can be created. These factors can then be multiplied by the short-term counts in order to estimate annual daily bicycle or pedestrian traffic at all the locations, not just those with long-term counters. Milligan et al. found that using National Bicycle and Pedestrian Documentation Project factors, generalized for a few regions in North America and applying them to pedestrians in Winnipeg resulted in greater error than if Winnipeg-specific motor vehicle factors were used (*16*). This finding shows the importance of establishing long-term count sites within the city or geographic area where short-term count sites are located.

FIGURE 2 Inductance loops and infrared sensors detect bicyclists and pedestrians constantly on the Lance Armstrong Bikeway in Austin, Texas. (Photo: Jim Lyle, TTI.)

1. What Are You Counting?

2. How Long?	Technology	Bicyclists Only	Pedestrians Only	Pedestrians & Bicyclist Combined	Pedestrians & Bicyclist Separately	Cost
Permanent	Inductance Loops[1]	●			◐	$$
	Magnetometer[2]	○				$-$$
	Pressure Sensor[2]	○	○	○	○	$$
	Radar Sensor	○	○	○		$-$$
	Seismic Sensor	○	○	○		$$
	Video Imaging: Automated	○	○	○	○	$-$$
	Infrared Sensor (Active or Passive)	○[3]	●	●	◐	$-$$
	Pneumatic Tubes	●			◐	$-$$
	Video Imaging: Manual	○	○	○	●	$-$$$
Temporary/ Short Term	Manual Observers	●	●	●	●	$$-$$$

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

FIGURE 3 Simplified flowchart for selecting nonmotorized count equipment. (Source: FHWA TMG 2012 Update.)

WHERE, HOW MANY, AND FOR HOW LONG?

The TMG recommends criteria for choosing count sites, methods for creating factors, and advice on how many sites are desired. Sites could be chosen to evaluate changes over time, before and after a construction project, or to understand regular active transportation traffic over an area. The number of sites is determined by the specific needs of a monitoring program, along with consideration of costs. Manual counts can be done for a few locations inexpensively, but as the number and length of counts increase, automatic equipment can be less costly considering staff time. San Diego, California, now has a large number of sites and has experienced a number of varying site challenges (*17*). The National Bicycle and Pedestrian Documentation Project provides guidance on performing 2-h manual counts, but Nordback recommends 7 days as the most cost-effective short-term count time period (*18*), implying the importance of monitoring technology.

Several newly published guides on developing active transportation monitoring programs are available, including The Colorado Mile Markers: Recommendations for Measuring Active Transportation (*19*), Counting Bicyclists and Pedestrians to Inform Transportation Planning (*20*), and The Minnesota Bicycle and Pedestrian Counting Initiative: Methodologies for Non-Motorized Traffic Monitoring (*21*). Some of the organizations that addressed active transportation monitoring programs include the North Central Texas Council of Governments, which took a collaborative approach on the topic by hosting a peer exchange on bicycle and pedestrian count programs and summarized its findings in an FHWA report (*22*); the Finland transport agency that published a comprehensive guide for municipalities, though only available in Finnish (*23*); and the Swedish National Road and Transport Research Institute (VTI), which issued a guide that includes the recommendation that short duration counts should be at least 2 weeks long. This guide contains an executive summary in English (*24*).

The question of how many permanent counters are needed for a comprehensive count program is just beginning to be addressed by researchers. A recent report published by the Colorado Department of Transportation (DOT) indicates that seven permanent count stations per factor group may be appropriate (*25*).

The largest project to date establishing a baseline of bicycling and walking traffic in the United States was developed in San Diego (*26*) by leveraging multiple different funding sources and expertise over time. Billy Fields established a comprehensive active transportation monitoring program that looked beyond counts in New Orleans (*27*), and the Texas A&M Transportation Institute (TTI) developed a baseline program in the Austin, Texas, region that stratifies facility types and urbanization levels (*28*). In some cases, practitioners have developed local plans to regularize monitoring like the Strategic Plan for Non-Motorized Traffic Monitoring in Colorado (*29*), the Delaware Valley Regional Planning Commission (DVRPC) (*30*), and the CAMPO Active Transportation Monitoring Plan (*31*).

A summary of the experience of three states (Minnesota, Colorado, and Oregon) in creating bicycle and pedestrian count programs was presented at TRB in 2014 (*32*). Other states such as Vermont, North Carolina, and Washington State are either establishing or improving bicycle and pedestrian count programs. Similarly, local and regional agencies have been and continue to expand such programs with and without coordination with their state DOTs.

Each of these resources can provide perspective with local experiences beyond guidance in the FHWA TMG. Monitoring programs exist for cities with as few as one to over 100 different monitoring sites. Data collected over time become valuable to show trends, so sustaining the counting program is important.

MANUAL TECHNIQUES

Standardized Protocols and Adjustment Factors

Perhaps the best-known method in manual bicycle and pedestrian data collection is the National Bicycle and Pedestrian Documentation Project (NBPDP) (*33*). This collaboration between Alta Planning + Design and the ITE Pedestrian and Bicycle Council was the first to standardize a manual counting protocol with coordinated count dates enabling comparison of counting locations or cities. This method provided the first standardized technique to improve comparisons across locations and years, but data are still vulnerable to seasonal and regional variations due to weather influence. This project developed and published free forms for both manual counts and intercept surveys, complete with a data entry spreadsheet to standardize reporting. The 2-h minimum manual count limits the use of the data to certain comparisons and statistical methods. Also, manual transcription with paper and pencil takes time to record and analyze. The method provides a low entry hurdle with minimum initial investment to counting, and was developed assuming local jurisdictions may have access to staff or volunteers, but not equipment. However, due to large temporal variation (mainly due to weather), collected data are of limited value for systematic comparisons but have been helpful for advocacy work that involves quantifying active transportation for the first time.

The project team also developed adjustment factors to convert manual counts on a given date to an annualized figure comparable to the average annual daily traffic (AADT) figure commonly used for vehicular traffic. Adjustment factors are inevitable to interpret short-term count data in a meaningful way; however, data availability is not yet sufficient to derive a reliable nationwide correction model.

