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Methods and Technologies for Pedestrian and Bicycle Volume Data Collection

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Abstract

This report documents and presents the results from NCHRP Project 07-19, *Methods and Technologies for Pedestrian and Bicycle Volume Data Collection*. This project tested and evaluated a range of automated count technologies that capture pedestrian and bicycle volume data. The focus of the study was to evaluate the technologies in different count settings, including ranges of temperature, varying weather conditions, mixed traffic conditions, mixed travel directions, and different facility types (e.g., roadways, multiuse paths), to determine their accuracy and reliability in different contexts. This report documents the project's findings on the accuracy and consistency found for the different automated count technologies. It provides a complete account of the process used to select technologies for testing, identify test sites, and evaluate the effectiveness of the technologies. It is clear from the testing that it is critical for practitioners to calibrate and evaluate the effectiveness of the counters they install at specific sites to have the most accurate understanding of how well the counters capture non-motorized volumes under site-specific conditions.

Summary

NCHRP Project 07-19 evaluated six automated count technologies that capture pedestrian and bicycle volume data. The following presents a summary of the technologies and sites tested, evaluation criteria, research findings, and conclusions. The intent of this research is to inform practitioners about the range of available non-motorized counting technologies and methods that may be useful in establishing non-motorized count programs that can serve as a comprehensive, long-term source of data on pedestrian and bicycle travel patterns within their community.

Chapters 1 and 2 of this report provide background information and a synthesis of the state of the practice related to non-motorized count programs. Chapters 3 and 4 focus on the project's testing program and findings. Chapter 5 presents the research conclusions and suggestions for additional future research.

COUNTING TECHNOLOGIES TESTED

A literature review was conducted to identify available technologies, products and vendors that would be candidates for testing. Information was also gathered from organizations with established pedestrian and bicycle count programs to learn about the range of counting technologies they use. Through correspondence and conversations with product vendors, information was gathered about the availability and state of development of different technologies.

Based on the information gathered in the activities described above and discussions with the project panel, the following technologies were selected for testing.

- **Passive infrared.** Passive infrared sensors, also called piezoelectric sensors, detect infrared radiation given off by pedestrians and bicyclists. They are widely used in the U.S. and have undergone a number of tests that have been reported in the literature. However, many of these tests are not recent and used various evaluation approaches, so it was thought to be interesting to investigate how the technology has improved.
- **Active infrared.** These devices send an infrared light beam from a transmitter to a receiver. When the beam is broken by a bicyclist or pedestrian, a count is detected. An existing active infrared counter was available to the research team and was included in the test.
- **Bicycle-specific pneumatic tubes.** Pneumatic tubes detect the pulses of air generated when a vehicle or bicycle rides over the tube. Many transportation agencies already use standard pneumatic tubes, designed for motor vehicle counting, as part of their motorized counting programs, and are familiar with how to install and use them. However, this project investigated pneumatic tubes with a smaller profile that are specifically designed to count bicycles.

- **Inductive loops.** Many transportation agencies are also familiar with inductive loops embedded in the pavement, as they are commonly used for motor vehicle and bicycle detection and at traffic signals. A magnetic field is produced by running an electrical current through the loop. When metal parts of a bicycle pass over a loop, the magnetic field is affected and a bicycle is counted. This project investigated both embedded loops and temporary loops that can be placed on top of the pavement that are specifically designed for bicycle counting.
- **Piezoelectric strips.** Piezoelectric strips are not used extensively for bicycle counting efforts in the U.S., but are quite common in other parts of the world, particularly Australia and New Zealand. These strips emit electrical signals when deformed by bicycle wheels running over them. Reports of this technology have been generally very positive, so the technology was felt to be worth investigating more rigorously.
- **Radio beam**. These devices send a radio beam between an emitter and a receiver and count pedestrians and bicyclists when the beam is broken. Radio beam devices have not been formally tested in the literature to date, but have been anecdotally reported as working well. Therefore, the technology was felt to be worth investigating.
- **Combination**. Combination devices use one sensor technology (e.g., passive infrared) to detect all users (pedestrians plus bicycles) and another technology (e.g., inductive loops) to detect bicycles only. Therefore, the device can output pedestrian and bicycle counts separately.

Figure S-1 illustrates the sensor technologies tested by this project.

A number of other counting technologies were considered, but were not included in the test for the following reasons:

- The technology was not yet available in, or was just entering, the U.S. market (e.g., fiber-optic pressure sensors, thermal counters);
- The technology was generally limited to niche applications, such as counting on unpaved trails (e.g., pressure sensors, acoustic sensors, magnetometers); or
- The technology was better suited to indoor applications, due to the need for an electrical power supply or relatively frequent battery changes (e.g., laser scanners).

In addition, automated counting from video was considered, but not evaluated. Although this technology has been the subject of a number of academic research projects, the one commercial application of it operates as a service, where clients send videos to the vendor to be counted. According to the vendor's website, its staff conduct quality-control checks of the counts, so any evaluation we would have performed would have been of the service (which may involve a combination of automated and manual data reduction) and not necessarily of the automated technology itself. In addition, an agency that this project had planned to partner with to test the service experienced budget cuts during the testing period and was not able to conduct counts as planned using the service.

(a) Bicycle-specific pneumatic tubes

(b) Surface inductive loops

(c) Radio beam

(d) Embedded inductive loops

(e) Passive infrared

(f) Active infrared

(g) Piezoelectric strips

Figure S-1. Tested Counting Technologies Illustrated

Table S-1 summarizes the amount of usable data collected, categorized by the environmental and user volume conditions under which the data were collected. Combination technologies are included twice: once for each component of the counting device (e.g., passive infrared and inductive loops).

Table S-1. Counting Technologies Tested by Environmental and User Volume Conditions

Condition	Passive Infrared	Active Infrared	Pneumatic Tubes	Inductive Loops	Inductive Loops (Facility)	Piezo-electric Strips	Radio Beam
Total hours of data	298	30	160	108	165	58	95
Temperature (°F) (mean/SD)	70 / 15	64 / 26	71 / 9	73 / 12	71 / 17	72 / 10	74 / 10
Hourly user volume (mean/SD)	240 / 190	328 / 249	218 / 203	128 / 88	200 / 176	128 / 52	129 / 130
Nighttime hours	30	3	10	13	19	15.75	3.5
Rain hours	17	0	4	7	7	0	6
Cold hours (<30 °F)	12	5	0	0	7	0	0
Hot hours (>90 °F)	11	0	0	5	5	3	4
Thunder hours	8	0	0	2	2	0	0

Note: SD = standard deviation.

SITE SELECTION

Test locations were selected to achieve a range of weather conditions, mix of facility type (e.g., on-street, multiuse path, sidewalks), and mix of road users (e.g., pedestrian and bicycle volume mix). Other considerations included the presence of willing local agencies to participate in the research study by providing necessary permits and local staff support, and the research team's ability to access the site for installation, monitoring, and data collection. Based on the above considerations, a mixture of the technologies noted above were tested in the following regions:

- Davis, California;
- Minneapolis, Minnesota;
- Portland, Oregon;
- San Francisco Bay Area, California;
- Arlington, Virginia and Washington, D.C.; and
- Montreal, Quebec, Canada.

Chapter 3 provides additional detail about the site selection and specific site characteristics, including photographs and descriptions.

EVALUATION CRITERIA

Technologies were primarily evaluated for their accuracy in correctly counting pedestrian and bicycle volume. Accuracy was evaluated by comparing the count recorded by a given automated counter to ground-truth counts produced by manually reducing video data from the site. Chapter 3 includes a comprehensive explanation of how ground-truth counts were conducted. The majority of the sites were monitored over a 6-month timespan, with videotaping occurring during two one-week periods during this span, corresponding to times when volume or environmental conditions of interest to the researchers were expected to occur. Selected hours from these 2 weeks of video were then manually counted to establish ground-truth counts. The hours to be manually counted were selected by first identifying any periods with conditions of interest (e.g. high volumes, extreme weather events) at sites with multiple counters, followed by sites with environmental variables in the middle–low range with multiple counters, and finally supplementing with sites with single devices. In addition to accuracy, counting technologies were also evaluated qualitatively based on the team's assessment of ease of implementation, labor requirements, security from theft or vandalism, maintenance requirements, software requirements, cost, and flexibility of downloading and working with the count data.

FINDINGS

The analysis conducted for each of the counting technologies was accomplished in three phases: (1) Graphical (exploratory) phase, (2) accuracy calculations, and (3) development of correction factors. Table S-2 provides a brief summary of the qualitative assessment of each technology and the key accuracy findings. Greater detail regarding the findings for each technology is provided in Chapter 4.

Table S-2. Counting Technology Key Findings

Technology	APD	AAPD	WAPD	*r*	N	Average Hourly Volume
Passive infrared	-8.75%	20.11%	18.68%	0.9502	298	240
Product A	-3.12%	11.15%	10.66%	0.9804	176	236
Product B	-16.86%	33.05%	29.75%	0.9711	122	246
Active infrared	-9.11%	11.61%	11.90%	0.9991	30	328
Bicycle-specific pneumatic tubes	-17.89%	18.50%	14.15%	0.9864	160	218
Product A	-10.54%	11.27%	11.94%	0.9884	132	244
Product B	-52.55%	52.55%	39.93%	0.9704	28	99
Surface inductive loops	0.32%	7.57%	5.70%	0.9968	29	145
Embedded inductive loops	0.63%	9.35%	8.36%	0.9929	79	122
Surface inductive loops (facility counts)	-20.09%	21.55%	29.34%	0.9420	59	222
Embedded inductive loops (facility counts)	-10.74%	15.44%	19.86%	0.9904	106	187
Piezoelectric strips	-11.36%	26.60%	25.24%	0.6910	58	128
Radio beam	-18.18%	48.15%	27.41%	0.9503	95	129
(Product A, bicycles)	-31.16%	72.55%	70.18%	0.1041	28	26
(Product A, pedestrians)	-26.27%	52.50%	46.67%	0.7368	27	87
(Product B)	-3.63%	28.13%	19.17%	0.9328	40	230
Combination (pedestrians)	18.65%	43.78%	21.37%	0.9916	47	176

Notes: APD = average percentage deviation, AAPD = average of the absolute percent difference, WAPD = weighted average percentage deviation, *r* = Pearson's Correlation Coefficient, N = number of detectors, Average volume = hourly average pedestrian and bicycle counts based on video observation.

Facility count statistics reflect both errors inherent to the counting device or technology, and bypass errors (i.e., missed detections due to bicyclists traveling outside the device's detection area).

[1]A negative APD indicates undercounting of device.

[2]AAPD weights overcounting and undercounting as absolute percentages.

[3]WAPD accounts for the low volume bias of the AAPD measure by weighting the AAPD based on the ground-truth volume.

[4]Values of Pearson's *r* closer to +1 indicate a stronger positive correlation.

Passive Infrared

Based on the project's literature review and practitioner survey, passive infrared appears to be the primary sensor technology used at present in the United States for single-mode and mixed-mode (pedestrians and bicyclists) environments. Devices using this technology are relatively easy to install; however, care should be given to the background conditions that may trigger false detections, such as the presence of windows or other reflective surfaces that can accumulate heat in the sun.

Occlusion (i.e., where one person blocks another from view when both pass the counter's sensor at the same time) was found to occur with higher user volumes, resulting in undercounting. Overall, the testing found an average undercounting rate of 8.75% and a total deviation of 20.11%. Passive infrared sensors from two different vendors (Product A and Product B) were tested, and a large difference between the accuracy of Product A and Product B was found. Product A had a net undercount of 3.12% and Product B had a net undercount of 16.86%. The undercounting rate includes instances of overcounting that offset the undercounting that occurs. The total deviation indicates the absolute deviation from the actual pedestrian and bicycle volumes counted; therefore, the absolute sum of the under- and overcounting amounts to a 20.11% deviation from the actual.

Active Infrared

One active infrared sensor was tested. In practice, there appears to be less use of these sensors, compared to passive infrared sensors. Project 07-19 found the active infrared sensor to be fairly accurate with high consistency. It was moderately easy to install, but special attention should be given to align the transmitter and the receiver. In the Project 07-19 testing, the device was found to undercount volumes by 9.11% with a total deviation from actual counts of 11.61%. The undercounting rate includes instances of overcounting that offset the undercounting that occurred. The total deviation indicates the absolute deviation from the actual volumes counted; therefore, for the active infrared sensor, the absolute sum of the under- and overcounting amounts to an 11.61% deviation from actual.

Bicycle-Specific Pneumatic Tubes

Bicycle-specific pneumatic tubes were installed and tested primarily on multiuse paths and bicycle lanes, except for two sets installed on a shared-use lane with relatively low motor vehicle traffic. The tubes are relatively easy to install but on-going, routine checks of the site should be conducted to make sure site activity (e.g., large trucks unloading or loading in the bicycle lane) does not pull up or dislodge the tubes. This consideration is particularly important in mixed-traffic settings where motorized vehicles may be present.

Project 07-19 testing found the net average accuracy of bicycle-specific pneumatic tubes to undercount by an average of 17.89%. The research team tested pneumatic tubes from two different vendors and found a large difference between the accuracy of Product A and Product B. Product A had a net undercount of 10.54% and Product B had a net undercount of 52.55%. Practitioners are encouraged to evaluate the specific products to understand their relative accuracy as it can vary widely for a given technology. The total deviation from the actual counts was found to be 18.50% on average (considering Product A and Product B). The total deviation for Product A was 11.27% and for Product B was 52.55%.

Radio Beam

Project 07-19 tested radio beam technology at four locations: three multiuse path sites and one wide sidewalk site. Two of the devices installed on multiuse paths distinguished bicyclists from pedestrians, while the other two devices simply counted all users.

The sensors that did not distinguish bicyclists from pedestrians encountered an average undercounting of 3.63% with a total deviation of 28.13%. The sensors which distinguished bicyclists from pedestrians yielded average undercounting rates of 31.16% when counting bicyclists and 26.27% when counting pedestrians, with total deviations of 72.55% and 52.50%, respectively. These findings merit the caveat that volumes at these sites were fairly low, so percentage deviations are high with a relatively small number of missed detections.

Inductive Loops

Project 07-19 evaluated the effectiveness of inductive loops on multiuse paths and on-street bicycle facilities. Inductive loops for more permanent installations are embedded into the pavement and therefore tend to be more labor intensive to install than other technologies. Semi-permanent inductive loops are also available, which are affixed to the pavement surface with a rubberized compound. The advantage of semi-permanent loops is that the majority of the hardware (aside from the loops themselves) can be reused at future sites, so multiple sites can be sampled for a lower cost compared to installing permanent loops. Semi-permanent loops are rated at approximately 6 months of installation.

Inductive loops have a defined detection area on the pavement. This is different than some of the other sensor technologies, such as passive infrared, that establish an invisible screen line across a facility.

Depending on the site characteristics and how the inductive loops are installed, the detection zone for the loops may not extend the entire width of the facility. This instance can result in bypass errors, where bicyclists ride through the site but do not pass through the inductive loop detection zone and therefore are not counted. As a result, it is important to install the inductive loops to cover the full facility width.

The inductive loop technology was found to have a high degree of accuracy and consistency for counting the bicyclists that ride through the detection zone. For travel through the detection zone, Project 07-19 found an average overcounting of 0.55% and an average total deviation from the actual counts of 8.87%. Larger undercounting can occur at a site if the bicycle travelway is wider than the detection zone for the loops. On-street installations where bicyclists may not always travel in the bicycle lane pose the most challenging context for establishing a sufficiently wide detection zone.

Piezoelectric Strips

Project 07-19 has limited findings for the piezoelectric strip technology due to the research team's difficulty in obtaining devices to test and difficulty in downloading data from the single device that was received. Due to these challenges, findings from Project 07-19 are based on one sensor that was installed previous to Project 07-19 on a multiuse path. Findings from evaluating the sensor's effectiveness over the duration of Project 07-19 indicates the sensor on average experiences an undercount of 11.36%.

Combination

NCHRP 07-19 included two combination passive infrared/inductive loop systems. These systems are able to distinguish pedestrian and bicyclist volumes by taking the passive infrared data (which counts all pedestrians and bicyclists together) and subtracting the inductive loop data (which only count bicyclists). The focus of NCHRP 07-19 was on evaluating the sensor technologies, so each component was included with its respective category (passive infrared or inductive loops). The inductive loops were analyzed by comparing against the count of number of bicyclists, and the passive infrared sensors were analyzed by comparing against the sum of the number of pedestrians and the number of bicyclists. However, the combination devices were also evaluated on the accuracy and consistency of their estimates of pedestrian volumes, with an average undercount of 18.65% and total deviation of 43.78%.

CONCLUSIONS

Correction Factors

Various regression model forms were tested for correcting counted volumes to actual volumes. Tested correction functions included interactions between volumes and environmental factors (such as temperature), which can be interpreted as modifications on the accuracy rates under the given conditions. In many cases, however, a simple linear model (i.e., multiplicative factor) may be the best option for practitioners.

Table S-3 presents correction factors for each of the sensor technologies tested by NCHRP Project 07-19. In cases where multiple products representing the same technology were tested, individual anonymized product results are presented along with the overall results for the technology. More complicated correction functions can be found in Chapter 4 of this report.

Table S-3. Counter Correction Factors Developed by NCHRP Project 07-19

Sensor Technology	Adjustment Factor	Hours of Data
Active infrared*	1.139	30
Combination (pedestrians)	1.256	47
Inductive loops	1.050	108
Passive infrared	1.137	298
Product A	1.037	176
Product B	1.412	122
Piezoelectric strips*	1.059	58
Bicycle-specific pneumatic tubes	1.135	160
Product A	1.127	132
Product B	1.520	28
Radio beam	1.130	95

Note: *Factor is based on a single sensor at one site; use caution when applying.

It can be seen that the accuracy of the counted volumes varied significantly between products when multiple products were tested for a given sensor technology. However, the consistency of the counted volumes was generally similar, meaning that the adjusted volumes resulting from applying a correction factor would be expected to be similar between the tested products.

This finding of product-specific accuracy differences suggests that a specific vendor's implementation of a technology (e.g., the algorithm used to decide whether a detection should be registered) can be as important as the technology itself in determining accuracy. This result also indicates that "one-size-fits-all" correction factors for particular sensor technologies may not be particularly useful, and that product-specific factors should be used instead. Given that site-specific conditions that can also influence accuracy, it is recommended that users develop their own local correction factors for their devices whenever possible.

Factors Influencing Accuracy

Counter accuracy varied notably depending on site-specific characteristics. Significant site-specific factors influencing the accuracy of the counts included proper calibration and installation of the devices, and taking care to avoid situations that can result in over- or undercounts. For example, passive infrared sensors are susceptible to false positives when windows, mirrors, or other reflective surfaces are positioned behind the pathway being counted. Counters can also be subject to bypass errors, where a pedestrian or bicyclist is able to go around the counter's detection zone and avoid being counted. Thoughtful selection of counting locations that minimize opportunities for avoiding the counter can help minimize bypass errors.

For screenline sensor-based technologies (e.g., radio beam, passive infrared), occlusion is one of the most significant factors in undercounting. The degree to which occlusion may contribute to undercounting is a factor of pedestrian and bicycle platooning (i.e., groups of persons traveling side-by-side). All of the counting technologies that were tested that are subject to occlusion effects showed a linear relationship between counted and actual volume that could be corrected using a simple multiplicative factor.

Factors Not Found to Influence Accuracy

Several factors anticipated to affect the accuracy of counting technologies were not evident in the NCHRP 07-19 testing. For example, concern has been expressed that the age of inductive loops influences their accuracy. However, the inductive loops tested by this project included loops that were 2 and 3½ years old, and diminished quality was not detected in those loops' counting accuracy. Similar concerns have been expressed related to the age of pneumatic tubes. However, over the six-month duration of the testing, count quality was not observed to decline over time.