A large study in San Diego County, California, combined the NBPDP methods with automatic counters to develop one of the most comprehensive studies of bicycle and pedestrian volumes and behavior available to-date (*26*). This project set the stage for the combination of manual counting techniques with professional equipment to document spatial and temporal variation in active transportation. Further research is could be helpful in developing adjustment factors and models that make use of local continuous count data, as well as weather and other potential predictors.

Technology-Assisted Manual Counting

An innovative advancement in manual counting techniques is a smartphone application in development at the University of Zurich (Thomas Götschi with Joshua Moody), which is called BikeCount (*34*) (Figure 4). It extends manual counting by replacing paper forms with an electronic wizard-based form on the smartphone. In addition, it provides a mid-block segment count and an intersection count method, as well as offering attributes such as gender and helmet use.

The app takes advantage of several smartphone features, such as automatically recording latitude and longitude, compass direction, and time-stamping count events. In the near future, wireless data transmission and integration in an online database are planned.

Aside from removing the paper trail from bicycle counts, the project has a more ambitious vision. The purpose of large numbers of short-term counts, possibly through crowdsourcing, is to inform spatial models. These models would combine the app counts with data about land use, traffic, weather, and most importantly, continuous counts from permanently installed counters. While calculating networkwide estimates of bicycle traffic, such a model would also determine statistical uncertainty of the results, and feed this information back to the mobile app. These features could direct users of the app to collect data where it is most needed, and for times periods that balance statistical validity with time spent counting, which would improve travel model estimates.

Networkwide estimates of bicycle traffic would serve research and planning efforts with regards to safety and infrastructure improvements, among others.

The BikeCount app is available in the iPhone app store; however, the project is in need of support to realize additional features. Another app, bikeandwalk by Bill Leddy, is also available. It delivers count data by e-mail.

PORTABLE COUNTERS

Portable counters provide a compromise of manual counts and continuous counts. They can be applied in more locations than continuous counters while being less affected by short-term variations in traffic flow due to weather, hour of the day, or weekday (depending on count duration). As indicated in Figure 4, portable counters, most often in the form of pneumatic tubes

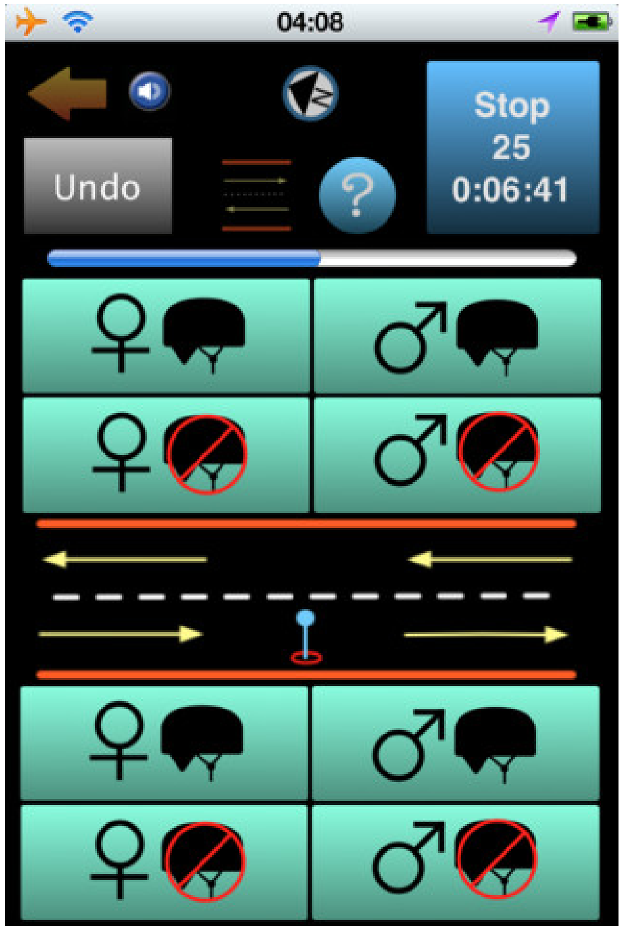

FIGURE 4 BikeCount midsection count screen.

for bicyclists or infrared sensors for both active modes, offer a balance of low cost for the amount of data they collect, with flexibility to move sites as needed. The accuracy of these units vary in environmental conditions, the make and model of the device, and the software programming. Generally, these devices have shown comparability to manual count accuracy, but both pneumatic tubes and infrared sensors often under-count. Pneumatic tube counters sometimes do not register lightweight riders such as children, and may also trigger false positives by motor scooters or very short wheelbase cars (Figure 5). Infrared counters can miss pedestrians in groups, and work best on paths with restricted widths (*35*, *36*).

In trail contexts, TTI measured three models of infrared counters against manual counts with average errors ranging from overcounting by 26%, to undercounting by 47% (*36*). A University of California, Berkeley, study evaluated the accuracy of Eco-counter's PYRO infrared unit compared with manual counts taken from video footage, and found a consistent undercounting bias, which can be used to develop equipment adjustment factors(*35*).

Recent research by the Boulder County Transportation Department revises existing classification schemes used by MetroCount brand pneumatic tube counters and demonstrates that if properly classified and set up, pneumatic tubes can be used to count bicyclists and motorists simultaneously. This technique requires that use of smaller diameter tubes and an updated vehicle classification system (*37*).

FIGURE 5 Pneumatic tube bicycle counter in Vancouver, British Columbia. (Image: Jean-Francois Rheault, Eco-Counter; used with permission.)

PERMANENT COUNTERS

When long-term data showing changes over seasons or years are desired, certain types of bicycle and pedestrian counters can be installed permanently as part of the facility. These counters are also useful to create seasonal adjustment expansion factors to estimate longer time periods from shorter counts, and to generalize trip purposes for a given facility (*18*, *29*, *38*). For off-street trails, they have been used to estimate bicycle miles traveled and pedestrian miles traveled for specific path lengths (*39*). Recent studies have focused on how to best estimate such expansion factors (*18*, *40–44*).

The most common permanent tool to count bicyclists is an inductance loop, which detects metals in a bicycle passing over the sensor (Figure 6). Accuracy of inductive loop counters has been measured by many and found to vary depending on location (*45*), but accuracy of 96% has been measured on a shared bicycle and motor vehicle road (*40*). Infrared sensors can capture both pedestrians and bicyclists on a path, and the addition of a processing unit can subtract bicycles detected using an inductance loop or other means to differentiate both modes at a given location.

Permanent counting stations are typically more expensive than other types of equipment, but offer several distinct advantages:

- Local weather and seasonal factors can be understood. Continuous data from a given location can allow development of adjustment factors for rain, snow or temperature variation. Since one location is monitored continuously, counts taken nearby can be adjusted for weather or season.
- Short-term counts can be extrapolated to other time periods. If daily, weekly, monthly and seasonal variations are tracked with a continuous station, local adjustment factors can be developed similar to motorized counts extrapolation to AADT. The TMG (*15*) and research on average annual daily bicyclists (AADB) by Nordback et al (*18*) and Hankey et al. (*43*) provide the latest guidance on these techniques. Recent evidence from San Diego indicates consistency in the percentage of total daily bicycle travel occurring during the p.m. peak period, suggesting the use of p.m. peak

FIGURE 6 Permanent counter on a shared-use path in Arlington, Virginia, with an inductance loop in the pavement and the infrared counter and processing unit hidden in the wooden post at left. (Image: Krista Nordback, P.E., Ph.D.; used with permission.)

percentage can be used with p.m. peak period manual counts to simply extrapolate daily bicycle volumes, much as is done with vehicular travel and estimation (*46*).

- Permanent sites are easy to communicate. Traffic counts are traditionally the purview of traffic engineers and specialists with limited appeal to a broader audience. New permanent station technologies allow immediate display of active transportation counts accessible to citizens. Copenagen and Portland are two cities with "bike barometers," physical signposts along a bikeway showing real-time count data. This information is now being broadcast online through a cellular transmission from permanent sites, resulting in simple web pages sharing the real-time information with anyone such as the example from Austin, Texas (*47*) (Figure 7).

Turner and Lasley recently published guidance on reviewing the quality of automatic counters, resulting in three principles of quality assurance (*36*):

1. Quality assurance starts before data are collected. Quality assurance should start before data are collected, and should include actions taken throughout the entire traffic monitoring program cycle.
2. Acceptable data quality is determined by its use. Data quality is a relative concept that has different meanings to different data consumers, depending upon how they intend to use the data.
3. Measures can quantify different quality dimensions. Previous research on traffic data quality measures recommended six key measures: accuracy, validity, completeness, timeliness, coverage, and accessibility.

Counts only report how many bicyclists and pedestrians are in a given location at a certain time. Questions like why they are traveling or what infrastructure they value can best be obtained through survey methods.

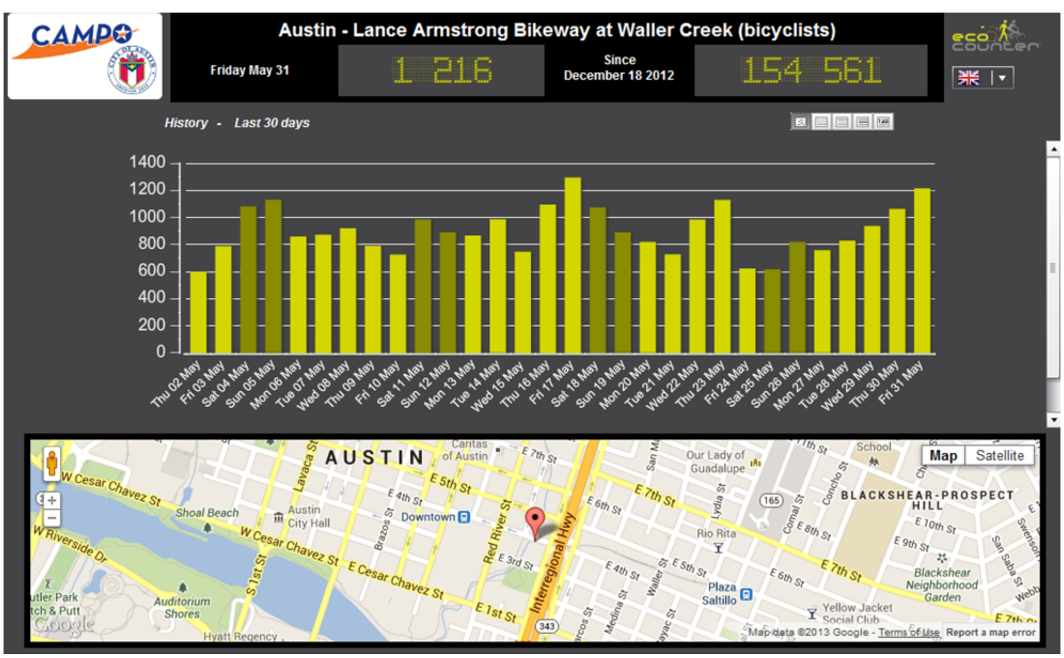

FIGURE 7 Real-time display of continuous bicycle count data in Austin, Texas.

Monitoring Travel Behavior

Surveys for monitoring travel behavior can include populations other than bicyclists or pedestrians, thus providing comprehensive information on an entire community. As previously discussed, the ACS is the best-known source of survey data for bicycling and walking in the United States, but it only includes a question on the commute trip purpose, and is limited to a small sample. The NHTS covers other trip purposes, but is generally an even smaller sample suitable for only national-scale evaluation, unless a community adds a larger sample. The key distinction is between population-based surveys (ACS, NHTS, etc.) and surveys of target populations (cyclists), typically defined by target locations (e.g., trail users). Only population-based surveys can quantify mode shares of an entire geographic area's population. However, surveys of targeted populations can provide much more detailed travel behavior information that could be specific to a certain mode or demographic.