No clear impact or effect of temperature on the accuracy of the technologies was found. The temperatures captured within the duration of this research did not reach the extremes of cold and heat included in other studies; however, for the temperature ranges captured in the research, no impact on the accuracy of the tested devices was observed. Similarly, there was no indicative or quantitative effect found on count accuracy due to snow or rain events. There were limited snow and rain events within the data set, but those that did occur did not appear to influence the quality of the data. Anecdotally, the research team is aware of situations that have occurred with active infrared technologies having a higher rate of false positives during heavy rain events; however, this phenomenon was not observed in this project's testing.

Recommendations for Practitioners

It is recommended that practitioners calibrate and conduct their own ground-truth count tests for the automated technologies they deploy at a given site or set of sites. This project's research results are intended to provide information to practitioners on the types of technologies that may be most promising for a specific circumstance, use, or location where automated count technology is being considered. The project's accuracy findings should not be blindly applied to other sites than those at which these technologies were tested at, and it should not be assumed that the same degree of accuracy will occur at other site locations or with other products. Practitioners can use the research approach described in this report and accompanying guidebook to, on a smaller scale, test and evaluate the performance of their automated count technologies at their installation sites.

Chapter 1: Background

OVERVIEW

This Final Report summarizes the work conducted by NCHRP Project 07-19, Methods and Technologies for Pedestrian and Bicycle Volume Data Collection. It consists of the following chapters and appendices:

- Chapter 1, Background, provides the research problem statement that led to this project and summarizes the work scope.
- Chapter 2, State of the Practice, summarizes the project's literature review and a summary of the project's outreach efforts (an online practitioner survey and two sets of agency interviews).
- Chapter 3, Research Approach, describes the process used to test various non-motorized counting technologies.
- Chapter 4, Findings and Applications, presents the results of the this project's testing.
- Chapter 5, Conclusions and Suggested Research, suggests potential future research and implementation activities to continue expanding the state of the practice.
- Chapter 6, References, lists the source material referenced in this report.
- Appendix A provides the online survey instrument.
- Appendix B provides additional detailed results from the practitioner survey.
- Appendix C summarizes non-motorized count programs that had been described in the literature as of 2012.

This project also developed a practitioner-friendly *Guidebook on Pedestrian and Bicycle Volume Data Collection* that incorporates the findings and lessons-learned from this project. Readers who are unfamiliar with non-motorized counting in general are encouraged to review the guidebook prior to reading this Final Report, to obtain useful background information about non-motorized counting.

RESEARCH PROBLEM STATEMENT

Background

The lack of pedestrian and bicycle volume data is a barrier to transportation agency efforts to plan more effective facilities and to improve safety for pedestrians and bicyclists. Transportation agencies have well-established procedures for collecting, summarizing, and disseminating motor vehicle traffic volumes, but these procedures do not generally provide pedestrian and bicycle volume data. Most pedestrian and bicycle volume data collection is done for specific project locations after preliminary selection of candidate project locations has been made. The lack of system-wide pedestrian and bicycle volume data limits the ability of transportation agencies to provide or improve pedestrian and bicycle facilities where the need is greatest and is an impediment to developing better predictive methods for pedestrian and bicycle crashes.

There are many potential sources of pedestrian and bicycle volume data that are not being used. For example, many transportation agencies have cameras that capture images of pedestrian and bicycle traffic, but these data are not used to extract such volume data because this would be very time consuming. Other examples include: (a) use of video cameras installed for security reasons by public agencies and private companies that, incidental to their security purpose, capture images of normal pedestrian and bicycle flows; (b) pushbutton actuations at crossings with pedestrian signals that can be captured and correlated with pedestrian volumes; (c) data from bike sharing programs; (d) data from applications of other advanced technologies—such as passive detection technologies (e.g., microwave, infrared sensors, loop detectors, pressure sensitive mats, and communication devices); and (e) software to extract pedestrian and bicycle data from other existing sources. The feasibility of using these sources, including addressing privacy and security issues and extrapolating to estimate 24 hour counts and annual counts, need to be investigated. Research is, therefore, needed to develop guidance for practitioners on existing, new, and innovative methods and technologies to capture pedestrian and bicycle volume data.

Objectives

The objective of this research is to assess existing, new, and innovative technologies and methods and provide guidance for transportation practitioners on to how to best collect pedestrian and bicycle volume data. The assessment should consider, among other factors, feasibility, availability, quality, reliability, cost, and compatibility. The guidance should include methods to (a) efficiently mine and manage existing data sources; (b) acquire and use data from new and innovative technologies; and (c) summarize and disseminate pedestrian and bicycle volume data for site-specific, local, and system-wide needs assessments, project development, and safety management.

RESEARCH APPROACH

The research objectives for NCHRP 7-19 were addressed through a work program involving a number of tasks, described below.

Task 0: Kickoff Meeting & Amplified Research Plan

Within 15 days following the project's contract start date, the research team submitted an Amplified Research Plan to NCHRP. The Amplified Research Plan included an updated Research Approach reflecting panel comments on the proposal.

Task 1: Conduct Literature Review

A literature review was conducted of technologies and methods for pedestrian and bicycle volume data collection and management.

Task 2: Develop Research Approach

A detailed plan was developed to identify and assess (a) methods and technologies that are currently used or potentially could be used by state and local agencies to collect and extrapolate pedestrian and bicycle volume data; and (b) new, innovative, and emerging technologies. The detailed plan included a survey of appropriate practitioners at agencies such as state DOTs, MPOs, local agencies, vendors, and universities. The assessment should consider factors including, but not limited to, feasibility, availability, quality, reliability, cost, and compatibility.

Task 3: Survey and Outreach

The practitioner survey was implemented according to the approved Task 2 plan.

Task 4. Interim Report and Panel Meeting

An interim report was prepared providing (a) summary of results from Tasks 1 through 3; (b) preliminary findings on methods and technologies; (c) recommendations on methods and technologies to investigate further in Task 5; and (d) an updated work plan for Tasks 5 and 6. The interim report was accompanied by an appendix providing the raw information collected in Task 3.

Task 5. Investigate Approved Methods and Technologies

Counting methods and technologies were investigated, following the panel-approved work plan developed during Task 4.

Task 6. Develop Guidebook, Final Report, and Presentation

A stand-alone document was prepared, providing guidance for practitioners on methods and technologies. It included illustrative case studies. Additionally, this final report was prepared documenting the research that was used in preparing the guidance, and a PowerPoint presentation was prepared summarizing the results.

Chapter 2: State of the Practice

INTRODUCTION

This chapter presents information on the state of the practice of non-motorized volume counting that was developed by NCHRP Project 07-19. It includes the project's literature review and the results of the project's practitioner surveys and interviews.

LITERATURE REVIEW

The literature review was conducted in mid-2012. It focused on relevant domestic and international literature on pedestrian and bicycle volume data collection technologies and methods, with a goal of identifying material that could be incorporated into a practitioner's guide on non-motorized volume data collection. The review also covers literature on pedestrian and bicycle volume data correction factors and extrapolation methods, as well as data management tools and data sharing systems. Finally, the review identifies emerging technologies. Summaries of existing non-motorized count programs described in the literature are provided in Appendix C.

Value and Applications of Pedestrian and Bicycle Volume Data

Recent Research

The majority of literature addresses the lack of pedestrian and bicycle volume data and the potential value and applications of improving the availability and reliability of these data. For example, the *AASHTO Guide for the Development of Bicycle Facilities* (AASHTO 2012) does not provide guidance on how to collect or apply volume data, but does list potential applications. The primary benefits and applications of pedestrian and bicycle volume data cited in the literature include potential to:

- Determine existing travel patterns and demand;
- Identify corridors where current use and potential for increased use is high;
- Track historic trends;
- Evaluate the effectiveness of programs and/or facilities to promote walking and biking (e.g., before-and-after studies);
- Improve pedestrian and bicycle safety and evaluate the impact of different design treatments on crash rates;
- Identify locations for pedestrian and bicycle facility improvements and design appropriate treatments;
- Create facilities that increase user comfort and attract a wider range of pedestrians and bicyclists;
- Forecast pedestrian and bicycle travel demand.

At the national level, NCHRP Project 07-17, *Pedestrian and Bicycle Transportation along Existing Roads* (Toole Design Group et al. 2014), has surveyed methodologies and data used by local, county, regional and state transportation agencies to prioritize pedestrian and bicycle infrastructure projects along existing roadways in the United States. One of the early phases of the study was to conduct a national survey to collect information on different agencies' data collection and prioritization methodologies. Respondents were asked how they collected and managed pedestrian and bicycle count information. Of the 179 respondents, 31 percent indicated that they collected pedestrian count data, 24 percent indicated that they collected bicycle count data, and 18 percent indicated collecting both pedestrian and bicycle information.

As shown in Table 2-1, the majority of the NCHRP 07-17 survey respondents reported using manual counts to gather pedestrian and bicycle volume data. The majority (61%) of the 87 respondents who collect pedestrian count data reported collecting this information manually. Video and automated counters were used much less frequently (17% and 21% respectively).

Table 2-1. Reported Pedestrian Count Methodology Used by Agency Type

Type of Agency	Video Observations	Automated Counters	Manual Data Collection
Advocacy/nonprofit organization	2	2	5
College or university	1	1	2
County	1	2	1
Federal government	0	1	2
Local government	6	6	19
Metropolitan planning organization	2	3	14
Private consulting firm	0	0	1
School or school district	0	1	1
State DOT	3	1	8
Transit agency	0	1	1
Grand Total	**15**	**18**	**54**

Source: NCHRP Project 07-17 (Toole Design Group et al. 2014).

The distribution of methods used to collect bicycle count data was similar to approaches used to count pedestrians. As shown in Table 2-2, the majority of the 74 respondents who collect bicycle count data reported collecting this information manually (54%). Video observations and automated counters were used less frequently (24% and 22% respectively).

Table 2-2. Reported Bicycle Count Methodology Used by Agency Type

Type of Agency	Video Observations	Automated Counters	Manual Data Collection
Advocacy/nonprofit organization	1	2	3
College or university	1	0	1
County	1	1	1
Federal government	0	0	1
Local government	10	10	16
Metropolitan planning organization	1	2	11
Private consulting firm	0	0	1
School or school district	0	0	1
State DOT	3	1	4
Transit agency	1	0	1
Grand Total	**18**	**16**	**40**

Source: NCHRP Project 07-17 (Toole Design Group et al. 2014).

The survey did not delve into the reasons why agencies chose to conduct manual counts, but based on responses to other questions about their pedestrian and bicycle program, concerns about cost and lack of staff resources to dedicate to pedestrian and bicycle issues may play a role. The study underscores the fact that, while data collection has become more sophisticated as it pertains to technology, there is little consistency between agencies with regard to how data are applied to prioritization methodologies. The survey and follow-up interviews conducted for NCHRP 07-17 may serve as a resource to help researchers identify agencies that are collecting bicycle and pedestrian volume data, and develop a better understanding of how it is being applied (at least as it pertains to prioritization).

Developing a Pedestrian and Bicycle Volume Data Collection Plan

Recent Research

Pedestrian and Bicycle Data Collection in US Communities

This report (Schneider et al. 2005) describes methods used for collecting pedestrian and bicycle volume data and provides guidance on interpreting the results to help guide the long-term planning of pedestrian and bicycle infrastructure. The report also addresses the benefits and shortcomings of collecting data on travel behavior, and concludes that there is no single best method of collecting use or facility data. Rather, a variety of data collection approaches may be appropriate, based on the nature of local needs. The report also profiles different strategies to reduce the costs of collecting bicycle and pedestrian data, including using automated technologies and volunteer labor. Finally, the report emphasizes the importance on repeating data collection over time to help benchmark progress in building a non-motorized transportation system.

AASHTO Guide for the Development of Bicycle Facilities, 2012 Edition

Section 2.6 of the *AASHTO Guide for the Development of Bicycle Facilities, Fourth Edition* (AASHTO 2012) discusses the importance of identifying high-use corridors and understanding usage patterns before installing counting equipment. It also notes the following important elements of a data collection program:

- Collecting baseline data;
- Conducting counts over multiple years and seasons to account for event-related and seasonal variations in volumes;
- Accounting for existing conditions (e.g., facility type and land use) and traffic patterns; and
- Analyzing safety and demographic trends along with volumes.

National Bicycle & Pedestrian Documentation Project (NBPD)

The NBPD is led by Alta Planning + Design in collaboration with the Institute of Transportation Engineers (ITE) Pedestrian and Bicycle Council. It was started in 2004 as a response to the lack of useful data available on walking and bicycling and is a first attempt to create a repository for pedestrian and bicycle count and survey data collected from multiple communities throughout the U.S. The NBPD provides the following resources for practitioners establishing a data collection program:

- Materials and directions to conduct counts and surveys in a consistent manner;
- Standard count dates and times;
- A location where this information can be sent; and
- A mechanism to make this information available to the public.

Since its inception, the NBPD has developed a Program Description, Training Guidelines, and Count/Survey Forms. These items are available to the public and intended to establish a consistent method for collecting and reporting bicycling and walking data (Alta Planning + Design 2012a and 2012b, Jones 2009).

The NBPD has proposed a methodology for conducting volume counts and developed bicycle and pedestrian count and survey forms. The NBPD envisions that participating agencies and organizations will use the forms and methodology provided to conduct annual counts and surveys during the National Documentation Days in the second week of September. Supplemental data may be collected during set dates in January, May, and July to provide seasonal data.

2013 FHWA Traffic Monitoring Guide (TMG)

The TMG was developed by the Federal Highway Administration to provide guidance to states on collecting traffic-related data. While acknowledging the wide range of practices and systems currently in use, the TMG provides a basic structure for statewide traffic data collection programs and includes information on how data are to be organized and coded. The original version of the TMG did not address non-motorized travel. However, the 2013 version includes a new chapter that is devoted specifically to non-motorized traffic.

"Chapter 4.0: Traffic Monitoring for Non-Motorized Traffic" (FHWA 2013) opens with a discussion of key differences between monitoring for motorized and non-motorized traffic, including:

- The data collection scale is smaller. The number of monitoring locations is smaller and includes limited location samples (which may not represent the area as a whole and may make biased conclusions about data). Many locations are chosen based on highest usage levels or strategic areas of facility improvement; site selection criteria are therefore needed.
- Higher usage levels on lower functional class roads is expected—people feel more comfortable riding/walking at lower speeds/volume of traffic.
- Short counts are more common due to difficulties in automating of counting and differentiating sex, gender, and helmet use.

TMG Chapter 4 also outlines the process for developing permanent and short-term non-motorized data collection programs, following the same steps outlined for motorized traffic in TMG Chapter 3:

- Review existing count program(s). Coordinate with local and regional agencies and other departments or organizations not related to transportation (e.g., parks and recreation, health departments, retail/business associations, bike/ped advocacy groups) to determine what data and equipment are available and what data needs are. The review should assess:
    - Overall program design:
        - Monitoring locations: where and why chosen
        - Equipment: availability and limitations, if any
        - Existing data: who uses data for what purposes, additional data needs, if no data are available then who would use the data and for what purposes?
    - Traffic Patterns: If data are available, evaluate daily, weekly, and seasonal variations in counts and whether these patterns are similar at different locations.
    - Data Processing: Identify data format (structure, interval, metadata, reporting), quality control processes, adjustment procedures, and processes for dealing with missing data.

    - Summary Statistics: Identify statistics that are currently computed and those that may be needed, such as Annual Average Daily Traffic, seasonal average daily traffic, average daily traffic by month and day of week, and peak hour volumes for peak seasons.
- Develop an inventory of available count locations and equipment.
- Determine traffic patterns to be monitored. Define what type of roads/facilities will be monitored (e.g., off-street paths, local streets, arterials, state roads). If existing data are available, determine the types of traffic patterns expected on the network (e.g., commuting, recreational, utilitarian, mixed trip).
- Establish seasonal pattern groups. Limited previous research indicates that non-motorized traffic patterns can be classified into the following categories (each with their own unique time-of-day and day-of-week patterns):
    - Commuter trips: highest peaks in the morning/evening and low traffic during midday; more traffic during weekdays than weekends; and month-of-year traffic patterns are consistent regardless of season or climate.
    - Recreation/Utilitarian: strong peak during the middle of the day, more traffic on the weekends than on weekdays varying by season, and strong peak during late spring and summer.
    - Mixed Trip: includes trips that are both for commuting and recreational/utilitarian.
- Determine the appropriate number of count locations. Since there is little information about spatial and temporal variations of non-motorized traffic, the number of count locations is usually based on what is feasible given existing traffic monitoring budgets. If budget is not an issue, three to five continuous count locations are recommended per distinct factor group as the project begins, but the number of permanent locations can change as more data is collected. As of the time of writing, there had been no definitive U.S. guidance on the required number of short-duration count locations, although NBPD recommends 1 count per 15,000 population. (Note that Scandinavian research summarized later does provide guidance on the number of count locations.)
- Select count locations. For permanent counters, the TMG recommends selecting locations that are representative of prevailing non-motorized traffic patterns to help create reliable adjustment factors. For short-term counts, the TMG recommends focusing on targeted locations where activity levels and professional interest are the highest to provide more efficient use of limited data collection resources (e.g., random samples are likely to result in many locations with little to no non-motorized use). The National Bicycle and Pedestrian Documentation (NBPD) recommends the following sites:
    - Bike/Ped activity corridors:
        - Multi-use paths and parks – at major access points
        - On-street bikeways – at locations with few alternative parallel routes

        - Downtown areas – locations near transit stops
        - Shopping malls – location near entrance of mall and transit stop
        - Employment areas – near main access road
        - Residential areas – near higher density developments, parks and schools
    - Locations representing urban, suburban, and rural locations
    - Key corridors to gauge impacts of future improvements
    - Locations with existing and ongoing historical counts
    - Locations with gaps/pinch points for bikes/peds
    - Locations with high collision rates
- **Select count location type.** The intended use(s) of the non-motorized traffic data will dictate which types of counts are most appropriate:
    - Screenline (mid segment) counts are primarily used to identify general use trends for a whole segment.
    - Intersection counts are primarily used for safety and/or operational purposes.
- **Determine duration of counts.** Prevailing practice has been 2 consecutive hours on a single day, but is evolving to longer durations to account for variability. Factors to consider include:
    - Manual vs. automated collection. Suggested duration for automated technologies is 7 to 14 days. Manual counters should be given breaks every 2 hours. The NBPD recommends conducting 1- to 3-hour manual counts on sequential days.
    - Count magnitude and variability – Consider longer duration counts to determine variability throughout the day and week.
    - Weather – Seasonality and conditions affect traffic. Weather conditions should always be recorded (i.e., precipitation, temperature).
    - Month/season – Data collection months should represent average or typical use levels, generally the spring and fall. The NBPD recommends mid-May and mid-September.
    - Factor availability – Short term counts should be adjusted to represent an annualized estimate.
- **Compute adjustment** factors**.** Seasonal, monthly, day-of-week, and other adjustment factors should be computed following a similar process as traffic volumes.

The TMG concludes by introducing data codes to document different aspects of pedestrian and bicycle data collection, including directional orientation, road classification, type of facility, and the approach and technology used to gather data.