SURVEY METHODS

Multimodal Surveying

Clifton and Muhs recognized the problem with many travel surveys; they found that these surveys assume trips are taken by only one mode. They therefore developed a survey method that captures the information of multimodal trips (*48*). The authors reviewed a vast literature on the topic, and offered recommendations to minimize the loss of multimodal passenger trip information. "Last-mile" connections to and from transit trips are the best-known example of missing multimodal information, such as walking to a bus stop, or carpooling to a park-and-ride station. The issue of how short of a trip to track was addressed by recommending walking trips over 150 ft to be included in multimodal surveys. Several recommendations are offered to improve computer-assisted telephone interviews, along with suggestions on the use of GPS to obtain observed, rather than reported travel data.

Pedestrian and Bicyclist Travel Survey

Forsyth, Agrawal, and Krizek recently developed a replicable method called the Pedestrian and Bicyclist Survey (PABS), meant to address the national surveys' shortcomings in depth of questions and sample size (*49*).They developed and validated questions to use at a jurisdictional level that can be used to develop a baseline of active transportation and monitor community-level changes in travel behavior. The survey is sent via postal mail to randomly selected households and is intended to be inexpensive and simple enough for most jurisdictions to be able to complete in-house. This method fills a gap in the survey methods provided at the national level and those that are corridor specific. The questions were tested for statistical reliability, and should provide comparable results if used by multiple jurisdictions.

Stated Preference Survey

The previous survey methods have focused on reporting travel behavior regarding travel in the past, but stated preference in surveying methods allow predictive modeling for facilities and routes that may not exist yet. They usually rely on the respondents' experience with given facility types, and can be described with text (*50*), the addition of photographs (*51*), or video as used in development of the Bicycle Compatibility Index (*52*). Depending on the methods and sample size, stated preferences may be extrapolated to represent a given group of people such as avid bicyclists, and predictive models can be created to predict behavior in settings that do not currently exist. Sener and others' work on the route preferences of bicyclists in Texas is one example, finding that a given route's travel time (for commuters) and motorized traffic volume were the most important factors in route choice (*50*). Work in the San Francisco Bay Area has looked at both motorist and bicyclist perception of facilities (*53*).

Intercept Survey

In many ways the most direct methods of surveying bicyclists and pedestrians is through capturing them while using a specific route during an intercept survey. Specific methods vary, including a short interview like the NBPDP's one-page Standard Bicycle Survey, and the one-page Standard Pedestrian Survey (*33*) (Figure 8). This standard method provides a repeatable protocol that has been used in several locations around the United States. Longer or more detailed surveys may be difficult or inconvenient to complete at a short stop along a journey. Rose used a mail-back questionnaire after intercepting bicyclists along an off-road path, and

FIGURE 8 Intercept survey. (Image: Alta Planning + Design.)

achieved a 77% response rate via mail from the bicyclists (*54*). This method provides the legitimacy afforded an in-person intercept survey with the convenience and detail of a mail-back response survey. Sperry and others have used this foot-in-the-door approach to achieve greater detail from a brief intercept survey with an Internet-based survey response. Sperry's Internet-based response rate was a lower 20%.

Bikeshare Surveying

Few studies have systematically analyzed demographic and travel behavior data from bike sharing, but the expansion of shared bicycle systems is enabling this method. Buck, Buehler and others analyzed a membership survey of Capital Bikeshare, with significant findings on the demographics and use of Washington, D.C.'s, bike share system (*55*):

> Compared to area cyclists, CaBi short-term users and annual members are more likely female, younger, have lower household incomes, own fewer cars and fewer bicycles, and are more likely to cycle for utilitarian trip purposes. Furthermore, CaBi trips mainly replace public transport and walk trips. CaBi short-term users and members show similar characteristics, but short-term users are more likely to ride for recreational trip purposes and less likely to wear a helmet.

This example of surveying takes advantage of Capital Bikeshare's desire to improve its management and expansion planning efforts, and provides insight from a maturing system as many others are currently under development.

Similar work in the Denver area based on members' surveys has found that 35% to 50% of bike share members replaced a car trip, and members are more likely than the general population to be between 25 and 44 years in age, male, white, non-Hispanic, high income and education, and self-report high health status (*56*).

An important reminder with any survey is that survey design should be tailored around the target population, and the extrapolation of that population to a broader group must be done carefully. National surveys such as the ACS and NHTS capture broad trends with a small sample size covering the entire United States; however, the data are limited. In converse, an intercept survey can provide detailed information on the users of a specific corridor, but the results cannot be extrapolated to a population larger than the type of users surveyed on that corridor. Each of these survey methods has its constraints, and several new technology solutions described below are showing promise to potentially reduce the cost and increase the accuracy of some of the results.

INFORMATION AND COMMUNICATION TECHNOLOGY METHODS

Relatively new applications of technology to monitor active transportation travel can cross the boundaries of whether a method is focused on understanding traffic counts or behavior. Smartphone technology and other systems can integrate an online survey instrument or other methods with screenline counting or route data storage. Though many of these techniques were pioneered for automobile applications, researchers and practitioners are using new tools to make active transportation data collection more efficient.

Global Positioning System Devices

Since GPS devices have become more commonplace, unobtrusive, and inexpensive, researchers have started using them for increasing the quantity of observed, rather than reported travel behavior data. Although GPS is particularly powerful for this application because of its unique combination of recording actual routes and specific times, a major drawback is spatial accuracy in the type of units used for bicycling and walking. GPS data is particularly good at showing the routes people actually chose on a trip, information that is often missing from simple traffic counts or surveys of trip origins and destinations. In this way, GPS data can be used for estimating volumes of travel on a specific route and understanding behavioral aspects through route choice.

Several issues affect the accuracy of GPS data: trees and buildings obscuring GPS signals, the geometric arrangement of the GPS constellation of satellites, and the quality of the GPS unit (*57*). Because of this, GPS routes can appear to bounce around to either side of an actual route when accuracy is decreased. But for tracking routes longer than only the shortest walking trips, modern GPS devices represent a relatively accurate and inexpensive way to record natural travel data (*58*). One recent study that tested algorithms for calibrating GPS-observed walking trips to actual trips had the best results when trips were more than 3 min long and more than 30 m in distance (*59*).

Aside from the issue of variable spatial accuracy from GPS data, the method of employing GPS-enabled smartphones for travel surveys is showing promise as a new method. Several GPS applications for tracking pedestrian and bicycle trips exist; one such application, CycleTracks, was developed by the San Francisco County Transportation Authority and has been widely used and adapted for transportation planning purposes (*60*). TTI and the University of Texas Center for Transportation Research partnered to use Austin, Texas, as a case study using CycleTracks (*61*) (Figure 9). From May to October 2011, they obtained more than 3,600 separate routes, though fewer than 10% of the respondents reported details on trip purpose and other attributes. Since GPS tracks do not usually neatly match roadway network centerlines, the team implemented an algorithm to match GPS tracks to a roadway network enhanced with additional bicycle and pedestrian facilities. Researchers identified the method to be a viable and inexpensive method to gather bicycle travel behavioral data as found in a Portland, Oregon, –based study (*62*), but also determined that extensive postprocessing of the data is needed to maximize the usefulness of the data. Continuing research on using smartphone GPS capabilities to map cycling and walking is being conducted in Montreal (*63*).

Bluetooth

Static Bluetooth device monitoring has been used for counting vehicles for several years, and the method was recently adapted for pedestrians (*64*). This method goes beyond a simple count because Bluetooth devices have a unique identification code, allowing monitoring of the rate or direction of travel if multiple monitoring points are employed. This method can be used in heavy crowds where infrared or manual techniques are less successful. One drawback of this technique is that not all individuals carry a Bluetooth device and some carry more than one. Estimating pedestrian counts requires factoring average population Bluetooth use, and so margins of error can be high in relatively small counts.

FIGURE 9 CycleTracks smartphone application splash screen.

Webcams and Crowdsourcing

Hipp and others have experimented with the use of video-based sensors to capture ambient activity via public webcams, and using the footage to estimate active transportation (*65*). Their novel approach avoided the accuracy problems of computer-sensing technologies to evaluate extensive images by using human reviewers through the Amazon Mechanical Turk website to crowdsource evaluation of the images. This unobtrusive method is also inexpensive and shows promise as a counting method, particularly in complex settings for which traditional counters are not well suited. A disadvantage of this method is that it requires visibility through lighting, so most locations can only be counted during daylight hours.

Automated Video Image Processing

Recorded video provides a relatively infallible backup for confirming the accuracy of active transportation trips, and automated processes are enabling computer-extracted counts. Several recent studies have improved the accuracy of this method.

Recent research on automated methods to extract traffic information from a video stream often uses a common approach. Software processes the video generally in about four steps. First, stationary objects (the background) are digitized and removed from consideration as candidate traffic. Next, moving objects are tracked as points across the video feed. Some methods such as those described by Svensson et al. develop a three-dimensional box model of the moving objects, which can then be classified as a type of vehicle, pedestrian, or other object (*66*). Then, a boundary is placed to exclude moving objects from the area of interest, such as an intersection. The computer can then process the data stream, yielding traffic counts and sometimes speeds and other information on a continuous basis. Zaki et al. have extended this technology to classify bicyclists in a traffic stream and to isolate their lane positioning, speed, and other variables (*67*). They were able to apply this technology to complex road intersections such as roundabouts to observe very specific bicyclist behavior in the facility, with promising implications for adding detail for roadway design safety studies. As with any video-based method, it is only operational in daylight or under adequate lighting, and bicyclists occluded by vehicles reduced its accuracy. The overall accuracy of bicyclist counts was not far from other automated methods, usually within 15%. Additional research on this method at Portland State University is described in the Ongoing Research on Data Collection Methods section.

Charreyron et al. pioneered the use of an off-the-shelf product called the Microsoft Kinect that uses computer vision, rather than video storage and processing to perform pedestrian counts (*68*). By combining this tool with a depth sensor, researchers also were able to estimate pedestrian speed. However, this method is subject to the same challenges because of low-light conditions and visual obstructions. Continued work at McGill is developing video image recognition for pedestrians (*69*).

Video image processing offers a unique blend of basic data such as traffic counts, along with the potential to provide detailed lane positioning and other data visible from video. Additional research will evaluate other uses of this technology and commercial devices based on this technology may be broadly available for active transportation monitoring in the near future.

Bicycle Sharing Systems

In this e-circular, bicycle sharing systems are considered a form of information and communications technology data source for bicycle volumes because third-generation systems employ the use of technology for security and payment, leaving a trail of data that can be of use for planning and management purposes (*70*). Since current bike share systems typically provide a duration of prepaid use, then a higher rate for longer use, riders tend to keep the bicycle only for the duration of a trip. Each trip begins and ends in a docking station, which digitally records the time, the unique bicycle number, and other information, providing a rich data source for examining behavior of bike share users. It should be noted, however, that the bike share population is a subset of the broader bicycling population, and extension of its results are limited for community-level studies.

O'Brien has integrated accessible bike share data sets into a comprehensive world map that provides operational statistics at a systemwide level, and also for individual docks (*71*). O'Brien's website provides current information, but he and collaborators have mined existing data for further understanding of bike sharing systems, including volume and flow data. Figure 10 is from a recent paper that provides a visualization of station-to-station flow from Washington, D.C.'s, Capital Bikeshare system on weekdays and weekends, along with clusters of docks with similar use characteristics.

In addition to the spatial perspective of volume analysis, bike share data allow for temporal study. Figure 11 summarizes four large American systems with that of London's Barclays Cycle Hire. London's system has the strongest weekday use early in the morning, while Washington, D.C.'s, system peaks in the afternoon. All of the systems studied show a similar use graph during the weekend, with very little traffic early in the morning, and then peaking in the early afternoon. These trends are typical of previous bicycling studies in the United States (*36, 38, 43, 73, 74*).