Turner and Lasley

As an extension to work on establishing data collection programs, Turner and Lasley (2013) recommend a procedure for evaluating the quality of data under pedestrian and bicycle volume collection efforts. This procedure emphasizes the importance of data quality assurance prior to data collection, such as data collector training and equipment testing. Six criteria are proposed for evaluating data quality: accuracy, validity, completeness, timeliness, coverage, and accessibility. Accuracy and validity are explored in greater detail, with significant implications for the evaluation of automated counting devices. These two concepts are defined by the authors as:

> "**Accuracy**: The measure or degree of agreement between a data value or set of values and a source assumed to be correct. Also, a qualitative assessment of freedom from error, with a high assessment corresponding to a small error.
>
> **Validity**: The degree to which data values satisfy acceptance requirements of the validation criteria or fall within the respective domain of acceptable values."

Controlled evaluations and field evaluation are mentioned as potential approaches for investigating data accuracy. Controlled evaluations are recommended for testing a variety of factors, including group spacing, pedestrian/bicyclist speed, distance between detector and subjects, equipment mounting height, as well as a number of other external factors. Field evaluation, by contrast, is better suited to testing devices under conditions common to the facility on which they are installed. For instance, counters installed along a single-file hiking trail don't need to be evaluated for accuracy under contrived situations such as large clusters of hikers, as these situations are not likely to occur normally.

Danish Road Directorate

The Danish Road Directorate has developed guidance for conducting manual and automated traffic counts, including counts of bicycle traffic (Vejdirektoratet 2004). At the time of writing, the vast majority of automatic bicycle counting in Denmark was performed using loop detectors. The main differences between motorized traffic counting and bicycle counting that the Road Directorate identifies are:

- Bicycle counts are subject to greater error than motorized vehicle counts.
- The best bicycle count results occur when the counts take place on cycle tracks or bicycle paths separated from motorized vehicle traffic. When loop detectors are placed close to motorized vehicle traffic, some cars and trucks may also be counted.
- Ideal conditions are needed to get good results when counting in cities.
- It is not recommended to use loop detectors to count bicycles when they operate in mixed traffic with other vehicles.

According to the Road Directorate, pneumatic tubes are feasible to use for short-term automatic counts, but there was little Danish experience with them for bicycle counting at the time the guidance was written. Radar and video were also identified as potential counting methods, when bicycles could be separated from other traffic, but there was no Danish experience with either method as of the time of writing (Vejdirektoratet 2004).

The Road Directorate also notes that there can be considerable differences in bicycle volumes from one week to the next, both due to weather effects and the fact that bicycle volumes are often relatively small. As a result, longer count durations are required to get good results, compared to motorized vehicle counting. Short-term bicycle counts are not advised. Table 2-3 shows the uncertainty in the estimate of bicycle average annual daily traffic (AADT) based on the length of the count, in weeks. For example, with a one-week count in a week without holidays, the average daily bicycle volume will be within 34% of the AADT 95% of the time (Vejdirektoratet 2004).

Table 2-3. Accuracy of AADT Estimation Based on Count Duration

Count duration (weeks)	All weeks	Weeks without holidays
1	39%	34%
2	28%	24%
3	23%	20%
4	20%	17%
5	18%	15%
6	16%	14%
7	15%	13%
8	14%	12%

Source: Danish Road Directorate (Vejdirektoratet 2004).
Note: Percentages indicate the potential error in the AADT estimate at a 95-percent confidence level.

Swedish National Road and Transport Research Institute

Niska et al. (2012) recommend methods for cities to use to track the annual change in pedestrian and bicycle traffic within the city. They find that it is not possible to accurately estimate the year-to-year change in citywide bicycle traffic with the resources available to most cities (i.e., a limited number of count sites and short-duration counts), but that counts can be used to measure changes on specific streets or routes and to identify longer-term trends in citywide bicycle traffic. To get the most comparable year-to-year results, the authors recommend:

- Using a good spread of counting sites, both in terms of geographic distribution and total number of sites.
- Counting for 2–4 weeks, supplemented by at least one permanent counting station, during times of year with relatively stable weather and no vacation periods (e.g., May or September).
- Documenting the characteristics of each year's count, including the method used to select sites, the count duration, the weather, the measurement method, the method used

to process the counts (e.g., weather adjustments, method used to determine averages), and a description of each site.

- Randomly selecting sites each year, if resources permit.

Niska et al. conducted bicycle counts over 2 years in two Swedish cities (Lund and Jönköping) using more than 200 short-term count locations and at least one permanent count location, supplemented with travel surveys. Table 2-4 shows the error in the estimate of year-to-year change in bicycle traffic based on the number of randomly selected count locations within each city used to estimate the change.

Table 2-4. Error in Prediction of Year-to-Year Change in Bicycle Traffic Based on Number of Count Sites in Two Swedish Cities

Number of Sites	Lund	Jönköping
5	±36%	±39%
10	±26%	±27%
15	±21%	±22%
20	±18%	±19%
30	±15%	±16%
40	±13%	±14%
50	±11%	±12%
100	±8%	±9%
200	±6%	±6%

Source: Niska et al. (2012).

Sensing Technologies for Non-Motorized Counting

This part of the literature review summarizes current and emerging sensing technologies that can be used to conduct pedestrian and bicycle counts. This section generally uses the term “technology” to refer to the type of sensor used to detect pedestrians or bicyclists; individual devices may vary in the types of technology that can be used to power the device and to store and transfer data.

General Overviews of Technologies

FHWA Traffic Monitoring Guide (TMG)

Chapter 4, Bicycle and Pedestrian Monitoring, of the TMG (FHWA 2013) discusses the different available technologies and data collection methodologies for monitoring non-motorized traffic in the U.S. The chapter describes the challenges of tracking pedestrian and bicycling activity, including issues related to the ways bicyclists and pedestrians travel, such as diverging from specified routes and traveling in closely spaced groups. The chapter also provides an overview of different data collection equipment, describing the technology used, equipment characteristics, preferential installation location, and important variables.

The chapter notes that the NBPD offers guidance on collecting manual counts, as well as an overview of automatic count technologies. It recommends different automatic count technologies based on the count location and purpose (Alta Planning + Design 2012a). Outputs of the NBPD methodology have not been rigorously tested to date.

A review of the literature reveals a range of counting technologies currently in use in the U.S., from simple manual counts with paper forms to sophisticated image sensing equipment supported by computer algorithms that identify and count pedestrians and bicyclists. General categories of technologies currently in use include:

- *Manual counts*: data collectors perform counts in the field, and record results with a writing implement and paper, automated count board, or smartphone application.
- *Pneumatic tubes*: two rubber tubes are stretched across the right-of-way, and record counts when vehicles pass over them.
- *Piezoelectric strips*: material that produces an electric signal when deformed is laid on or under the ground in two strips.
- *Pressure/acoustic pads*: pads are placed in or on the ground to detect bicycle or pedestrian activity by changes in weight and sound waves.
- *Inductive loop detectors*: wires are installed in or on top of pavement to detect bicycle activity through their disruption of an electromagnetic field.
- *Active infrared*: bicycles and pedestrians are detected when an infrared beam is broken.
- *Passive infrared*: identifies the heat differential of bicyclists or pedestrians when they pass through the detection area.
- *Laser scanning*: laser pulses are sent out in a range of directions, details of the surroundings, including pedestrians and bicyclists, are recorded based on reflected pulses.
- *Radio waves*: detect bicycles and pedestrians when a radio signal between a source and a receiver is broken.
- *Video image processing*: uses visual pattern recognition technology and computerized algorithms to detect bicyclists and pedestrians.
- *Magnetometers*: detect bicycle activity through changes in the normal magnetic field.
- *Radar*: emits radio wave pulses and counts bicyclists and pedestrians based on an analysis of reflected pulses.

Swedish National Road and Transport Research Institute

Niska et al. (2012) summarize the state of Swedish knowledge about the applicability of various technologies to bicycle counting, as shown in Table 2-5.

Table 2-5. Applicability of Count Technologies to Different Counting Environments

Counting Environment	Radar	Infrared	Pneumatic Tube	Inductive Loop	Fiber optic Cable	Video	Manual
Cycle track	X	X	X	X	X	X	X
Shared-use paths	(X)[6]	(X)[6]	X	X	X	X	X
Low speed	X	X			X	X	X
Mixed traffic[1]	(X)[4]	(X)[4]	(X)[5]			--[7]	X
High traffic volume	X	X	X	X	X	X	X
Snow-covered street	X[3]	X		X		X[3]	X
Permanent station	X	X		X	X	X	
Two-week count	X	X	X	(X)[2]			
Intersections						X	X

Source: Niska et al. (2012).
Notes: Parentheses indicate that the technology is possible, but may have detection problems.
[1] Mixed motor vehicle and bicycle traffic.
[2] Adhesive loops exist that do not need to be permanently installed.
[3] High snowfall can create problems.
[4] Distinguishing bicyclists can be problematic with high volumes, with many missed detections.
[5] Vibrations for motor vehicles, particularly trucks, interpreted as bicyclists.
[6] Difficult to distinguish between pedestrians and bicyclists.
[7] No experience with this application.

Reviews of Specific Sensor Technologies

The sections below describes how each general type of sensor technology counts pedestrians or bicyclists. Most of the categories described include specific examples of technologies that are either available on the commercial market or have been developed for academic research projects. Since the automated detection field is developing rapidly, this review is not intended to represent an exhaustive list of specific devices that have been created. Instead, it provides a snapshot of the general categories of counting technologies and several examples of specific products to illustrate these categories.

Manual Counts

Human data collectors can be used to record pedestrian and bicyclist counts using paper sheets, traffic count boards, "clicker" counters, or smartphone apps. Counts are usually recorded for one to 4 hours in discrete time intervals, generally 15 minutes. However, some count boards are also capable of time-stamping all data points. Manual counts can be done in conjunction with automobile counts and have the flexibility to gather additional information desired about travelers, such as directional and turning information, gender, helmet usage (for cyclists), or behaviors, such as use of mobile devices. However, each individual data collector can only observe and record a certain amount of information accurately, so more personnel are needed to collect more types of data. Manual counts can be performed at screenline, intersection, or midblock locations.

Many jurisdictions rely on manual counts taken on an annual basis at strategically chosen and distributed locations, either with the assistance of hired professional consultants or volunteers (Cottrell and Pal 2003). Care must be taken with volunteers to mitigate the effects of ulterior motives, in which the volunteer may discretionarily bias counts upwards or downwards. To reduce error, data collectors should be trained so they have a clear understanding of the count methodology. In addition, managers should plan data collection efforts carefully, ensuring that there are enough data collectors at high-volume locations so that each person can do their portion of the counts accurately.

Diogenes et al. (2007) compared manual pedestrian counts at various intersections in San Francisco recorded using pencil and paper, clicker devices, and video. Video-based manual counts were taken to represent the ground truth. Both of the field counting methods exhibited systematic undercounting compared to the video counts (-8% to -25%), with higher rates of undercounting towards the beginning and end of the count periods. This study showed the importance of data collector training, motivation, and management for obtaining accurate manual counts.

Greene-Roesel et al. (2008) found very little difference in counts obtained manually from video and in the field. In this study, in comparison to that by Diogenes et al. (2007), the counter was given a much simpler task in terms of data to collect while counting. This suggests that to obtain highly accurate data manually in the field, it is advisable to focus on counting all pedestrians, rather than noting characteristics about the pedestrians.

Schneider, Arnold, and Ragland (2009) counted pedestrians for two-hour periods at 50 intersections in Alameda County, CA. The methodology specified that pedestrians should be counted each time they crossed a different leg of the intersection. To prevent confusion about whether or not to count people who stepped outside the crosswalk lines, pedestrians were counted whenever they crossed the roadway within 50 feet of the intersection. One to four data collectors were used, depending on the intersection volume (four data collectors were needed at an intersection with nearly 1,800 pedestrian crossings per hour). This study used paper forms.

Schweizer (2005) reported being able to count roughly 2,000-4,000 pedestrians at an unspecified location using a clicker, but only half as many using pencil and paper. Appendix B of Jones et al. (2010) includes a thorough training guide for conducting manual counts.

Pneumatic Tubes

Pneumatic tubes are currently widely used to count automobiles, but they can also be used for bicycle counts. This technology is applied by stretching two rubber tubes across the right-of-way. When a bicycle or other vehicle passes over the tubes, pulses of air pass through to a detector which then deduces the vehicle’s axle spacing, and hence classifies it by vehicle type. This technology can be very effective when automatic data is needed for several days to several weeks. Pneumatic tubes have the benefits of being highly portable and easy to set up. Additionally, many jurisdictions are familiar with their operation from experience with automobile counts. However, pneumatic tubes suffer the consequences of being susceptible to theft, vandalism, and wear-and-tear. Additionally, care should be taken with the installation of pneumatic tubes in locations where pedestrians and bicyclists share a right-of-way, as they can present a tripping hazard to pedestrians. Rubber tubes also do not maintain their properties in cold conditions and can deteriorate under high bicycle or vehicular traffic, thus reducing their accuracy. Travel direction can be detected through the use of two tubes (Alta Planning + Design 2011).

ViaStrada (2009) performed a field test of bicycle counting using two pneumatic tube models in New Zealand. The tubes were installed in both off-road and on-road mixed traffic situations. Preliminary results presented in the report appeared promising in the off-road locations, but some installation difficulties pertaining to the width of the lane arose in the on-road locations. Accuracies reported for off-road locations were -11% (Error-Adjusted Index[1]=81%), -14.6% (EAI=82%), 0% (EAI=88%), and -1% (EAI=94%).

Hjelkrem and Giæver (2009) tested two models of pneumatic tubes in mixed traffic and found bicycle count accuracy rates of -27.5% and -1.9%. Pneumatic tubes have also been discussed in previous literature reviews (AMEC E&I and Sprinkle Consulting 2011; Somasundaram, Morellas, and Papanikolopoulos 2010).

Piezoelectric Strips

Piezoelectric strips can be installed embedded within paved surfaces to count bicyclists. Piezoelectric materials emit an electric signal when they are physically deformed. Counters utilizing this technology consist of strips laid across the right-of-way that record and analyze electric signals produced similarly to pneumatic tubes. There is a current deficit of academic literature pertaining to piezoelectric strips for bicyclist counting. Schneider et al. (2005) discuss a case where the Iowa DOT used piezoelectric strip detectors to count bicyclists on multi-use paths. The Iowa DOT reported ease of use as a determining factor in selecting piezoelectric strips. As another example case, South East Queensland has developed a bicycle/pedestrian counting apparatus utilizing a commercially available piezoelectric strip system for bicycle counts and passive infrared for pedestrian counts (Davies 2008).

Pressure/Acoustic Pads

Pressure and acoustic pads are primarily used to count pedestrians on unpaved trails. These pads are installed in-ground, either flush with or under the surface. Installation can be difficult in paved situations, as the pavement must be cut. Counts are detected either by the change in weight on the pad (pressure) or by sound waves from footsteps (acoustic). One disadvantage of pads is that they depend on direct contact from pedestrians or bicyclists, and hence are primarily suited to channelized situations in which pedestrians or bicyclists are restricted to travel single file. Pads are also susceptible to problems when the ground freezes. No thorough tests of acoustic or pressure pads were found, but they are discussed in a number of literature reviews (Alta Planning + Design 2011; AMEC E&I and Sprinkle Consulting 2011;

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[1] Error-Adjusted Index is calculated as $\frac{\sum_{t=1}^{T} M_t - O_t - U_t}{M_t}$, where M_t is the manual count, O_t is the number of over-counts, and U_t is the number of under-counts.

Somasundaram, Morellas, and Papanikolopoulos 2010; Ozbay et al. 2010; Bu et al. 2007). This technology may be uncommon due to cost, lack of site flexibility (best for narrow walkways/trails), or other factors.

Fiber-optic Pressure Sensors

Fiber-optic pressure sensors detect changes in the amount of light transmitted through an imbedded fiber-optic cable based on the amount of pressure (weight) applied to the cable. The sensitivity of the counter can be adjusted based on the desired minimum or maximum weight to be counted. These sensors form the basis for some commercial "bicycle barometers" in Europe—permanent bicycle counting stations (Figure 2-1) that display to bicyclists and others how many bicyclists have passed by the location that day and/or year (Olsen Engineering 2012). (Bicycle barometers can also use other types of sensors, such as inductive loops.)

Figure 2-1. Bicycle Barometers

Source: Paul Ryus, Kittelson & Associates, Inc.

Inductive Loop Detectors

Inductive loop detectors consist of loops of wire with a current running through them. To count bicyclists, these devices are placed on top of the roadway or paved trail surface (temporary) or under the surface (embedded). Embedded loops must be installed by cutting the pavement surface. Bicycles are detected when they ride over the loops because they temporarily change the magnetic field produced by the current in the wires. Loop detectors must be placed in locations of low electromagnetic interference to work accurately. Loop detectors may overcount when bicyclists ride over certain points on the devices (they register two counts instead of one) and may undercount when multiple bicycles pass over the detector nearly simultaneously. Bicyclists moving at walking speed do not pose an accuracy problem for inductive loops designed to distinguish bicyclists (Nordback et al. 2011).

Nordback and Janson (2010) have tested traditional induction loops which do not distinguish between bicycles and other vehicles on off-road multiuse paths, and novel inductive loops capable of distinguishing bicycles from other vehicles on off-road paths and on shared roadways (Nordback et al. 2011) in Boulder, CO. The off-road counters (traditional induction loops) were found to have an average accuracy of -4% as compared with manual counts, with an average absolute value percent difference (AAPD)[2] of 19%. The novel induction loops tested demonstrated -3% accuracy on separated paths (AAPD 8%) and +4% accuracy on shared roadways (AAPD 24%).

ViaStrada (2009) tested two models of inductive loops in New Zealand at both on-road and multi-use trail sites. On-road sites had count accuracies of +2% (Error-Adjusted Index=88%), -10% (EAI=88.8%), +5% (EAI=90.2%), and +4% (EAI=75.7%). Off-road sites demonstrated accuracies of 0% (EAI=88%), -3% (EAI=87%), +25% (EAI=74%), and -10% (EAI=85%). Hjelkrem and Giæver (2009) tested four models of induction loops in Norway on sidewalks, mixed traffic roads, and bike lanes in uncontrolled traffic. In this study, the loops demonstrated accuracy rates of -16.5% to -2.5%. Sidewalk locations had the highest accuracy, with a range of -6.0% to -2.5%. No estimate of variance of errors was given.

Active Infrared (Active IR)

Active infrared sensors count pedestrians and bicyclists using an infrared beam between a source and a receiver. When the beam is broken by an object in its path, a count is recorded. These devices can record counts with ranges of about 30 meters between transmitter and receiver (Bu et al. 2007). However, they are incapable of distinguishing between objects breaking the beam. False positives can be recorded due to anything passing through the detection site, including vehicles, insects, leaves, animals, or rain drops. Further, false negatives can result from pedestrian occlusion.

Jones et al. (2010) utilized a Trailmaster active infrared device in San Diego County, CA. After an initial validation count, it was determined that the device operated more accurately at a 45-degree angle relative to the direction of travel of pedestrians. Accuracy rates were found to be -12% to -18% for all travelers, and -25% to -48% for pedestrians, with an inverse relationship between accuracy and flow. No estimates were made on variance of errors.