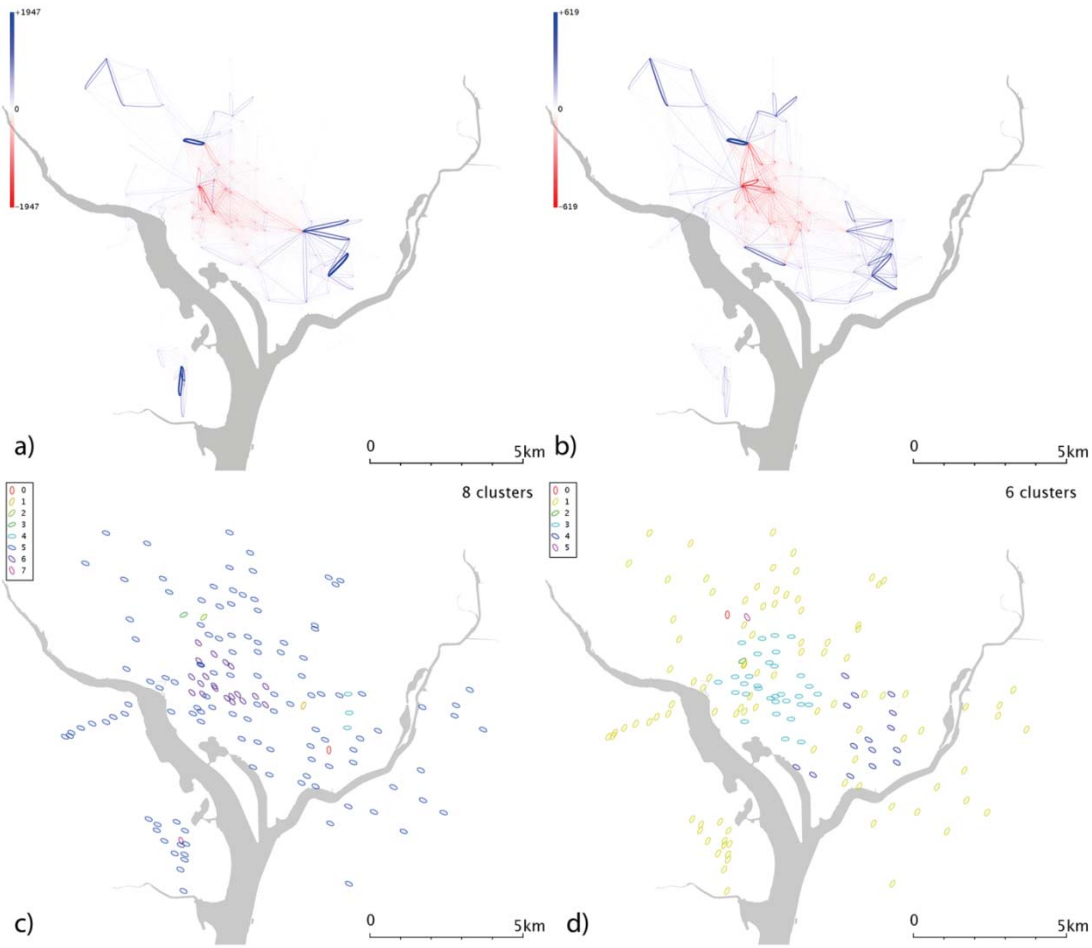

FIGURE 10 Washington, D.C.'s, spatially scaled networks and communities: (*a*) weekday spatial network; (*b*) weekend spatial network; (*c*) communities from weekday spatial network; and (*d*) communities from weekend spatial network (*72*).

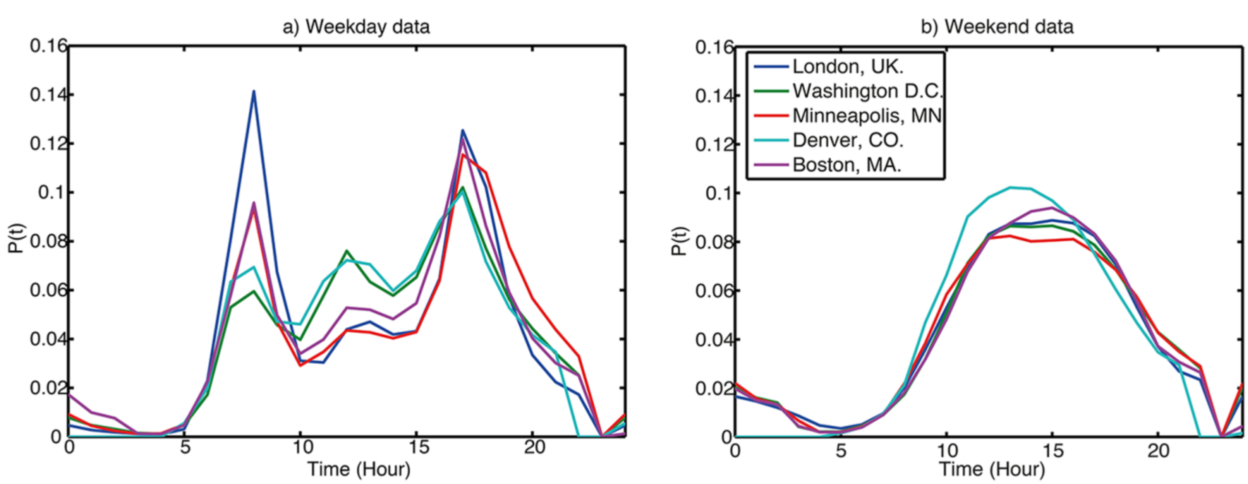

FIGURE 11 Level of activity (total number of bicycles leaving docks) in the system as a function of hour of day over the reporting period: (*a*) weekday data and (*b*) weekend data (*72*).

Archiving and Sharing Data

Data sharing is critical to making bicycle and pedestrian data useful. When data are not shared, they often go unused. When data are not used, errors go undetected and thus uncorrected. In the worst case, unused data may even be misplaced or lost. For these reasons, data sharing and archiving results in better use of existing resources and improved data quality and preservation.

Many examples exist around the country of how these data can be both archived and made available publicly. FHWA currently archives vehicular traffic data at the national level through the TMAS. TMAS provides online data submittal by state DOTs, and information on use of the data can be obtained through FHWA District Offices. Though TMAS does not include bicycle and pedestrian data as of this writing, the updated FHWA TMG Chapter 7 provides a required data format to do so.

A future version of TMAS will provide bicycle and pedestrian data processing for point-based locations (2013 TMG formatted data). Data from TMAS has quality control methods, delete capability, export features, and reports. TMAS provides long-term data storage of all records sent in and approved along with a processing software solution that will allow for data sharing and collaboration of data sets from numerous sources [federal, state, cities, metropolitan planning organizations (MPOs), and locals].

Although many agencies are collecting information related to bicycling and walking travel, there is still a need to consider archiving, storing, and sharing data. Nationally accepted data standards are beginning to be developed and implemented, such as the standard format presented in Chapter 7 of the 2013 TMG, which lacks nationwide acceptance and usage. It is anticipated that this acceptability and usage will change as the technology and equipment begins to automatically advance toward developing data exports that conform to national data standardized formats. Supporting the need for nationwide data, a national data clearinghouse effort is being discussed within the TRB Bicycle and Pedestrian Data subcommittee. This national data archiving, storing, and sharing concept is in its early development stages but promises to be a national data source for those looking to obtain information about bicycle and walking across the United States.

Efforts to create data clearinghouses on the regional or state level are multiplying across the country. Such efforts include those in the Philadelphia, Los Angeles, and Portland metro areas.

Ongoing Research on Data Collection Methods

In addition to NCHRP 7-19, other efforts are under way to refine bicycle and pedestrian data collection methods. Below are examples of such projects. In referencing data collection methods, the following projects have been listed in no specific order.

METHODS FOR COUNTING, MEASURING, AND MODELING—UNIVERSITY OF MINNESOTA

The University of Minnesota Humphrey School of Public Affairs is working through the Center for Transportation Studies on a project sponsored by the Minnesota DOT called "Methodologies for Counting Bicyclists and Pedestrians in Minnesota: An Integrated Approach to Measuring and Modeling Non-Motorized Traffic." Greg Lindsey is leading the project with Jason Cao as co-investigator. The project started in October 2011 with a purpose "…to define a consistent approach to integrating methodologies for measuring bicycle and pedestrian traffic on on-street and off-street facilities in Minnesota" (*75*). Researchers have worked with state and local transportation officials to establish short-duration monitoring locations across the state, and are providing guidance on implementing and institutionalizing the methods. The project is scheduled for completion in early 2014.

DESIGN AND IMPLEMENTATION OF BIKE–PEDESTRIAN DATA COLLECTION METHODS—PORTLAND STATE UNIVERSITY

Portland State University is conducting "Design and Implementation of Pedestrian and Bicycle-Specific Data Collection Methods in Oregon," led by Miguel Figliozzi and Christopher Monsere of the Civil and Environmental Engineering Department. Supported by the Oregon DOT and the FHWA, the researchers propose to develop a plan for long-term implementation and data collection guidance (*76*).

The first phase of the project focuses on review of statewide data collection efforts and bicycle and pedestrian-specific data technologies. The second phase focuses on sampling and factoring techniques. The third phase includes a pilot study to illustrate how Oregon DOT may use 2,070 signal controllers to measure pedestrian activity, a surrogate for pedestrian traffic, using pedestrian phase actuations, and how inductive loops used for signal detection may also be used for counting purposes. Pneumatic tubes for bicycle counting are also tested. Recommended guidelines to assist Oregon DOT in choosing count sites are also being included. Figliozi and Monsere's data collection project is scheduled to be completed in early 2014.

APPLICATION OF INTERACTIVE VIDEO SENSING AND MANAGEMENT FOR PEDESTRIAN AND BICYCLE SAFETY STUDIES—PORTLAND STATE UNIVERSITY

Feng and others at Portland State University are working on a project to create an interactive video sensor processing system that combines computer vision techniques into a user-friendly interface with settings to help study some of the most frequent traffic safety issues such as vehicle and pedestrian conflicts or bicycle compliance with traffic signals. The system will be tested on Southwest 4th Avenue on the Portland State University campus, a location chosen for visible multimodal traffic behaviors. The project is scheduled for completion after December 2013.

Ongoing Research on Archiving and Sharing Data

BICYCLE DATA CLEARINGHOUSE FOR MANUALLY COLLECTED COUNTS—UNIVERSITY OF CALIFORNIA AT LOS ANGELES

The University of California at Los Angeles Luskin School of Public Affairs is developing a Bicycle Data Clearinghouse, with support from the Los Angeles County Metropolitan Transportation Authority and the Southern California Association of Governments (*77*). They are working to "…compile, organize, make accessible, and create a data standard for bicycle count data collected in Los Angeles County," collecting existing data and developing an interface for storing data in one centralized location. The project developed an interactive mapping website for access to the data, an interface for uploading new data, and a manual providing guidance on a standard method for conducting bicycle volume counts. They are also conducting counts and surveys at Union Station, and documenting methods for estimating miles of travel and greenhouse gas emission reductions from bicycle volumes. Some of the challenges the research team noted include (*78*):

- The standardization of historical data, some of which required thoughtful interpretation;
- Proposing a count data collection protocol that can work for a diverse community of jurisdictions; and
- Creating a user-friendly mechanism for collecting new data.

COUNTDRACULA—SAN FRANCISCO COUNTY TRANSPORTATION AUTHORITY

Just to the north of Los Angeles, the San Francisco County Transportation Authority (SFCTA) is engaged in several projects related to bicycle and pedestrian data (*79*). SFCTA is known for developing the CycleTracks application that records bicycle trips using smartphone GPS. They are now developing "CountDracula," a database framework for storing street traffic counts. This system will create a standard format of traffic counts that integrates with their travel demand model, SF-CHAMP, which integrates observed bicycle trips into the activity-based travel model (*80*).