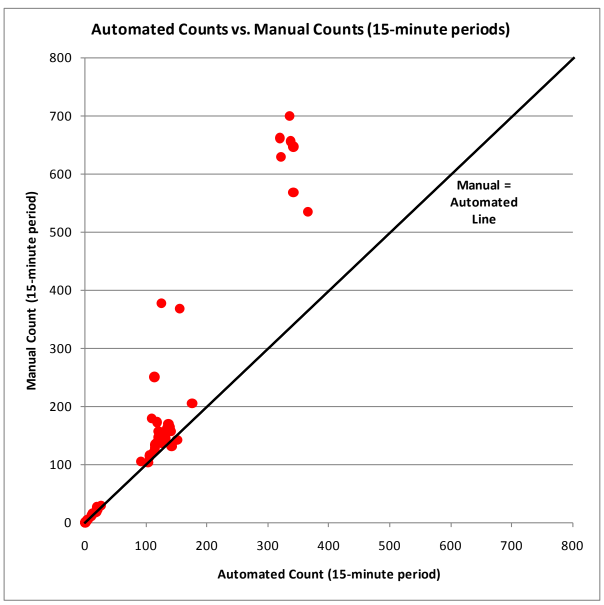
Passive Infrared (Passive IR)

Passive infrared sensors identify and count pedestrians and cyclists based on the infrared radiation (i.e., heat) that they emit. The placement of passive IR counters is critical to obtaining good results. Ideally, the device should be placed facing away from the street towards a fixed object (such as a wall) in a location where pedestrians are not likely to tend to linger (e.g., away from bus stops). Additionally, caution must be taken during installation to avoid problems with

[2] Average Absolute Value Percent Difference is calculated as the sum of absolute differences between each automated count and its corresponding actual count divided by the total number of observations.

reflection due to water or windows and interference from power lines. Errors arise due to occlusion with groups of pedestrians.

Passive infrared counters have been tested in a number of projects. Greene-Roesel et al. (2008) tested a passive IR counter at three sidewalk locations in Berkeley, CA. Automated counts were compared with video based manual counts, and were found to undercount at a fairly consistent rate (between -9% and -19% each hour). Schneider, Arnold, and Ragland (2009) also found relatively consistent rates of undercounting for sidewalk volumes of up to 400 to 500 pedestrians per hour at locations with different sidewalk widths and during sunny, cloudy, rainy, and dark conditions. However, Schneider et al. (2012) found that the rate of undercounting for passive IR counters increased as pedestrian volumes increased in San Francisco. The researchers hypothesized that there were more groups of pedestrians passing the counter side-by-side when pedestrian volumes increased, so occlusion rates increased. In order to correct for higher rates of undercounting at higher pedestrian volumes, Schneider et al. (2012) proposed a preliminary adjustment function for Eco-Counter passive infrared sensors, as seen in Figure 2-2. Undercounting is likely to depend on the width and design of the sidewalk in addition to the volume of pedestrians, so further research is needed to refine this adjustment function.



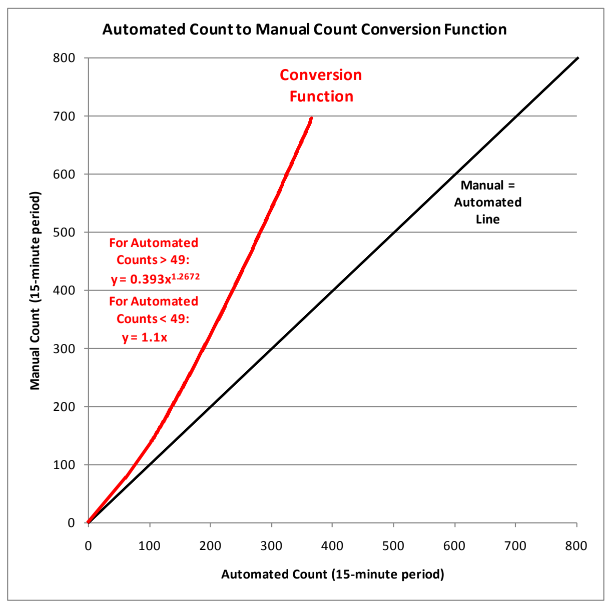


Figure 2-2. Example Passive Infrared Sensor Adjustment Function

Source: Schneider et al. (2012).

Fifteen-minute manual validation counts were compared with automated counts at passive infrared sensor locations in Alameda County and San Francisco, CA (left graph in Figure 2-2). The locations had a variety of sidewalk widths and temperature conditions. Undercounting increased at higher volumes. Researchers used these counts to propose a preliminary automated counter adjustment function (right). Undercounting is likely to depend on the width and design of the sidewalk in addition to the volume of pedestrians.

Hudson, Qu, and Turner (2010) performed accuracy tests on a multi-use path in Texas using three different passive IR counters and one active IR counter. These counters were tested in a controlled manner for a variety of situations, including varied bicyclist speeds and pedestrian group spacing. Additionally, the devices were compared using a number of error metrics, including overall error, missed detection error, and false detection error. Overall, the Eco-Counter passive IR device proved to have lower error rates than the other three counters tested. This result may be due in part because this test occurred four years later than the other three, so the technology had more opportunity to mature.

Jones et al. (2010) tested a passive IR counter (Jamar scanner) at various locations throughout San Diego County, CA. The device was found to have an accuracy of -15% to -21% relative to manual counts. It was also discovered that the device functioned more accurately when oriented at a 45-degree angle to the path of travel of pedestrians, rather than 90 degrees, to help avoid occlusion errors.

Ozbay et al. (2010) tested an Eco-Counter pyroelectric sensor and a TrafSys thermal sensor on trails in Piscataway, NJ. This study reported mean absolute percentage errors of -28% to 0% for the Eco-Counter and -15% to 1% for the thermal sensor, with higher errors generally occurring at higher volume count locations. The study also includes detailed installation, calibration, and data retrieval notes.

Montufar and Foord (2011) tested a variety of devices in cold weather, including an Xtralis ASIM IR 207 passive IR detector. The ASIM device showed very high levels of sensitivity regardless of temperature, but an increasing level of selectivity with increasing temperature. Hence, level of performance appears to decrease at lower temperatures for this device.

Laser Scanning

Laser scanners emit laser pulses in a range of directions and analyze the reflections of the pulses to determine characteristics of the device's surroundings, including the presence of pedestrians or bicyclists. Two varieties of laser scanners exist: horizontal scanning and vertical scanning. Horizontal scanners require an open detection area with no obstructions. Vertical scanners must be mounted above the detection area. Laser scanners face operational difficulties in inclement weather, such as rain, snow, and fog, due to interference with the laser pulses (Bu et al. 2007). Laser scanning also entails heavy computational loads, so a dedicated CPU may be necessary to store and analyze the data.

Numerous technical papers can be found on the topic of pedestrian tracking and counting using laser scanners (Musleh et al. 2010, Cui et al. 2007, Katabira et al. 2004, Shao et al. 2007, Navarro-Serment et al. 2008).

Tanaka (2010) reports on the development and testing of a vertical laser scanner pedestrian counter. This device had an accuracy of greater than -5% error relative to manual counts. However, this system has not been tested in high pedestrian volume scenarios, which seem likely to introduce higher levels of error. Shao et al. (2011) developed a laser scanner mounted on a swinging arm to help solve difficulties of occlusion inherent to stationary laser scanner counting. A reported difficulty in the study is that the scanner's swinging frequency is insufficient to deal with highly crowded environments, so the authors propose combining this technology with an additional detector for high pedestrian densities. Laser scanners have been applied more heavily to vehicle-mounted detection systems than to ground-based pedestrian counting.

Radio Beams

Radio beams count pedestrians in a similar manner as active infrared counters. However, instead of an infrared beam, a radio signal is utilized. This allows the source and receiver to be placed behind certain objects (e.g., wood) that do not interfere with the signal, hence decreasing the risk of theft or vandalism. Radio beam counters require single file pedestrian travel, and hence are best suited to low volume or constrained locations. Discussions of this technology are very limited in the literature, with a brief mention by Somasundaram, Morellas, and Papanikolopoulos (2010). In New Zealand, the Queenstown Lakes District Council is noted anecdotally as utilizing these counters on two multi-use paths, and reporting them as the best counting technology that they had found based on 20 years of experience (ViaStrada 2009).

Video

Video analysis involves counting pedestrians or bicyclists from images created by cameras. Video analysis requires mounting a camera overhead, so it is necessary to find a mounting point where installing the camera is permitted. There are two main types of video analysis: manual and automated. Manual video analysis entails recording video at a study location and an analyst performing manual counts on the footage. Manual video counts offer the ability to slow down and replay footage to increase accuracy in situations where distinguishing individuals might otherwise be difficult. However, manually analyzing one hour of video can take roughly three hours, leading to far higher labor costs than manual counts in the field (Diogenes et al. 2007). As a counterpoint, manual counts conducted using video have been found to be more cost effective than human surveys conducted in the field, with labor savings of roughly a factor of 2 (Manhard Consulting 2011). In this study, the greatest cost savings were seen at rural and/or remote sites, with light traffic and simple configurations.

Automated video analysis is sometimes referred to as computer visioning or image processing. Rather than having a technician view a video to perform counts, computer algorithms are used to identify when changes in the background image are actually pedestrians passing through the detection area. This process allows pedestrians to be counted automatically. Automated counting cameras are under development and have been used in several academic studies (Ismail et al. 2009; Malinovskiy, Zheng, and Wang 2009; Ribnick, Joshi, and Papanikolopoulus 2008; Li et al. 2012; Hu, Bouma, and Worring 2012). Similarly, Nguyen et al. (2012) propose a system to count pedestrians based on tracking. However, current technology has difficulties identifying and counting individual pedestrians traveling in groups. Reliable systems exist for indoor counting applications, but varying light intensities and other environmental factors make automated video counting substantially more difficult in outdoor settings.

Somasundaram, Morellas, and Papanikolopoulus (2010) have developed an algorithm to separately identify bicyclists and pedestrians in video footage, reported to work at roughly 70%

accuracy. In a separate report from the same authors published two years later (Somasundaram, Morellas, and Papanikolopoulus 2012), the counting algorithm's accuracy is reported to have been improved to 86% for bicyclist classification and 98% for pedestrian classification.

Brändle, Belbachir, and Schraml (2010) have developed an overhead counting device for mixed cyclist and pedestrian flows known as SmartCountPlus. Based on an initial test of 128 passings with varied combinations of cyclists and pedestrians, the device's accuracy has been reported at 92% for riding bicyclists and 100% for pedestrians. For mixtures of pedestrians, riding cyclists, walking cyclists, and pedestrians with umbrellas, accuracies are reported at 43% to 96%.

Ling et al. (2010) have developed a system utilizing both a stereo camera and a laser scanner. The authors report an accuracy of over 90% in a realistic environment, including dense groups of pedestrians, but also state plans to further develop the technology to higher levels of consistency.

Prabhu (2011) finds that the Autoscope Solo Terra counts pedestrians with greater than 85% accuracy in multiple experiments. Additionally, this paper discusses and tests a novel system combining the Autoscope technology with lower cost algorithmic processing of recorded video for increased accuracy in high pedestrian volume situations.

Malinovskiy et al. (2009) have developed a method for tracking and tracing pedestrians and bicyclists using ordinary video footage. This system counts based on traces, and has worked around some of the inaccuracies that arise due to occlusion. As of 2009, this technology was reported as operating at an average 92.7% accuracy, where accuracy is calculated as 100%–100%×((Overcounts + missed counts)/manual counts).

Thermal Imaging Cameras

Thermal imaging cameras are a combination of passive infrared and video counting technologies. This is an emerging technology and is therefore not documented in the literature.

Magnetometers

Magnetometers are currently widely used for detecting motor vehicles. Counts occur when ferrous (i.e., magnetic) objects enter the region above the device and alter the Earth's magnetic field. No field tests have been found using these devices. The TMG (FHWA 2013) suggests that magnetometers might not perform well for bicycle counting in mixed traffic with motor vehicles. A manufacturer claims that magnetometers are best suited to "rural, rugged, and remote" applications for mountain bike counting (TRAFx 2012). Reasons cited for this include the device being easier to bury and hide than other bicycle counters, and its high sensitivity to ferrous objects.

Radar

Tests of bicycle and pedestrian counters using Doppler radar technology have not been widely documented. These devices operate by emitting electromagnetic pulses and deducing information about the surroundings based on the reflected pulses. Vienna, Austria reportedly utilizes radar-based counters and has found them to work "flawlessly," as compared against manual counts (AMEC E&I and Sprinkle Consulting 2011). However, no academic literature was found to support this claim.

Paired Devices

In order to count both bicyclists and pedestrians at a location with mixed traffic, technologies can be paired. The specific technologies being paired depends on the location under study, but the technique entails utilizing one device that counts all passers-by (e.g., passive infrared), and one device that exclusively counts bicyclists (e.g., inductive loops). Pedestrian volumes can then be calculated by subtracting the number of bicyclists from the total traveler volume. This technique is necessary in mixed-traffic situations because no current technologies are capable of accurately isolating and counting pedestrians.

Sampling Data Collection Techniques

A number of other technologies and techniques are available for gathering pedestrian and bicycle sample data, but have not been successfully used for estimating total pedestrian and bicycle volumes. These approaches are better suited to developing origin-destination travel patterns, investigating route choice, and developing system-wide mode share estimates. Bluetooth detectors, GPS data collection, pedestrian signal actuation buttons, radio-frequency (RF) tags, surveys, and transit vehicle automatic passenger counters have all been used to gather sample data and establish minimum pedestrian and bicycle volumes on various facilities. However, it is not possible to reliably convert this sample data to total counts due to the influence of multiple location-specific factors (e.g., smart phone usage, transit mode share). A brief description of these techniques and their limitations is presented below.

- **Bluetooth Signal Detection.** Consumer electronics enabled with Bluetooth wireless capabilities have proliferated across the market in recent years. Bluetooth readers record the unique ID of Bluetooth-enabled devices passing near a detector, generating a sample count of facility users. In order to be detected by a Bluetooth reader, a pedestrian or bicyclist must have a Bluetooth-enabled phone or other device with the Bluetooth transmitter turned on. By setting up multiple detectors around an area and matching unique device IDs, Bluetooth readers can be used to evaluate travel times and route choice. It is not possible to differentiate between modes using Bluetooth data, therefore application of this technology to pedestrian and bicycle studies is limited to isolated non-motorized environments, such as trails, malls, and stadiums (Liebig and Wagoum 2012). Estimating total pedestrian or bicycle volumes based on sample data is problematic even in these isolated locations, due to the need for location-specific adjustment factors based on the percentage of users with Bluetooth-enabled devices, percentage of users with multiple Bluetooth-enabled devices (e.g., cell phone and earpiece), ratio of devices with transmitters turned on, etc.
- **GPS Data Collection.** Multiple agencies have used stand-alone GPS units or smartphone applications (e.g., Cycle Tracks) that utilize the phones' GPS functionality to collect non-motorized trip data (Hood, Sall, and Charlton 2011). These applications have been used primarily to evaluate route choice, but have also been used to compare demand at different locations. The sample data collected through this method can be

used to establish minimum volumes at a location, but cannot be adjusted to estimate total pedestrian or bicycle volumes. Sample bias is also an issue with these technologies, as those being counted have to, at a minimum, opt-in to the program and—for example, with smartphone apps—have to remember to use the counting device on each trip.

- **Pedestrian Signal Actuator Buttons.** Day, Premachandra, and Bullock (2011) found that for their particular test site, signal activation rates were a reasonable proxy for relative rates of pedestrian demand. However, they explicitly state that observing these rates is not an effective method for collecting total pedestrian counts. Portland currently counts and stores pedestrian button activations at 14 locations, with more locations planned, and is investigating the possibility of developing relationships between actuations and demand, based on site characteristics (Kothuri et al. 2012).
- **Surveys.** Surveys can be used to collect other pedestrian and bicyclist data, such as mode share and origin-destination information. Mode shares can then be extrapolated to determine total pedestrian volumes for a larger area, such as within a traffic analysis zone (TAZ), but estimates made in this manner do not serve as a suitable means of collecting count data due to the relatively small sample size in contrast with a relatively large sample area with complex land use patterns.
- **Transit Vehicle Automatic Passenger Counters (APCs).** APCs record the number of passengers boarding and alighting a transit vehicle, typically based on farebox data and infrared sensors located at the vehicle doorways. APC data can be combined with GPS data gathered be the transit vehicle's automatic vehicle locator (AVL) system to approximate the level of pedestrian activity at stop locations. APC data can be used in determining pedestrian waiting area space requirements for boarding passengers at the bus stop and in estimating cross-flow volumes for alighting passengers, which can influence pedestrian flow on sidewalks at busy bus stops. This method does not account for other pedestrian activity in an area, however, and cannot be used to estimate total pedestrian counts.
- **Radio Frequency Identification (RFID) Tags.** RFID tags are commonly used in the logistics industry for tracking individual packages, containers, etc. They can be read at a distance of 5–10 meters, depending on the antenna power and particular radio frequency used (Andersen 2011). Fredericia, Denmark has implemented a "Cycle Score" program that tracks how often participants visit specific sites (typically schools and worksites). Program participation is voluntary, but participation is encouraged through prize drawings (each check-in counts as an entry) and a website (www.cykelscore.dk) that provides rankings in various categories (most check-ins, most recent check-in, etc.). Participants in the program affix a laminated RFID tag to their front wheel. A box containing a tag reader, RFID antenna, power supply, and WiFi antenna is placed at each check-in location and forwards each check-in over the Internet to the city's bicycle program. Because affixing an RFID tag to one's bike is voluntary, this method only collects sample counts that may or may not be representative of the entire population.

Correction Factors and Extrapolation Methods

An important distinction is made in this project between the concepts of correction factors and extrapolation methods. Both approaches adjust raw data. However, they are differentiated as follows:

- **Correction factors (functions)** are used to eliminate systematic inaccuracies (e.g., over- or undercounting) in pedestrian or bicycle counts that result from the data collection technology used. Strictly speaking, a correction factor involves a simple multiplicative adjustment, while a function involves a more involved series of calculations; however, this report generally uses the term "factor" to cover both types of calculation.
- **Extrapolation methods** are used to expand short-duration counts to estimate volumes over longer time periods or to compare counts taken under different conditions.

Correction factors have been developed for a few pedestrian and bicycle counting technologies based on the accuracy studies described in the proceeding section. These correction factors may not be straightforward, linear, or necessarily similar to motor vehicle counter correction factors. Certain sensor technologies may over- or undercount by different amounts under different conditions, so different correction factors may be needed for the same type of technology in different situations. Most pedestrian and bicycle counting technologies have not been tested rigorously for accuracy, so variable correction factors are rare.

The remainder of this section summarizes extrapolation methods used in pedestrian and bicycle travel monitoring. More extensive information on these topics is provided in the TMG (FHWA 2013).

Extrapolation methods address common challenges faced when converting raw pedestrian or bicycle count data into useful information for technical analysis and public presentation. These factors can be applied as follows:

- **Temporal adjustment factors** extrapolate counts taken during a short time period to estimate the volume of pedestrians or bicyclists at the count location over a longer time period. They are also applied to compare counts that have been taken at different times of the day, week, or year.
- **Land use adjustment factors** control for different types of pedestrian and bicycle activity patterns near specific land uses.
- **Weather adjustment factors** account for the effect of weather conditions on pedestrian or bicycle activity.
- **Access/infrastructure sufficiency adjustment factors** account for the effect of pedestrian/bicycle access, facility type, and network development on pedestrian or bicycle activity patterns.
- **Demographic adjustment factors** control for surrounding area demographics.

The extrapolation process uses assumptions about long-term patterns of pedestrian or bicycle activity to estimate daily, weekly, or annual pedestrian or bicycle volumes from a short-duration (e.g., two-hour) count. Extrapolation is useful because resource limitations may prevent agencies or researchers from collecting data over an extended period of time at all locations where volumes are desired. Extrapolated data have been used to:

- Estimate pedestrian and bicycle exposure for safety analyses (i.e., express pedestrian or bicycle risk as the rate of reported pedestrian crashes per user). Crashes are often reported over long time periods (e.g., one year), so a parallel measure of exposure is needed.
- Compare long-term pedestrian and bicycle volumes between locations where short-duration counts were taken at different points in time.
- Estimate daily or annual pedestrian or bicycle volumes for comparison to nearby automobile volumes.