PORTAL—PORTLAND STATE UNIVERSITY

PORTAL (Portland Oregon Transportation Archive Listing) is the official data archive for the Portland metropolitan area including Vancouver and southwest Washington. PORTAL was originally funded by the National Science Foundation; currently it is supported by funding from Metro (regional MPO in Portland) and Oregon Transportation Research and Education Consortium. Since 2004, PORTAL has been archiving highway data. The archive has since been expanded to include other sources such as arterial, Bluetooth, incidents, transit, bicycle, and pedestrian data. Bicycle counts from inductive loop detectors, pedestrian actuations, and delay from signal controllers are currently being archived. Visualizations are also being developed (see http://demo.portal.its.pdx.edu/Portal/index.php/pedbike). As an online data archive, PORTAL is useful to academics, researchers and practitioners.

PEDESTRIAN AND BICYCLE COUNTS—DELAWARE VALLEY REGIONAL PLANNING COMMISSION

Delaware Valley Regional Planning Commission (DVRPC) provides public access to their bicycle and pedestrian counts using a map-based user interface. The site provides reports of hourly counts by day. The data include both pedestrian and bicycle counts. Counts were collected using automated counting technologies: pneumatic tubes for counting bicyclists and passive infrared counters for pedestrians. About 1 week of continuous hourly count data is available for each location and the data can be downloaded from the site. Because the count stations are linked to Google maps, Google street view for each location is also accessible through the website (http://www.dvrpc.org/webmaps/pedbikecounts/).

BICYCLE AND PEDESTRIAN COUNTERS—BIKEARLINGTON IN ARLINGTON, VIRGINIA

This site offers a counter dashboard with an interactive map of the continuous bicycle and pedestrian count locations in the city. Counter technologies include inductive loops, infrared counters, and piezo tubes. The data can be sorted by date, mode, day of week, weather, temperature (hot, mild, cold), and traffic direction and graphed (http://www.bikearlington.com/pages/biking-in-arlington/counter-dashboard/).

In addition to these local, research-based efforts, at least three state DOTs (Colorado, Minnesota, and Oregon) are currently working to establish nonmotorized traffic monitoring programs, as reported by Lindsey, Nordback, and Figliozzi (*32*):

> The FHWA Traffic Monitoring Guide 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.

DEVELOPING A GEOGRAPHIC INFORMATION SYSTEM FRAMEWORK

All kinds of bicycle and pedestrian monitoring data are inherently both temporal and spatial, and many agencies are using a geographic information system (GIS) to store and share the data with these attributes. Although storing monitoring data in a GIS can provide an excellent structure for collecting and sharing these datasets, at least two problems currently hold the marriage of GIS and bicycle and pedestrian data back.

First, most data collection techniques do not automatically geolocate the data. With the exception of smartphone-gathered data using an onboard GPS, a user must find and record geographic coordinates separately and then add this information to the collected records.

Second, bicycle and pedestrian facility network datasets are not developed in all locations. Though many jurisdictions develop this data for mapping bicycle routes or monitoring Americans with Disabilities Act compliance, no standard format for this data exists. The Safe Routes to School National Partnership pulled together a group of experts from around the nation to help with ideas for a national framework discussion on the use of GIS in Safe Routes to School and active transportation. The group convened in Austin for 2 days, April 22 and 23, 2013, and included participants from Alta Planning + Design, the Center for Neighborhood Technology, OpenPlans, University of California at Berkeley, the University of Oregon, TTI, and others. Discussion centered on strategies for leveraging existing sidewalk and bicycle facility data into a national architecture that could be supplemented with community-sourced information. Supported by the Center for Disease Control and Prevention, the Safe Routes to School National Partnership will develop a final report and webinar from the group's recommendations, and work with others to seek support for improving active transportation data availability. Ultimately, federal leadership may be considered for developing a national GIS framework for bicycle and pedestrian transportation. Additionally, the Rails to Trails Conservancy maintains a national GIS of trail locations, and makes it available to the public for free on TrailLink.com (*81*).

FUTURE DIRECTIONS

At this stage in bicycle and pedestrian monitoring, more questions and challenges are emerging than answers, though solid methods do exist. Many suggestions for future research focus on improving the accuracy of data, in terms of traffic volumes, spatial location and behavioral attributes such as trip purpose.

The integration of multiple technologies for travel monitoring solutions may be promising. One suggestion for improving the accuracy of GPS-observed travel behavior could employ the use of accelerometers (*59*) or other methods that can track movement indoors where GPS signals are obscured. Several companies and public agencies are already using smartphone applications for recording behavioral or routing information, but no standards exist for these types of data streams or methods to collate multiple providers' data for analysis.

Also, new intermodal transportation technology is blurring the lines between traditional travel modes. The growth of electric bicycles and similar technologies may be very similar in function to mopeds or scooters. Similarly, concept vehicles for one person with four, three, or two wheels share some operational characteristics with traditional automobiles, but also electric-assisted bicycles. Finally, bicycle sharing systems are already providing a significant data source through their integrated origin and destination information through electronic kiosks and GPS devices. New methods will likely be developed to deal with these complexities while integrating data streams for intermodal analysis. For national and international data to be interchangeable, new standards will need to align certain data fields from a variety of sources. Bicycle and pedestrian data practitioners will likely need to work with computer scientists, geographers and behavioral specialists to keep pace with innovation in intermodal transportation.

Conclusions and Possible Policy Implications of Active Transportation Monitoring

Without any or adequate bicycle and walking information, agencies responsible for designing, maintaining, and operating transportation facilities are at a loss for adequately accommodating bicyclists and walkers. Many agencies are beginning to realize how important gathering data for bicycle and pedestrian travelers can be to their overall multimodal transportation system. Policies are beginning to drive the need for data collection. For example, in response to the new federal transportation legislations (Moving Ahead for Progress in the 21st Century) governmental agencies are beginning to pass legislation and create performance measures that specifically delineate goals and objectives to increase walking and bicycle transportation. Without data collection and baseline information on walking and biking travel, it is impossible to evaluate these goals and objectives. National efforts will continue to offer great promise by helping agencies to advance the overall state of practice by taking advantage of existing data collection program resources, equipment, and knowledge. Likewise, researchers connecting projects to agencies with existing programs are likely to discover more efficient and effective ways to collect, store, analyze, and disseminate bicycle and walking information.

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