Extrapolation methods are based on two types of data: (*a*) pedestrian and bicycle activity patterns (often generated by automated counting technologies) and (*b*) short-duration counts (typically collected manually). The overall accuracy of extrapolated pedestrian or bicycle volume estimates depends on the accuracy of the overall activity pattern data and the short-duration count data. Therefore, temporal, land use, and weather adjustment factors have been developed to increase the accuracy of these inputs.

Recent Research

A summary of research on non-motorized volume adjustment factors and extrapolation methods is given in Table 2-6.

Current Factors in Use

This section summarizes the types of factors for adjusting and extrapolating counts currently in use, based on available literature and case studies.

Temporal Adjustment Factors

Temporal adjustment factors are used to account for "peaking" patterns, or the tendency for pedestrian or bicycle volumes to be distributed unevenly throughout the day, week, or year. For example, there may be high pedestrian volumes on sidewalks in a central business district at 5 p.m., but relatively low volumes at 3 a.m. A popular recreational trail may have higher bicycle volumes on weekends than weekdays.

The most basic form of extrapolation is to multiply a short-duration count by the inverse of its proportion of the longer time period to estimate the volume during the longer time period. For example, if each hour of the day had exactly the same number of pedestrians or bicyclists at a particular location, each hour would represent approximately 4.2% (1 hour/24 hours) of the daily volume. In this case, it would be possible to multiply the one-hour volume by 24 to estimate the daily volume. However, pedestrian and bicycle volumes are rarely constant over long periods of time. Several studies have developed temporal adjustments to more accurately reflect uneven distributions of pedestrian and bicycle activity.

Greene-Roesel et al. (2008) describes a method for establishing adjustment factors for automated counts on pages 65–81. A step-by-step approach is given for stratifying a region into similar location types, and determining temporal adjustment factors for these different location types. This method also provides a way to estimate the error of the adjusted volumes.

Davis, King, and Robertson (1988) investigated the predictive power of taking 5-minute sample counts at various points in an analysis period. Counts taken at the middle of the interval were the most predictive (over the beginning, end, or a random point in the interval), and accuracy was improved as sample times were increased from 5 to 30 minutes. Further, accuracy decreased with increasing length of prediction. Expansion models are given for 5, 10, 15, and 30 minute counts to predict 1, 2, 3, and 4 hour volumes.

Hocherman, Hakkert, and Bar-Ziv (1988) note that, in Israel, very little pedestrian traffic occurs between the hours of 2200 and 0700. In residential areas, the flow during this nighttime period is 3% ADT, and in CBDs is 7% ADT. Accordingly, they assert that one can get simply take 15-hour daytime counts (from 0700–2200) and multiply these volumes by the appropriate factor (1.03 or 1.07) to calculate 24-hour ADT.

Cameron (1977) demonstrated month-to-month variations in pedestrian activity at shopper locations in Seattle, with peaks occurring in August and December likely due to back-to-school and Christmas shopping, respectively. At the same locations, day-to-day peaks were observed on Fridays and Saturdays, with Fridays having pedestrian rates 24% above ADT. Hourly comparisons showed that the noon hour accounted for 14% of the average weekday total. On Saturdays, a peak was observed from 2 p.m. to 3 p.m. with gradual increases and decreases in traffic prior to and after the peak. At employee-dominated locations, Fridays had roughly 1/3 more traffic than ADT, while Saturdays averaged about ½ ADT. Sundays had the lowest traffic. Noon peaks at these locations made up roughly 13.5%–18.5% of the total daily pedestrian volume. At visitor locations, weekday peaks occur between 1 and 2 p.m., with 11.2% traffic. Saturdays have a high activity period from 1 to 4 p.m. with no distinct peak, and Sundays have high activity from 1 to 6 p.m. with a peak from 3 to 4 p.m.

Hocherman, Hakkert, and Bar-Ziv (1988) observed three distinct daily pedestrian volume peaks in residential areas and CBDs in Israel. In the residential areas, the peaks and hourly percentages of ADT were as follows: 7 to 8 a.m. (13.6%), 12 to 1 p.m. (8.6%), and 4 to 7 p.m. (7.6%–9.9%). In the CBDs, the peaks were similar: 7 to 8 a.m. (7.1%), 11 a.m. to 1 p.m. (8.8%–9.1%), and 4 to 7 p.m. (8.8%). They point to particular sociocultural reasons why the peaks are different in these two regions, namely the locations and start times of schools and the time that most stores open. Further, there was little seasonal variation in Israel, aside from during school vacations and on weekends.

Table 2-6. Summary of Research on Pedestrian and Bicycle Volume Patterns

Author(s), Year	Summary	Temporal Factors	Weather Factors	Land Use/Demographic Factors
Cameron, 1977	Automated ped counts in Seattle, WA	Observation of hourly and daily fluctuations	Decreased shopper volumes due to rain	Distinct patterns observed for separate pedestrian classes: shoppers, commuters, visitors, and mixed
Davis, King, and Robertson 1988	18,000 5-minute counts in Washington D.C.	• Middle of a count interval produces more accurate model. • Longer count intervals also produce more accurate models.	N/A	Six distinct volume patterns based on land use appeared across 14 sites
Hocherman, Hakkert, and Bar-Ziv 1988	84 count locations in Israel, with 135 daily counts in 15-minute intervals recorded	Three peaks observed in both CBD (0700-0800; 1200-1300; 1600-1900) and residential areas (0700-0800; 1100-1300; 1600-1900)	N/A	Different patterns observed in the CBD and residential areas
Lindsey and Nguyen 2004	Automated counts of pedestrians and bicyclists taken on multiuse trails in Indiana at locations on 6 different trails as well as at 5 locations along one trail	Higher traffic on weekends than weekdays (average 31% higher in September, 61% in October). Weekday peaks observed in late afternoon/early evening. Weekend peaks observed in mid-late afternoon.		Trail volume varied by population of city
Zegeer et al. 2005	Calculations of ADT explained in Appendix A. Adjustment factors from 8- to 12- hour counts at 22 intersections, and from 24-hour counts in Seattle, WA	Distinct flow patterns observed in three land use types, although all three are characterized by a midday peak	N/A	Different temporal patterns used in CBD, fringe, and residential areas
Lindsey et al. 2007	Long-term automated (active IR) counts on greenways in Indianapolis, IN	July and August represent monthly peaks; 60% higher volume on weekends than weekdays		
Phung and Rose 2007	Analysis of permanent inductive loop data from off-road paths in Melbourne, Australia	Identify commuter routes vs. recreational routes based on whether highest usage occurs on weekdays or weekends/holidays	• 8-19% reduction in bicycle volume with light rain (0.2–10 mm/day) • 13-25% reduction in bicycle volume with heavy rain (10+ mm/day) • Only heavy wind (>40 km/h, based on average of 9 am and 3 pm observations) had a statistically significant effect on volumes	• Bay Trail (recreational use, more exposed?) was much more impacted by weather than other facilities, with a 48% volume reduction with a combination of light rain and strong winds.

Author(s), Year	Summary	Temporal Factors	Weather Factors	Land Use/Demographic Factors
Aultman-Hall, Lane, and Lambert 2009	One year of automated pedestrian count data (pyroelectric) from Montpelier, VT	Single midday peak observed, presumably location-specific	13% decrease in volume during precipitation events	N/A
Schneider, Arnold, and Ragland 2009	Method to expand from 2-hour counts to weekly pedestrian volumes. Tested in Alameda County, CA	Weekly patterns averaged across days and locations presented graphically	• Rain reduces pedestrian volume by 35%-65%, larger effect on weekends • Cloud cover reduces volumes by 5%-24% • Warmer air temperatures associated with lower volumes, although very few extreme temperature events observed	Adjustment factors found for employment centers, residential areas, neighborhood commercial districts, and locations near multiuse trails
Miranda-Moreno and Nosal 2011	Three cycling seasons of automated bicycle counts(induction loop) from 5 counters in Montreal, QC, Canada analyzed for a range of factors	• AM/PM peaks demonstrated • Day-of-week effect appears to peak mid-week, with slight decreases on M/F and large decreases on Sa/Su • Monthly effects appear to peak in summer with increases in Spring and decreases in Fall.	Temperature, humidity, and precipitation all have significant effects, with variations across facilities and temporal variables. Lagged precipitation effect (rain in previous 3 hours or morning) demonstrated. Effects of temperature deviations from the average vary by season.	Bike facility installation appears to have increasing cycling levels.
Flynn et al. 2012	Longitudinal study on effects of weather on 163 frequent bicycle commuters' decisions to bicycle		Precipitation, temperature, wind, and snow all found to statistically significantly affect ridership likelihood, to varying degrees.	

Author(s), Year	Summary	Temporal Factors	Weather Factors	Land Use/Demographic Factors
Chapman Lahti and Miranda-Moreno 2012	One year of automated pedestrian counts (pyroelectric) from 5 counters in Montreal analyzed for a range of factors, controlling for seasons		Temperate months: • Flows increase with temperature, then decrease above 25˚C. • Lagged precipitation effect (1 hour) confirmed. • Precipitation effects - roughly linear. Winter months: • Flows linear w/ temperature on weekends, stabilize to a minimum level for decreasing temperatures on weekdays. • Humidity effects 3X greater on weekends. • Precipitation patterns similar to temperature patterns. • Lagged precipitation reduced flows by 14% on weekdays, insignificant on weekends.	Weekdays: Mixed commercial-residential areas had 70% less activity than highly commercial areas. Weekends: Same comparison lower by 57% in warm months and 40% in winter.
Milligan, Poapst, and Montufar 2012	Comparison of extrapolations from 2-hr counts to longer period volumes using 3 methods, along with ground truth data, in Winnipeg, Manitoba	Locally developed vehicle volume expansion factors better predictors than nationally developed pedestrian volume expansion factors.		
Hankey et al., 2012	Volume models developed based on bicycle and pedestrian counts along both on- and off-road bicycle and pedestrian facilities	Scaling factors developed based on time of day for expansion to 12-hour volumes.	Precipitation included as a variable in all models.	Comparisons between facility types. Regression volume models include race, education, income, crime, built environment, and facility-type variables.
Nordback 2012	Dissertation on predicting bicyclist volumes, including factoring techniques, with counts performed in Colorado	Investigated temporal factors using a factoring method and a statistical modeling method; found statistical modeling to be more predictive	Temperature found to be the greatest predictor, with quadratic and cubic forms, followed by hourly solar radiation, daily high temperature, daily low temperature, snow, and precipitation.	

Lindsey and Nguyen (2004) studied trail user volumes on six urban multiuse greenway trails in Indiana, including five count locations along one trail through Indianapolis. Twenty-four-hour volumes were collected using active infrared counters (TRAILMASTER 1500), and corrected using a linear adjustment function, based on 56 hours of field counts. Weekend average daily volumes were found to be on 36% higher than daily weekday volumes during September, and 61% higher during October. Peak hour factors[3] (PHFs) were generated for all sites on a monthly basis. In September, the weekday PHFs across all trails ranged from 1.5 to 2.5 and weekend PHFs ranged from 1.3 to 1.7. Similarly, in October, the values ranged from 1.5 to 2.7 on weekdays and from 1.6 to 2.1 on weekends. The overall lower values on weekends suggested that weekday peaking is a stronger effect for the locations under study.

In a follow-up study, Lindsey et al. (2007) performed continuous counts at 30 sites across a network of 5 greenway trails in Indianapolis using active infrared counters over periods of 1–4 years. July and August had the highest average monthly volumes. Weekend daily traffic was on average roughly 60% greater than weekday daily traffic. Hourly patterns varied between weekends and weekdays, as well as across locations.

Aultman-Hall, Lane, and Lambert (2009) found a distinct hourly pedestrian volume profile based on year-long counts at a site in downtown Montpelier, VT. A single midday peak was observed, which the authors attribute to site-specific causes. A 16% decrease in pedestrian volumes was also observed during the winter months.

Schneider et al. (2009) counted pedestrians automatically at 11 count locations throughout Alameda County, CA. Particular adjustment factors based on time of day were not given, but results for percent of weekly volume by hour of week were shown in a graphical format in Figure 2-3. This paper suggested that this approach can be repeated by conducting automated counts to determine the percentage share that a particular hour of the week accounts for, and using this factor to estimate weekly volumes.

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[3] Calculated as the ratio of mean peak hour traffic to mean hourly traffic.

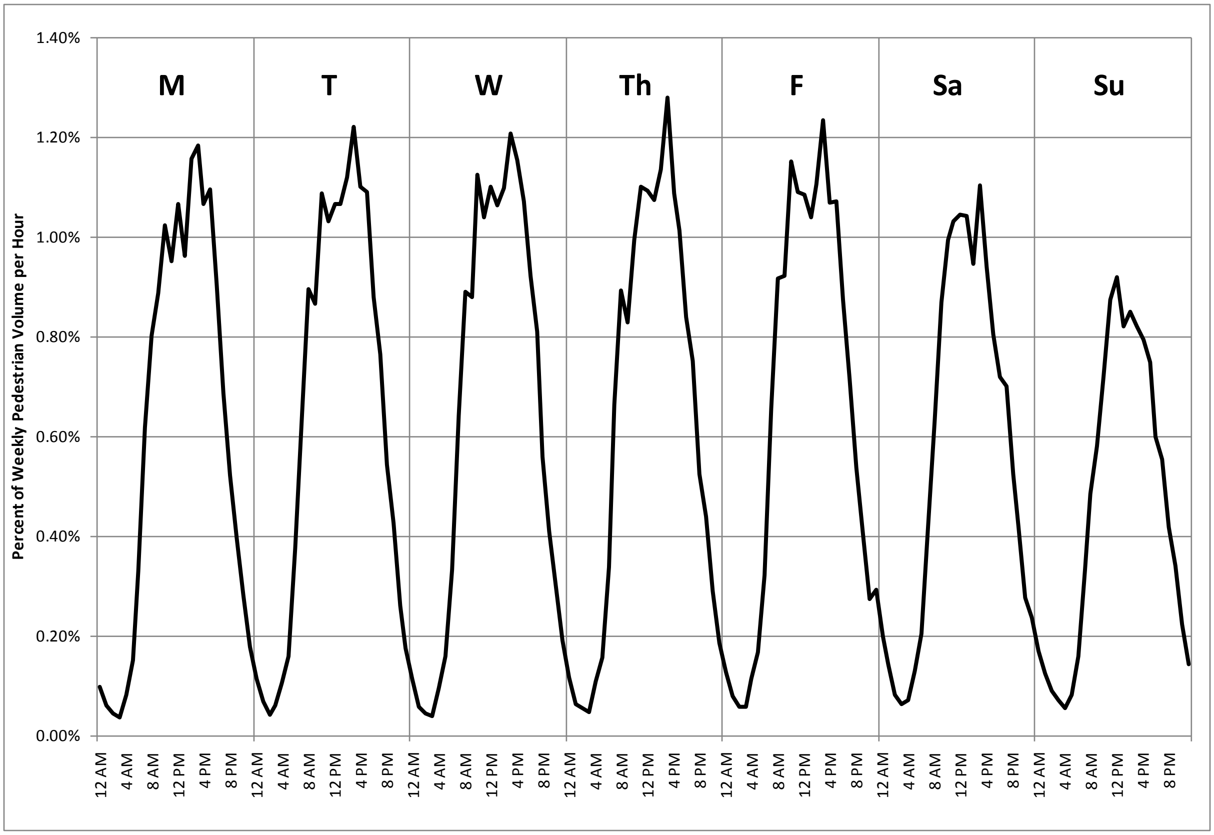

Figure 2-3. Typical Alameda County Weekly Pedestrian Volume Pattern

Source: Schneider et al. (2009).
Note: This weekly pedestrian volume pattern is based on average hourly counts collected at 13 automated counter locations in Alameda County, CA. The hourly counts were collected for approximately four months at each location (one month each quarter) between April 2008 and April 2009.

Jones et al. (2010) developed monthly adjustment factors based on automated counts obtained on multiuse paths and sidewalks in San Diego County, CA. These factors are presented in Table 2-7. The same study also determined day-of-week and time-of-day percentages, as shown in Tables 2-8 and 2-9.

Table 2-7. Daily Activity Share by Day of Week

Day	San Diego Average %
Monday	12
Tuesday	12
Wednesday	11
Thursday	11
Friday	14
Saturday	21
Sunday	19

Source: Jones et al. (2010).

Table 2-8. Monthly Expansion Factors on Multi-Use Paths and Sidewalks in San Diego County, CA

Month	Multi-Use Paths	All Other
January	1.0	1.0
February	0.89	0.89
March	0.5	0.5
April	1.0	1.0
May	1.0	1.0
June	1.0	1.0
July	0.57	1.0
August	0.89	1.0
September	1.3	1.0
October	2.0	1.0
November	1.14	1.0
December	1.0	1.0

Source: Jones et al. (2010).

Table 2-9. Hourly Share by Hour of Day

Hour Starting	San Diego Average %
8 a.m.	6
9 a.m.	8
10 a.m.	9
11 a.m.	9
12 p.m.	9
1 p.m.	8
2 p.m.	8
3 p.m.	8
4 p.m.	7
5 p.m.	7
6 p.m.	6

Source: Jones et al. (2010).

Turner, Qu, and Lasley (2012) developed a plan for Colorado DOT to collect non-motorized volume data. This report included recommendations for extrapolating short counts to estimate volumes over longer time periods. Specifically, it recommended developing distinct factor groups based on volume pattern variations across time of day, day of week, and month of year. Based on data sampled from automated counters around the state, they found the following factor groups to be the most predictive: commuter and work/school-based trips, recreation/utilitarian, and mixed trip purposes. For each of these groups, a general description of common peaking patterns was given for the three time regimes described above. Further, directions for short-duration counting site selection were proposed, generally based upon NBPD instructions.

Miranda-Moreno and Nosal (2011) observed a double peaking pattern on bicycle facilities in Montreal, Quebec. The a.m. peak occurs between 8 and 10 a.m., and the p.m. peak between 4 and 6 p.m. A slight midweek rise in volumes appeared (e.g., highest volumes on Tuesday through Thursday), with significantly lower volumes on weekends. This pattern confirms the authors' suspicions that these facilities are primarily utilitarian. Weekend daily volumes were found to be 65% to 89% lower than Monday volumes, the least ridden weekday. Ridership peaked in the summer months, with gradual increases and decreases in the months before and after. Summer volumes were observed to be 32% to 39% greater than in April. Additionally, no data was taken from December through March, as Montreal's bicycle facilities are closed during these months. Finally, use of these particular bicycle facilities appeared to be on the rise in Montreal, with 20–27% and 35–40% increases respectively in 2009 and 2010, compared to 2008.

Chapman Lahti and Miranda-Moreno (2012) compared temporal pedestrian volume patterns between the temperate months (April-November) and winter months (December-March) in Montreal. On weekdays, three distinct daily peaks were observed, as has been previously observed in a variety of locations. The a.m. and p.m. peaks were roughly the same in volume between seasons, but the midday peak had slightly lower volumes during the winter months, suggesting that these trips are optional for some pedestrians. Weekend volumes had a single mid-afternoon peak during both seasons, with gradual increases and decreases towards and away from the peak. Winter weekends had lower pedestrian volumes overall than temperate weekends.

Milligan, Poapst, and Montufar (2012) compare estimates of pedestrian volumes based on 2-hour counts to a best-estimate of ground truth based on the NBPD methodology. They also compare the pedestrian volume patterns to the daily vehicular traffic patterns in the central business district (CBD) of Winnipeg, Manitoba. This study demonstrates that in the particular intersection under study, vehicle expansion factors serve as a better estimate for the ground truth than do NBPD expansion factors. The vehicular factors were developed for Winnipeg, whereas the NBPD factors are based on data from a variety of locations throughout the U.S.. Accordingly, it can be concluded that location-specific factors are important in developing temporal expansion factors.

In addition to the above research, the TMG (FHWA 2013) includes guidance on how non-motorized volume data collection and reporting should account for time of day, day of the week and seasonal variability, and should account for any traffic patterns over time. Comprehensive information on this topic is limited, primarily because very few public agencies have collected and analyzed continuous non-motorized traffic data to date. The TMG relies on data collected from the Cherry Creek Trail in Denver to illustrate typical variations in pedestrian and bicycle volumes.

To account for daily, weekly, and seasonal variability, the TMG recommends non-motorized data collection programs include both continuously operating data collection sites to provide data on seasonal and day of week trends and short duration sites to account for specific geographic traffic patterns and time of day trends.

The NBPD has also started to identify Count Adjustment Factors (Alta Planning + Design, 2012b) that can be used to adjust counts conducted during almost any period on multi-use paths and pedestrian districts to an annual figure. These factors adjust one-hour counts to annual totals by considering weekly, monthly, and trends in walking and bicycling rates. However, this technique may be inaccurate for specific local contexts. More year-long automatic count data are needed from different parts of the county to expand the application of the adjustment factors provided by NBPD to more facilities, areas, and time periods.

Hankey et al. (2012) calculated scale factors based on 12-hour continuous counts along a variety of bicycle and pedestrian facilities in Minneapolis, MN. In theory, these factors can be applied to 1-hour counts performed in a given time period to determine 12-hour volumes.

Nordback (2012) compared the predictive power of using a factoring method akin to that proposed by the NBPD against using a so-called "hybrid model." While variations in accuracies exist based on the variable being considered, Nordback concludes that the statistical modeling approach generally provides higher accuracy estimates, but is more costly to use given the need for specialized modeling software and access to hourly weather data. The factoring method, by contrast, can provide low-cost estimates, albeit at a much lower level of accuracy.

Land Use Adjustment Factors

Land use adjustment factors account for variations in traveler volumes based on particular land uses in the vicinity of the counter. For example, the number of houses or jobs within a ¼ mile of the count location can have an effect on pedestrian volumes. Temporal extrapolation factors should be selected given the land use characteristics of the count location. For example, residential locations are less likely than CBDs to have midday pedestrian peaks.

Cameron (1977) conducted automated pedestrian counts in various locations throughout downtown Seattle. Distinct trends were noted based upon the general character of the population being observed, separated into classes of shoppers, employees, visitors, commuters, and mixed. These classifications were made based upon the volume trends observed for each location. Shopper locations demonstrated peaks during the noon and 2 p.m. to 3 p.m. hours, on Fridays and Saturdays, during August and December, as well as surrounding major shopping holidays. Employee locations are characterized by peaks on Fridays, from 7 to 9 a.m., 12 to 1 p.m., and 4 to 6 p.m. Waterfront shopping locations, classified as visitor populations, demonstrate hourly weekday patterns similar to shopper and employee count sites with a midday peak but have distinct hourly weekend trends. Commuter locations demonstrate trends similar to vehicle trends. Mixed volume locations do not fit neatly into any of the other four classes identified, with no distinct noon peak.

Davis, King, and Robertson (1988) observed six distinct pedestrian volume trend patterns at various count locations in Washington D.C. No conclusions were drawn pertaining to land uses.

Hocherman, Hakkert, and Bar-Ziv (1988) found similar daily peaking patterns in residential and CBD crossing locations, with slight differences. These differences were attributed to the location of schools exclusively in residential areas (hence a steeper early morning peak in these regions), and stores opening around 9 a.m. in CBDs (less steep of a morning peak in the CBD).

Zegeer et al. (2005) utilized different adjustment factors based on location type, using classifications of CBD, fringe, and residential. CBDs are defined as downtown areas with moderate-high pedestrian volumes, fringe areas are suburban and commercial retail areas with moderate volumes, and residential areas are characterized by low pedestrian volumes. These hourly adjustment factor patterns were based upon two datasets of automated counts, one involving 8- to 12-hour counts at 11 marked and 11 unmarked intersections, and the other based on 24-hour counts in Seattle, WA.

Schneider et al. (2009) explored land use characteristics of their count locations. Adjustment factors based on land use designations were derived for specific manual count intervals, and are summarized in Table 2-10. The manual count intervals are specified to control for temporal variations. The authors suggest that further research is necessary to account for additional land use factors not investigated in this study.

Table 2-10. Land Use Adjustment Factors

Land Use Category	Definition of Land Use	Manual Count Time	Multiplicative Adjustment Factor
Employment center	≥ 2000 jobs within ¼ mi.	Weekdays 12–2 p.m.	0.795
Residential area	≤ 500 jobs within ¼ mi. and no commercial retail properties within 1/10 mi.	Weekdays 12–2 p.m.	1.39
Neighborhood commercial area	≥ 10 commercial retail properties within 1/10 mi.	Saturday 12–2 p.m.	0.722
		Saturday 3–5 p.m.	0.714
Near multi-use trail	≥ 0.5 centerline miles of multi-use trails within ¼ mi.	Weekdays 3–5 p.m.	0.649
		Saturday 9–11 p.m.	0.767

Source: Schneider et al. (2009).

Schneider et al. (2012) used a similar approach to develop land use adjustment factors in San Francisco for six general land use categories: (*a*) Central Business District, (*b*) High-Density, Mixed-Use, (*c*) Mid-Density, Mixed-Use, (*d*) Low-Density, Mixed-Use, (*e*) Residential, and (*f*) Tourist Area. The proportion of weekly pedestrian volume on a typical weekday between 4 p.m. and 6 p.m. was slightly different at locations surrounded by these land uses (ranging from 1. 6% to 2.3%).

Miranda-Moreno and Nosal (2011) detected variations in bicycle ridership between facilities, controlling for temporal and weather factors. However, these effects were not deeply explored.

Chapman Lahti and Miranda-Moreno (2012) distinguished pedestrian count locations based on the land-use mix entropy index in a 400-meter buffer around the site, considering the following land use types: commercial, government/institutional, open space, parks/recreational, residential, and resource/industrial. Sites were then split into two classes based on entropy indices above and below 0.6. Locations with entropy indices below 0.6 (mixed commercial-residential) had ~70% lower counts than the commercial areas during the week year-round, 57% lower on temperate season weekends, and 40% lower on winter weekends.

Weather Adjustment Factors

Weather adjustment factors are used to account for weather patterns at the time that data is taken. For example, if a count is taken on a rainy day, volumes will likely be significantly lower than an average day. To adjust for this variation, the volume should be adjusted upward.

Cameron (1977) found that at shopper locations, Seattle’s heavy December rains did not diminish pedestrian activity (as a peak was observed in this month), but that rain levels above 0.05 in./day decreased pedestrian traffic by 5% below the average during the summer.

In a year-long study at a single site in Montpelier, VT, Aultman-Hall, Lane, and Lambert (2009) found a 13% decrease in average hourly pedestrian volume during precipitation events.

Schneider et al. (2009) developed multiplicative adjustment factors for pedestrian counts in Alameda County, CA based on weather patterns, as summarized in Table 2-11. The effects of rain and wind were inconclusive, although a factor for rain is included based on the limited available data. The authors suggest that further research is necessary to increase the sample size and develop more accurate weather adjustment factors.

Table 2-11. Weather Adjustment Factors

Weather Condition	Definition	Manual Count Time	Multiplicative Adjustment Factor
Cloudy	Ratio of solar radiation measurement to expected solar radiation is ≤ 0.6	All time periods	1.05
Cool temperature	≤ 50°F	All time periods	1.02
Hot temperature	≥ 80°F	12 p.m. to 6 p.m.	1.04
Hot temperature	≥ 80°F	12 a.m. to 12 p.m. and 6 p.m. to 12 a.m.	0.996
Rain	Measurable rainfall ≥ 0.01 inches	All time periods	1.07

Source: Schneider et al. (2009).

Miranda-Moreno and Nosal (2011) explored the relationship between bicyclist volumes and weather on four separated bicycle facilities presumed to be primarily utilitarian in Montreal, Quebec. Increases in temperature of 10% corresponded to 4%–5% increases in volume. When temperature went above 28˚C (82˚F) with relative humidity of 60% or greater, bicycle volumes dropped 11%–20%. Further, controlling for all other factors, 100% increases in humidity resulted in 43%–50% decreases in volumes. Moderate to high levels of precipitation combined with fog, drizzle, or freezing rain led to a 19% reduction. Additionally, precipitation was confirmed to have a lagged effect on ridership. Rain during any of the 3 previous hours led to a 25%–36% reduction in bicycle volumes, and rain in the morning led to a 13%–15% reduction in the afternoon, even with no rain in the afternoon.

Chapman Lahti and Miranda-Moreno (2012) investigated the effects of weather on pedestrian volumes, controlling for season and day of week, in Montreal. The seasons defined in this study are the temperate months (April-November) and winter months (December-March), classified based on whether the majority of days' recorded temperatures were above or below freezing.

During temperate months, flow was found to follow a concave down quadratic curve with temperature, peaking at temperatures of 20˚C–25˚C (68˚F–77˚F) with 27.5% increases over the 0˚C–5˚C (32˚F–41˚F) temperature range. Further, lagged precipitation effects were confirmed for pedestrians based on rain in the previous hour but not in the current hour, with an 8% decrease on weekdays and 11% decrease on weekends, and 6.8% on weekdays/7.8% on weekends for the second hour following rain. Precipitation intensity was found to have a roughly linear effect.

During winter months, temperature has a roughly linear effect on weekends, but volumes seem to stabilize at low temperatures on weekdays. This suggests that a certain number of weekday trips are more rigid than weekend trips. Humidity increases of 10% led to a 9% reduction in pedestrian volume on weekends, but only a 3% decrease on weekdays. Precipitation effects followed a similar pattern to the effects of temperature during the winter months. Lagged precipitation effects appeared to have a 14% effect on weekdays, but no significant effect on winter weekends.

Phung and Rose (2007) evaluated 13 off-road bicycle facilities in the Melbourne, Australia region and investigated the effect of various environmental conditions on hourly two-way bicycle volumes. They found that light rain (0.2–10 mm per day) reduced bicycle volumes by 8–19%, while heavy rain (10+ mm per day) reduced volumes by 13–25%. Only wind speeds of 40 km/h had a statistically significant effect on volumes. The combination of light rain and strong winds had quite variable results on volumes, ranging from 8–48% decreases, with the Bay Trail being much more affected than other facilities.

Flynn et al. (2012) investigated 163 regular bicycle commuters' responses to adverse weather conditions through a longitudinal study lasting 10 months, with responses sought on 28 predetermined days. Statistically significant results included nearly twice as high of a likelihood of cycling on days with no morning precipitation, a 3% increase in likelihood per degree temperature increase (°F), a 5% decrease per mph increase in wind speed, and a 10% decrease in likelihood per inch of snow on the ground.

Nordback (2012) explored a variety of weather factors and their impacts and predictive powers on bicycle volumes. Using single-variable regression models, hourly bicycle counts were found to be the most correlated with hourly average temperature (R^2=0.50), followed by hourly solar radiation (R^2=0.45), daily high temperature (R^2=0.32), daily low temperature (R^2=0.28), daily snow depth on ground (R^2=-0.17), daily snow fall (R^2=-0.11), and precipitation in the last 3 hours (R^2=-0.11).

Demand Variability Adjustment Factors

Hocherman, Hakkert, and Bar-Ziv (1988) found higher demand variability in residential areas than in central business districts (CBDs). Specifically, they observed hourly standard deviations of 2%–3.5% ADT (coefficients of variation, CVs, of 30%–50%) in the residential count locations. Variability was higher during peak periods. In the CBDs, hourly standard deviations were 1%–3.5% ADT (CVs of 20%–50%), and peak periods again have higher variability.

Access/Infrastructure Sufficiency Adjustment Factors

It is possible that facility characteristics could influence pedestrian or bicycle activity patterns. For example, a narrow multi-use trail may not be able to accommodate all bicyclists who would like to use it during a peak hour. Therefore, its peaks would be muted relative to a wider multi-use trail that has the same overall demand.

In San Diego County, CA, Jones et al. (2010) investigated pedestrian and bicycle flows on multiuse paths and sidewalks at various locations. Distinct peak periods were found based on the type of facility, as summarized in Table 2-12. However, land use was not controlled for in this analysis.

Table 2-12. Peak Period Volume Percentages as a Function of Season and Day of Week for Multi-use Paths and Sidewalks in San Diego County, CA

Season	Type of Day	Bicycles on Paths (peak period %)	Pedestrians on Paths (peak period %)	Pedestrians on sidewalk (peak period %)
Summer	Weekends	11–1 p.m. (21%)	11–1 p.m. (20%)	9–11 p.m. (15%)
	Weekdays	11–1 p.m. (17%)	11–1 p.m. (18%)	5–7 p.m. (16%)
Fall	Weekends	11–1 p.m. (15%)	11–1 p.m. (21%)	1–3 p.m. (15%)
	Weekdays	8–10 a.m. (16%)	8–10 a.m. (17%)	1–3 p.m. (20%)
Winter	Weekends	11–1 p.m. (24%)	11–1 p.m. (24%)	12–2 p.m. (18%)
	Weekdays	11–1 p.m. (19%)	11–1 p.m. (19%)	1–3 p.m. (19%)
Spring	Weekends	10–12 a.m. (19%)	10–12 a.m. (20%)	1–3 p.m. (16%)
	Weekdays	11–1 p.m. (16%)	11–1 p.m. (17%)	5–7 p.m. (15%)

Source: Jones et al. (2010).

Demographic Adjustment Factors

Intuitively, one might expect that differences in socioeconomic characteristics of the neighborhoods surrounding count locations would lead to differences in pedestrian and bicycle volume patterns. Income, car ownership rates, household size, and age of residents could all have effects on traveler volumes. However, very few studies have explored these effects.

Data Management and Sharing

This section describes several current systems for sharing pedestrian and bicycle volume data. The intent is to identify best practices for a future pedestrian and bicycle count data clearinghouse that efficiently makes volume data available to the public.

Recent Research

The national practitioners survey conducted for NCHRP Project 07-17, Pedestrian and Bicycle Transportation along Existing Roads (Toole Design Group et al. 2014), asked local, county, regional and state transportation agencies to identify how they managed pedestrian and bicycle count information. Of the 179 respondents, 87 reported that they collect pedestrian count data and 67 respondents shared how they managed their pedestrian count data. As shown in Table 2-13, nearly half (46%) indicated using a spreadsheet program to manage their count data.

Table 2-13. Reported Pedestrian Count Data Management Methodology by Agency Type

Type of Agency	GIS (e.g., ArcView)	Spreadsheet (e.g., MS Excel)	Database (e.g., MS Access)	Text (e.g., MS Word)	Other (not specified)
Advocacy/nonprofit organization	1	3		2	
College or University		2			
County		1	1		
Federal government			1	1	
Local government	4	11	4		3
Metropolitan Planning Organization	4	8	2	2	2
Private consulting firm					1
School or school district				1	
State DOT	2	6	1	1	2
Transit agency			1		
Grand Total	**11**	**31**	**10**	**7**	**8**

Source: Toole Design Group et al. (2014).

Of the 74 respondents who reported collecting bicycle count data, 57 provided answers to how they manage their bicycle count data. As shown in Table 2-14, over one-third of respondents (35%) indicated using a spreadsheet program to manage their count data. Additionally, 28 percent responded that they used GIS programs to manage their bicycle count data.

Table 2-14. Reported Bicycle Count Data Management Methodology by Agency Type

Type of Agency	GIS (e.g., ArcView)	Spreadsheet (e.g., MS Excel)	Database (e.g., MS Access)	Text (e.g., MS Word)	Other (not specified)
Advocacy/nonprofit organization	2	2	1		
College or University		1	1	1	
County		1			
Federal government					1
Local government	8	8	2	2	4
Metropolitan Planning Organization	4	5	1	2	2
Private consulting firm					1
School or school district				1	
State DOT	2	3			1
Transit agency					1
Grand Total	**16**	**20**	**5**	**6**	**10**

Source: Toole Design Group et al. (2014).

Current Data Storage and Sharing Practices

Many agencies share their collected pedestrian and bicycle volume data via annual or periodic reports documenting volume trends as well as other factors, such as helmet use or sidewalk riding. For example, the Minneapolis Public Works Department releases annual reports highlighting overall pedestrian and bicycle volume trends through charts and maps. In addition to collecting volume, the report for 2011 (Minneapolis Public Works Department 2012a) included all non-motorized count data since 2007 in table form. The Portland Bureau of Transportation (2012) provides the results of their annual bicycle count program through an annual report which utilizes charts and maps to document bicycle volume by helmet use, gender, and location. The Portland report also includes tabular historical bicycle counts. The San Francisco Municipal Transportation Agency (SFMTA) (2011a, 2011b) releases separate pedestrian and bicycle count reports. The annual bicycle report includes observed bicyclist behavior and American Community Survey Data to establish patterns in bicycle ridership. Current bicycle counts are also provided in the report. Pedestrian counts were conducted by SFMTA staff in 2009 and 2010 as inputs to a pedestrian volume model. These counts were reported along with a summary of the model and pedestrian crossing risk.

Other agencies store and distribute non-motorized count data in spreadsheet form downloadable from the agencies' websites. The San Francisco Bay Area's Metropolitan Planning Organization (MPO), Metropolitan Transportation Commission (2011), makes it's pedestrian and bicycle counts spreadsheet available online along with some limited trend analysis. The Columbus, OH MPO, the Mid-Ohio Regional Planning Commission (2010), releases an analysis report and the count spreadsheet for their biannual count program. The Puget Sound Regional Council (2012), Seattle's MPO, distributes bicycle counts via both spreadsheet and GIS shapefile, which includes geocoded counts for mapping uses.

Several agencies make pedestrian and bicycle counts available by online interactive maps. These maps allow for text querying as well as a visual search. The Portal demonstration website (Portland State University 2012) in Portland, OR displays counts from fixed bicycle and pedestrian counters (Figure 2-4 and Figure 2-5, respectively). These counts can be queried by date, time, and day of week range and the resulting volumes are plotted by hour and by day. The bicycle counts are collected from in-pavement loop detectors and thus provide continuous count data. The pedestrian data come from pedestrian pushbutton actuations. This data collection method is limited to intersections with pedestrian crossings equipped with pushbuttons (and signal controllers capable of logging the actuations). Counts of actuations must be converted into an estimate of volumes in order to reflect true pedestrian demand. Actuations can also be used to determine maximum pedestrian delay on a crossing (i.e., the time from when the button is first pressed to when the WALK signal is displayed).

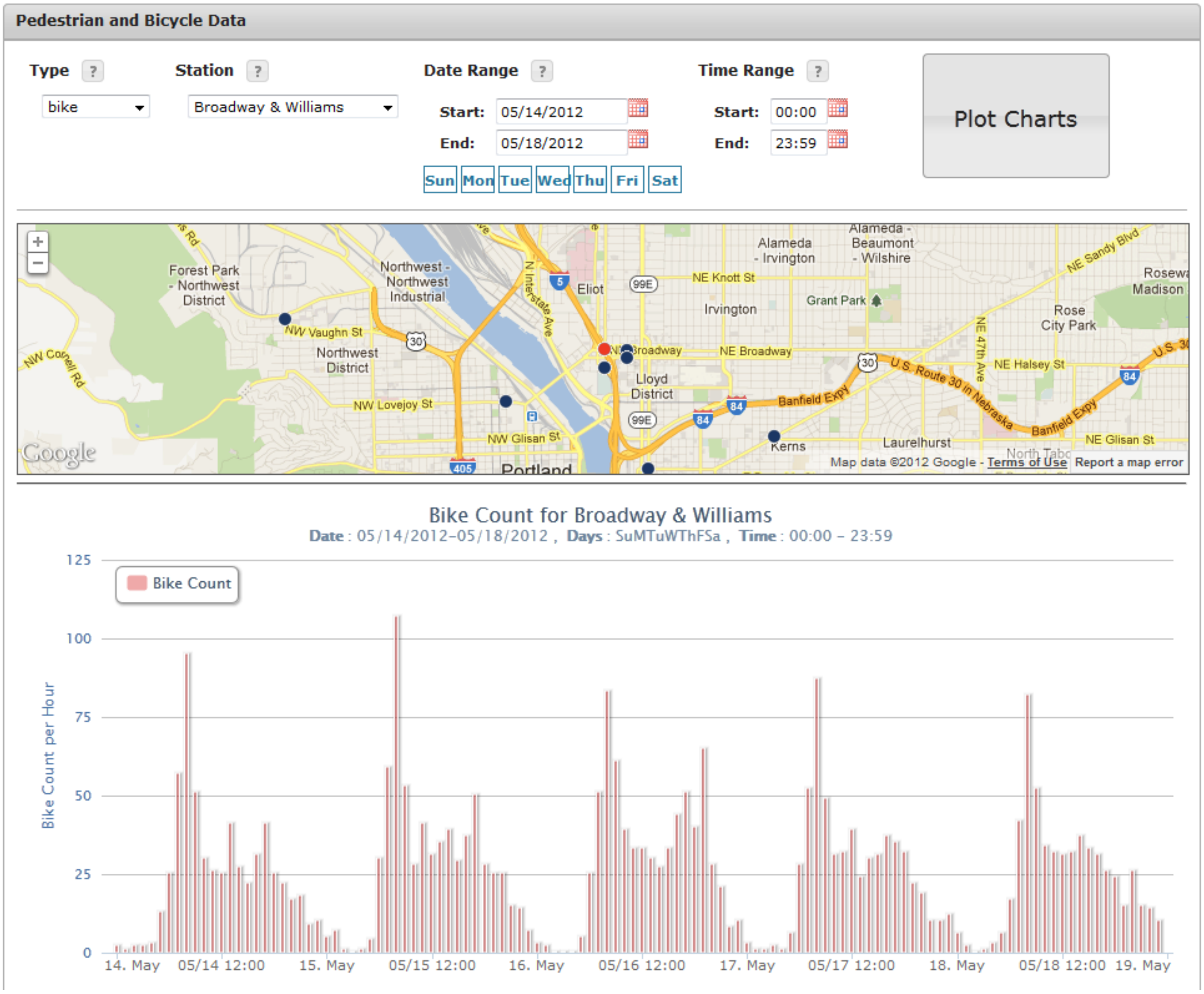

Figure 2-4. Portal Demonstration Site Bicycle Count Screenshot

Source: Portland State University (2012).

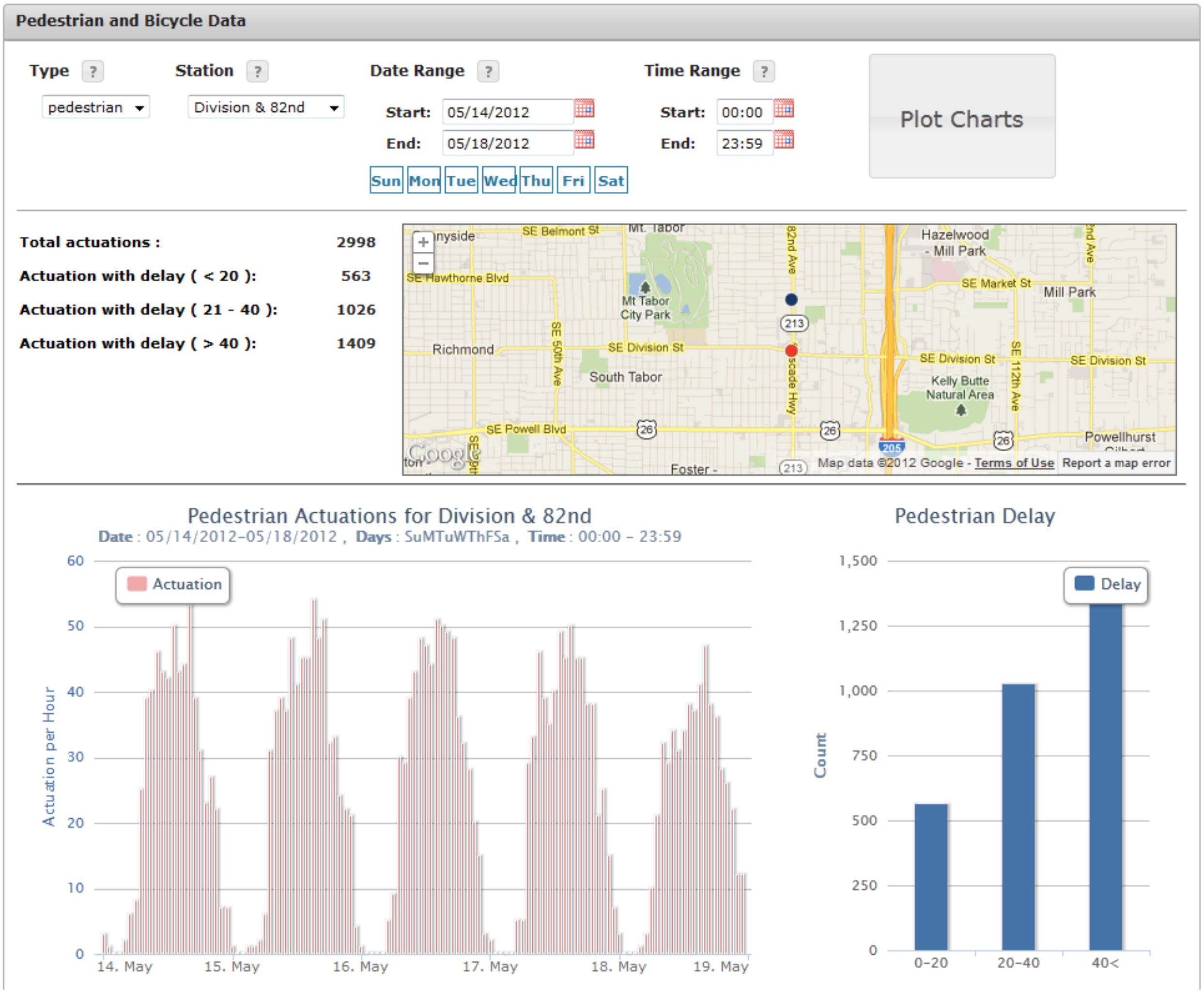

Figure 2-5. Portal Demonstration Site Pedestrian Count Screenshot

Source: Portland State University (2012).

BikeArlington (Arlington County 2012), an initiative of Arlington County (VA) Commuter Services, shares permanent bicycle and pedestrian counter data. The counts can be queried by date, time, and day of week range, mode, and direction. The resulting volumes are presented on the map at each counter location (Figure 2-6) and are graphed over time (Figure 2-7). The queried volume data can be downloaded. The count database links with daily temperature and precipitation data (Figure 2-8), which can be presented alongside the daily volume output. All exhibits are from a beta version of the website; changes will be made as the website develops.

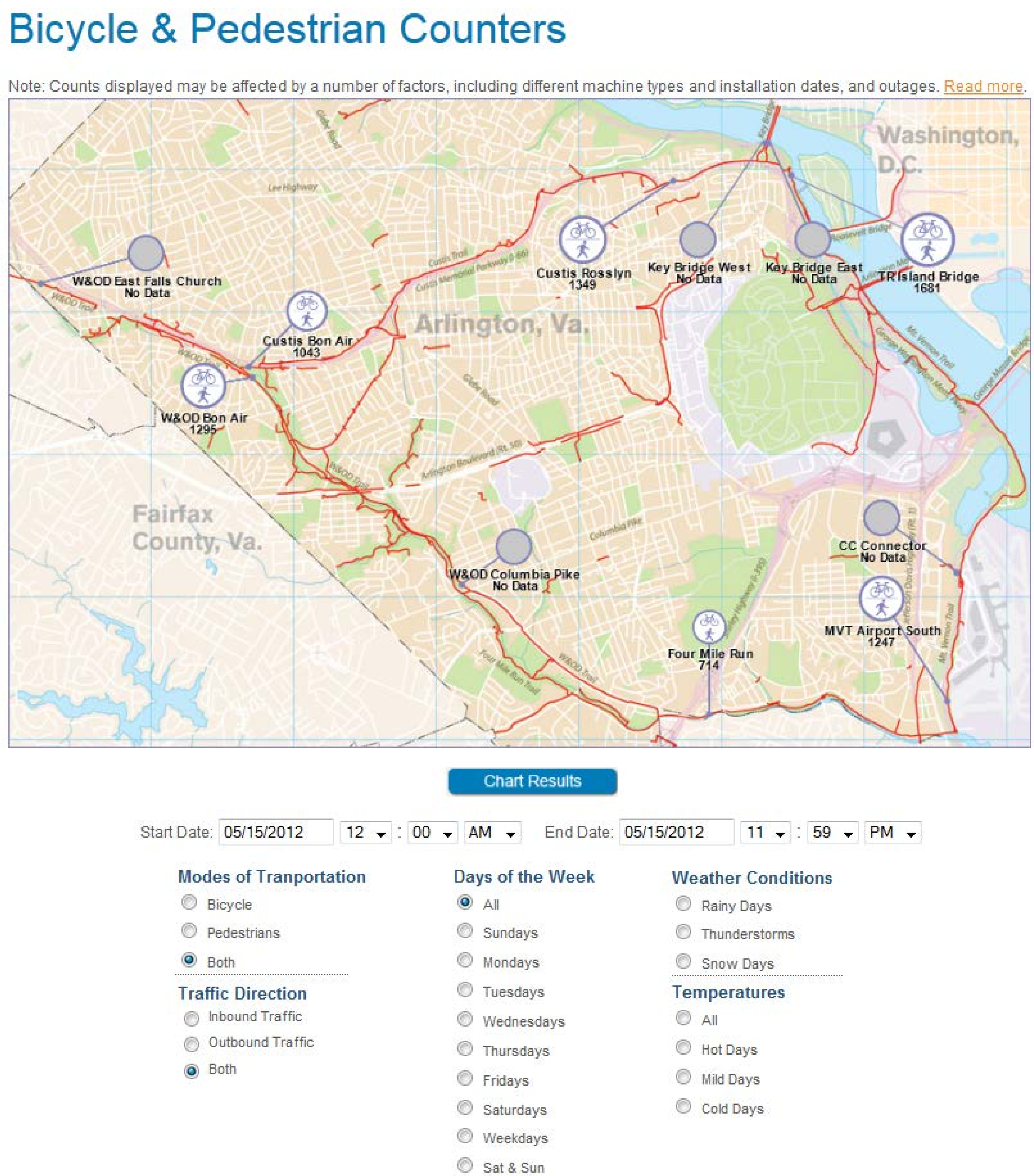

Figure 2-6. BikeArlington Bicycle and Pedestrian Counter Query Screenshot

Source: Arlington County (2012).

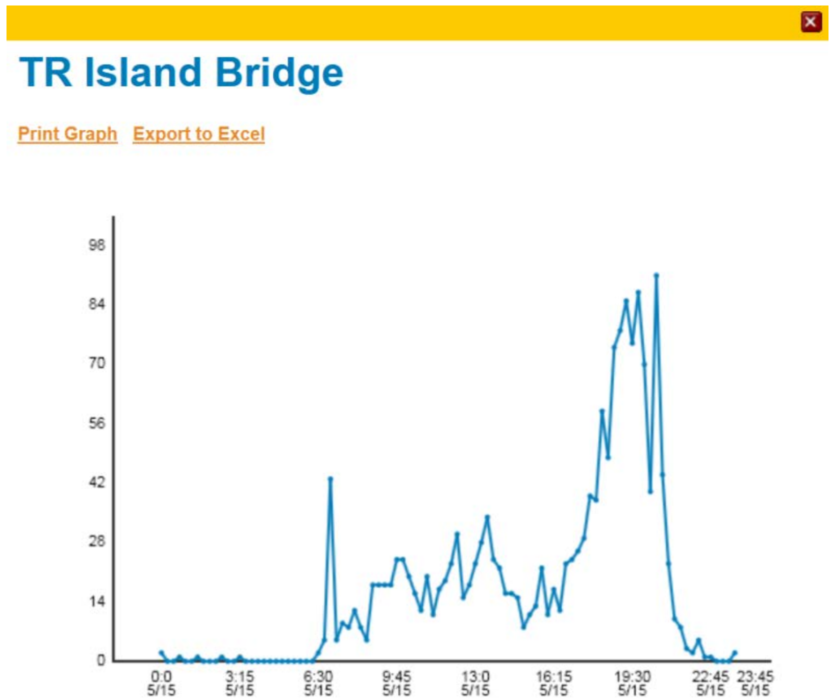

Figure 2-7. BikeArlington Count Volume Graph

Source: Arlington County (2012).

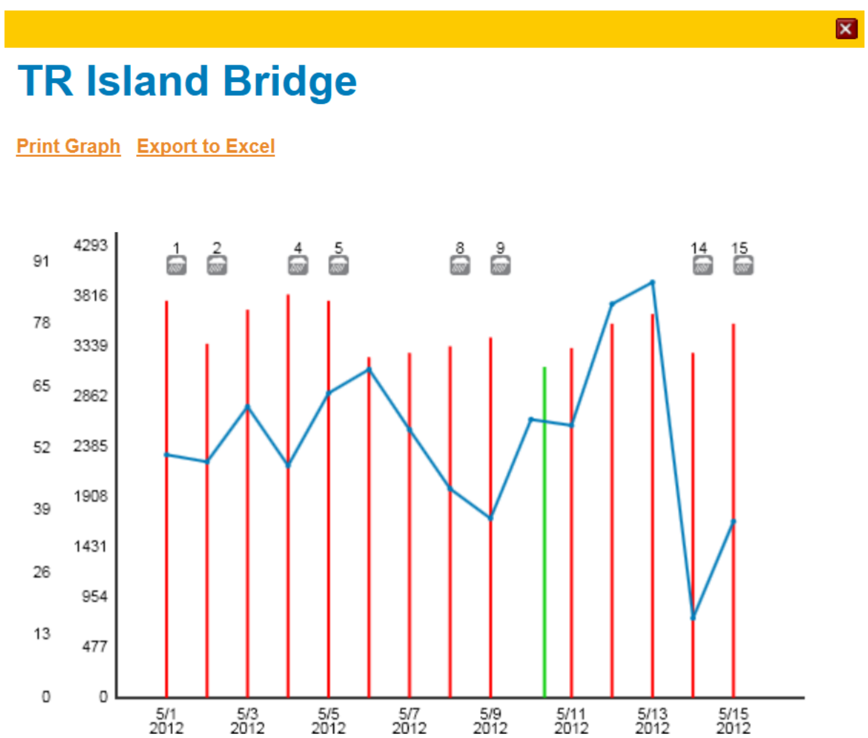

Figure 2-8. BikeArlington Count Volume Graph with Weather Conditions

Source: Arlington County (2012).

The Delaware Valley Regional Planning Commission (2012), the MPO for the greater Philadelphia area, offers an interactive map to share its bicycle and pedestrian counts (Figure 2-9). This map utilizes Google Maps for the base map and the bicycle route layer and each count offers a link to its location in Google StreetView. Bicycle and pedestrian counts are marked on the interactive map and each count location links to the detailed count record.

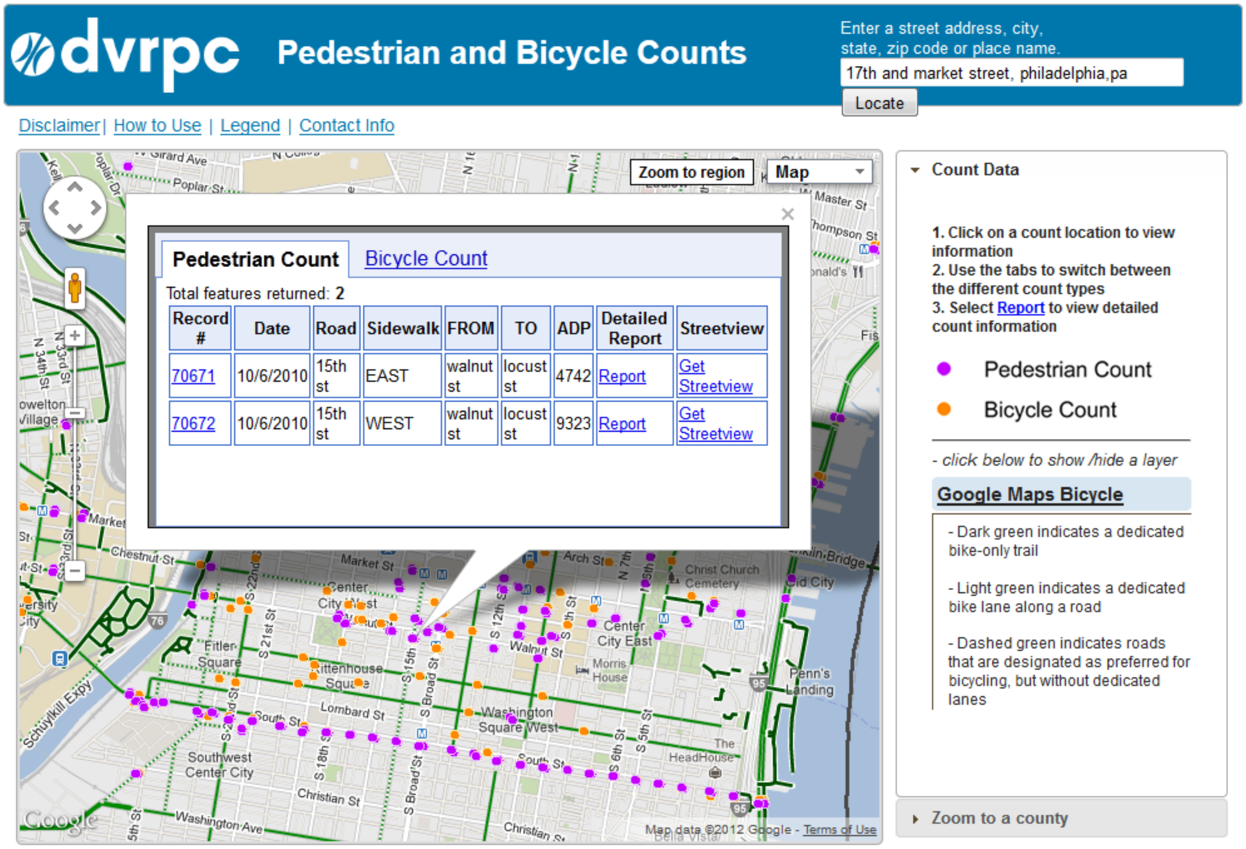

Figure 2-9. Delaware Valley Regional Planning Commission Pedestrian and Bicycle Counts Screenshot

Source: Delaware Valley Regional Planning Commission (2012).

The Boston Region Metropolitan Planning Organization (2012) utilizes Google Maps to present recorded non-motorized counts (Figure 2-10). Counts can be queried by municipality, facility, and date and the results are displayed on the map and can be downloaded. Each count location is linked to the count record. Available counts included bicycle and pedestrian volumes; some counts differentiate joggers, baby strollers, skateboarders, rollerbladers, and wheelchair users. The database includes data as far back as 1974.

Figure 2-10. Boston Region Metropolitan Planning Organization Bicyclist/Pedestrian Count Database

Source: Boston Region MPO (2012).

Copenhagen conducts 12-hour bicycle counts once a year in the spring at key points along the city limits and once a year in the fall on approach routes to the city center. The days chosen for counts have dry weather and, when combined with the time of year, represent high-volume conditions for bicycling. Copenhagen counts bicycles and mopeds together in these counts (mopeds account for about 1% of the total), but counts cargo bikes separately from other types of bikes. Count data are summarized annually in a report on the city's transportation trends, and include both AADT data at individual count sites and graphs showing average temporal variations in bicycle traffic for the city as a whole. The city uses the data to measure progress toward meeting mode-share goals, to compare year-to-year changes in bicycle and motorized vehicle volumes entering the city limits and the city center, to assess the impact of new bicycle facilities, and to help identify the need to improve bicycle facilities to accommodate growing bicycle volumes (Københavns Kommune 2011).

Other Scandinavian cities with regular large-scale manual bicycle counting programs include Odense, Denmark and Malmö, Sweden. Odense counts every other year; it uses the information in similar ways as Copenhagen (Odense Kommune 2004). Malmö counts at 1–2 year intervals, but only during the morning and afternoon peak periods; it also categorizes bicyclists by helmet usage (Malmö stad 2011).

The Danish Road Directorate has installed automatic bicycle counters at 54 locations on cycle tracks along national highways throughout Denmark. The count data from these locations are used, among other things, to track monthly and yearly trends in bicycle and moped usage and to compare them to motorized traffic trends. The counts are reported as a national index value (year 2000 AADT at a given site = 100) (Vejdirektoratet 2012).

FHWA Travel Monitoring Analysis System

The sections above show that many agencies at the local, regional, and state levels have started collecting pedestrian and bicycle counts during the last decade. The growth in these counts has inspired the FHWA Office of Highway Policy Information to develop a formal repository for these data within its Travel Monitoring Analysis System (TMAS) 3.0. For data to be included in the system, it must meet certain standards, including basic information about the count location, type of count (pedestrian or bicycle), direction of travel, time, count interval, and method of counting. This system will make it possible to compare pedestrian and bicycle counts over time and across jurisdictions throughout the United States.

The next section provides an initial assessment of various count technologies' ability to collect the data attributes contained in the draft FHWA pedestrian and bicycle count data format. Most technologies do not currently have the ability to automatically record weather data such as precipitation and temperature. As a result, secondary data sources will need to be used to document these attributes. Another limitation for several count technologies is their ability to detect and record directionality of pedestrian or bicycle travel.

Evaluation of Count Technologies Based on the Literature Review

Tables 2-15 and 2-16 summarize the strengths and limitations of each category of technology according to key evaluation criteria that are described below. This summary builds on the findings of several other reviews of recent pedestrian and bicycle counting methodologies (Alta Planning + Design 2012a; Schweizer 2005; AMEC E&I and Sprinkle Engineering 2011; Somasundaram, Morellas, and Papanikolopoulus 2010; Ozbay et al. 2010; Bu et al. 2007; Hudson, Qu, and Turner 2010).

- **Cost.** Monetary costs to be considered in evaluating count technologies include labor (installation, counting, analysis), device prices, and maintenance costs. These cost estimates are based on quotes from manufacturers and other documents/reports. Ranges reflect different prices offered by different manufacturers.

- **User Type.** User type indicates whether the data collection technology can count pedestrians, bicyclists, or both. Technologies that can be used to produce separate counts of pedestrians and bicyclists may be more useful than technologies that count either one user type or the other.
- **Mobility.** Mobility refers to the ease with which the counting technology can be moved after having been installed. Some technologies, such as handheld count boards, are extremely mobile. Technologies installed underground, such as embedded inductive loops and pressure/acoustic pads, are highly impractical to move after having been installed. Mobility therefore stands as a proxy for whether a technology is optimal for permanent or temporary count locations.
- **Ease of Installation.** Ease of installation for automated pedestrian/bicyclist counters ranges from no installation required (e.g., manual counts) to difficult installation (e.g., pressure pads). Devices requiring installations that are time consuming, disruptive to traffic, and/or require coordination with maintenance staff have been dubbed "difficult." Devices which require careful installation procedures above ground have been dubbed "moderate." Easy-to-install devices involve minor above-ground installation, such as simply being mounted to a pole. "None" is used to identify devices that require no installation.
- **Storage Capacity.** Storage capacity refers to the amount of data that the device is capable of holding. These are given in a variety of formats including duration (i.e., for continuous recording devices), number of counts (i.e., for discrete recording devices), and capacities dependent on other factors. Some devices can get around this limiting factor by automatically exporting data to a server through telemetry technology. This factor is likely more product-specific than technology-specific.
- **Battery Life.** All automated count devices require electricity to operate. It is possible to hardwire some devices to an existing power source, but this is not often practical due to count location characteristics. Accordingly, batteries are often used for field counts, so battery life is an important criterion for evaluation. Solar power is an option for some devices, but there is little information on this topic in the existing literature. Battery life can be affected by a number of factors not related to the sensing technology (e.g., size and type of battery, temperature); however, different sensing technologies draw different amounts of power and thus have different battery lives.
- **Accuracy.** The accuracy of a counting technology describes how close the counts it produces are to the actual number of pedestrians or bicyclists that should be counted. When the count from a particular technology is lower than the actual count, the technology is said to undercount. When the technology count is higher than the actual count, it is said to overcount. For consistency in this literature review, the percentage error is represented by the following calculation:

$$Error = \left(\frac{Technology\ Count - Actual\ Count}{Actual\ Count} \right) \times 100\%$$

Therefore, net undercounting is shown by a negative percentage and net overcounting is shown by a positive percentage.[4] Accuracy rates can vary greatly, depending on a large number of factors. Some potential causes include operating conditions, grouping patterns of travelers, device age, vehicle class heterogeneity, and the count location. For instance, pneumatic tubes are likely to experience lower accuracy in cold weather due to the rubber stiffening, as they age due to rubber fatigue, and in mixed traffic due to difficulties distinguishing bicycles from automobiles. Accuracy values quoted in this literature review are based on the testing conditions in the presented literature. Very few sources have presented data regarding the variability of accuracy values.

- **Count Interval.** When recording count data, it is sometimes impractical for data storage reasons to record every traveler as a discrete event. Instead, counts are often aggregated into discrete time intervals. The selection of the count interval duration represents a tradeoff between producing unmanageably large quantities of data points and losing temporal trend accuracy in long count periods. For manual counts, 15-minute to 1-hour count intervals are typically used. Automated counter intervals tend to be set by the manufacturer, selected by the user, or always reported as discrete observations. Thus, count intervals are product-specific, rather than technology-specific.
- **Metadata Recorded.** Additional information that can help in interpreting the recorded volumes should be included with all counts. Some possibilities include time/date, geographic location, and weather data. When resources are available, external weather history databases can be used to provide weather conditions during count periods. However, gathering these secondary data may be time intensive and may not be available for a specific count location. Therefore, it can still be useful to record weather data in the field in some situations. Metadata recorded are product-specific.
- **Data Extraction.** Count data are recorded on data loggers at the count location. A variety of technologies exist to transfer this data to an external computer. Some of these devices automatically send data to servers remotely, known as "telemetry." The primary telemetry technology is known as GSM (used by some cellular phone service providers). Additionally, data can be extracted on site using infrared, USB, or Bluetooth. The data extraction technique(s) are product-specific.
- **FHWA Format.** The Federal Highway Administration Office of Highway Policy Information is developing a formal repository for pedestrian and bicycle count data. The TMG (FHWA 2013) includes a data template describing the data fields and formats that will be required for each count submitted to this database. Therefore, it will be valuable

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[4] More sophisticated error metrics exist that consider individual undercounts and overcounts as errors, as discussed in the New Zealand *Continuous cycle counting trial* (ViaStrada 2009). While these error indices do not suffer the misleading possibility of undercounts and overcounts cancelling each other out and illustrating a higher accuracy than actually exists, they require substantially more analysis than some of the papers surveyed undertake. Therefore, this literature review uses the simple error calculation above, and includes more sophisticated measures whenever possible.

to have products that can populate these data fields automatically. Required fields include:

  - Direction of travel
  - Crosswalk, sidewalk, or exclusive facility
  - Type of user (e.g., bike/pedestrian/both)
  - Precipitation (optional)
  - Type of sensor (optional)
  - High and low temperature (optional)
  - Year, month, and day of count
  - Start time for the count record (military time, HHMM)
  - Count interval being reported (in minutes)
  - Count location latitude and longitude

  This criterion is a preliminary assessment of whether a product can collect the other attributes included in the FHWA data format, or if supplemental data collection is needed. It is worth noting that weather-related data can be added later using National Oceanic and Atmospheric Administration (NOAA) data, although this may not provide as precise a result as desired.

- **File Format.** Data can be exported in a variety of formats, with the choice of formats being specific to a particular product. Some are optimal for analysis, such as comma-separated values (.csv), Excel spreadsheet (.xls), PetraPRO-specific (.jcd), and Universal Traffic Data Format (.utdf). Other data formats are better suited to simple presentation, such as .pdf and .html.
- **Critical Limitations.** Critical limitations listed demonstrate situations or cases where the technology would be impractical and other considerations that must be taken into account.
- **Sources.** Bibliographic references to articles and documents providing information on each technology are listed in the sources column.
- **Locations in Use.** Examples of locations in the literature where the technology is currently in use or has been used in the past.
- **Count Type.** Pedestrian and bicycle counts are needed in a variety of types of locations. The most common types of non-motorized counts collected today are classified as *intersection* and *screenline.* Intersection counts typically represent all pedestrians crossing each leg of an intersection in either direction, and/or bicyclists approaching the intersection and their respective turning motions. Screenline counts document the total number of pedestrians or bicyclists passing a point along a sidewalk, roadway, bicycle lane or trail in either direction. The specific count location is often viewed as representing the pedestrian or bicyclist volume on the entire segment between adjacent intersections. However, volumes may vary along a segment due to driveways and other

access/egress points. Midblock crossing counts represent all pedestrians or bicyclists crossing a roadway between intersections. Few midblock crossing counts have been taken in practice, but they are important for evaluating midblock pedestrian or bicycle crossing risk and changing roadway designs to make crossings safer and more convenient.

Blank cells in the tables below reflect topics for which reliable data sources were not identified through the literature review. Further, the following evaluation criteria are worth studying but have not been discussed extensively in the literature. Accordingly, they are mentioned only briefly here and have not been included in the summary tables.

- **Maintenance.** Devices may require a variety of maintenance actions. These actions can vary in amount of time required and level of skill required (and, consequently, labor cost of the person maintaining the device). Some devices may require periodic maintenance—for example, video cameras might need to have their lenses cleaned. This project distinguishes between maintenance activities common to a particular sensor technology, maintenance activities common to a particular power source, and activities specific to a particular product or device.
- **Calibration/Recalibration.** Certain sensor technologies need to be calibrated periodically to avoid missed detections or false triggers. Inductive loops are notable in this regard, as they are highly sensitive to the strength of the electromagnetic signals produced by objects in the detection zone.
- **Reliability.** The various sensor technologies are likely to have different lifespans, which is a topic of interest to any budget-conscious agency. However, equipment reliability has not been discussed in the literature.
- **Ease of Uploading Data.** The user interfaces of counting devices vary, with data retrieval methods including analog readout screens, Bluetooth connectivity to PDA-type devices, and automatic telemetry uploads to remote servers, among others. These various data retrieval methods carry with them ranging associated costs, including fixed costs for any extra equipment needed, and variable costs including telemetry service fees and staff time. This factor is generally not technology-dependent, but rather reflects design decisions made by product vendors.

Table 2-15. Literature Review Summary of Pedestrian and Bicycle Data Collection Methods and Technologies: Data

Technology	Accuracy (location type, error variance data, study)*	Count Interval	Metadata Recorded	Data Extraction	File Format	Supports FHWA Format?	Critical Limitations	Sources
Manual counts	Depends highly on data collector behavior; improves with training, decreases with count duration	User Defined	Must be done by hand; geo-referencing difficult; can record any additional data desired	Must be input to computer by hand	Paper- must be input to computer by hand	Yes	Short-term counts only	Diogenes et al. 2007; Greene-Roesel et al. 2008; Schneider, Arnold, and Ragland 2009; Jones et al. 2010
Manual counts with smartphone apps	Not rigorously tested	5/15 minutes	Geographic coordinates; Time/Date	E-mail; iTunes sync cable	.csv; .html; .utdf; .jcd; .pdf graphic of intersection	Yes	Short-term counts only	
Manual counts with counting devices	Counter dependent	Time-stamped	Temperature (Titan II); Time/Date	USB, Bluetooth, serial port (varies by device)	ASCII, read by PetraPro	Weather data must be collected separately.	Short-term counts only	Diogenes et al. 2007; Schweizer 2005; Schneider, Patton, and Toole 2005
Pneumatic tubes	-27.5% MetroCount, on-road -14% to +3% off-road -1.9% EcoPilot, mixed traffic	15 min.	Timestamps	GSM, downloaded using proprietary software (Eco-Visio)		Weather data must be collected separately. Multiple tubes needed for directionality.	Temporary, tubes and nails to attach may pose hazard to bikes	Greene-Roesel et al. 2008; Alta Planning + Design 2011; ViaStrada 2009; Hjelkrem and Giæver 2009; Somasundaram, Morellas, and Papanikopoulos 2010
Piezoelectric strips	Not rigorously tested			GPRS/GSM; Bluetooth		Directionality and weather data must be collected separately.		Schneider, Patton, and Toole 2005; Davies 2008
Pressure or acoustic pads	Not rigorously tested	15 min.		GSM; IRDA; Bluetooth	Proprietary (Eco-Visio)	Directionality and weather data must be collected separately	Requires pedestrian contact to register a count	Greene-Roesel et al. 2008; Alta Planning + Design 2011; Somasundaram, Morellas, and Papanikopoulos 2010; Schneider, Patton, and Toole 2005; Bu et al. 2007

Technology	Accuracy (location type, error variance data, study)*	Count Interval	Metadata Recorded	Data Extraction	File Format	Supports FHWA Format?	Critical Limitations	Sources
Loop detectors – temporary	Not rigorously tested	15 min.				Directionality and weather data must be collected separately	Temporary	
Loop detectors – embedded	-4% standard loop detectors, multi-use path -4% EcoCounter ZELT shared roadway -3% EcoCounter ZELT, multi-use path -17.5% Eco-Twin, shared roadway -6% to -4.6% Datarec, sidewalk -10% to +5% on-road -10% to +25% off-road	15+ minutes (ZELT); 1+ min (bicycle recorder)				Directionality and weather data must be collected separately	Needs minimum road thickness for loops plus "cap" of 40mm, electro-magnetic interference can cause errors, requires pavement saw cuts	ViaStrada 2009; Hjelkrem and Giæver 2009; Nordback et al. 2011; Nordback and Janson 2010
Active infrared	-12% to -18% all travelers, multi-use paths -25% to -48% pedestrians, multi-use paths					Weather data must be collected separately. Multiple sensors needed for directionality	Can be triggered by non-travelers (insects, rain, etc.); occlusion errors	Jones et al. 2010; Bu et al. 2007
Passive infrared	-19% to -9% sidewalks (*0*) -36% to -11% multi-use path (*0*) -21% to -15% multi-use paths and sidewalks (*0*) -28% to +1% trails (*0*)	15 minutes		GSM, downloaded using proprietary software (Eco-Visio)		Weather data must be collected separately. Multiple sensors needed for directionality	Hard to distinguish groups of peds	Greene-Roesel et al. 2008; Schneider, Arnold, and Ragland 2009; Jones et al. 2010; Schneider, Patton, and Toole 2005; Schneider et al. 2012; Hudson, Qu, and Turner 2010; Montufar and Foord 2011

Technology	Accuracy (location type, error variance data, study)*	Count Interval	Metadata Recorded	Data Extraction	File Format	Supports FHWA Format?	Critical Limitations	Sources
Laser scanning				Ethernet, GSM, radio connection	.xls	Weather data must be collected separately.		Schweizer 2005; Bu et al. 2007; Musleh et al. 2010; Cui et al. 2007; Katabira et al. 2004; Shao et al. 2007; Navarro-Serment et al. 2008; Tanaka 2010; Shao et al. 2011; Ling et al. 2010
Radio waves	Not rigorously tested	User Defined		USB	.csv, .xls, .xml, .txt	Weather data must be collected separately. Multiple sensors needed for directionality	Only works for single file travel	Somasundaram, Morellas, and Papanikopoulos 2010
Video – manual analysis	Very high; limited by counter	User defined	Time of observation	N/A	Must be input to computer by hand	Yes	Extremely time intensive	Diogenes et al. 2007; Greene-Roesel et al. 2008
Video – automated analysis	Not rigorously tested				.pdf; .jcd; .utdf; .prn; .tf2; .csv; .xls	Weather data must be collected separately	Algorithms for bike/ped classification not fully developed	Somasundaram, Morellas, and Papanikopoulos 2010; Ismail et al. 2009; Malinovskiy, Zheng, and Wang 2009; Ribnick, Joshi, and Papanikolopoulus 2008; Li et al. 2012; Hu, Bouma, and Worring 2012; Nguyen et al. 2012; Somasundaram, Morellas, and Papanikopoulos 2012; Brändle, Belbachir, and Schraml 2010; Ling et al. 2010; Prabhu 2011

Notes: Blank cells correspond to information for which reliable sources could not be found in the process of the literature review.
*Accuracy values pertain to the conditions in which measurements were taken in the cited studies. Actual values may vary based on a range of factors.

Table 2-16. Literature Review Summary of Pedestrian and Bicycle Data Collection Methods and Technologies: Costs and Usage

Technology	Manufacturer (Product)	Approximate Device Cost	Approximate Labor Costs (if applicable)	Example Locations in Use
Manual counts	N/A	N/A	2 people-hours generally required per hour of counts performed, plus time to manually enter count data into computer	Alameda County, CA; Chicago, IL; Minneapolis, MN; Seattle, WA; San Francisco, CA; Toronto, Canada; New York, NY; Portland, OR
Manual counts with smartphone apps	TrafData (TurnCount)	$200–$500(iPhone/iPad)+ $40 (full version app)	1 person-hour per hour of counts performed	
Manual counts with counting devices	Jamar Tech (TDC Ultra); Diamond (MicroTally, Titan II)	$450–$1800, Software (PetraPro): $1000	1 person-hour per hour of counts performed	
Pneumatic tubes	Eco-Counter (TUBES); MetroCount (MC5600)	$2000–$3000		Chicago, IL; Vancouver, BC; Montreal, QC; Portland, OR; North Carolina
Piezoelectric strips	TDC Systems (HI-TRAC CMU); MetroCount (MC5720)			Iowa (DOT)
Pressure or acoustic pads	Eco-Counter (SLAB)			
Loop detectors – temporary	Eco-Counter (Easy ZELT)			Vancouver, BC
Loop detectors – embedded	Eco-Counter (ZELT); AADI(Datarec 7, Datarec410); Counters & Accessories (Bicycle Recorder)	$1750–$3000		Boulder, CO; Arlington, VA; San Francisco, CA; Madison, WI; Vancouver, BC
Active infrared	TrailMaster (TM-1550); CEOS (TIRTL)	$760-$860		Massachusetts
Passive infrared	Eco-Counter (PYROzoom) ; Jamar (Scanner);	$2000–$3000		Arlington, VA
Laser scanning	Logobject (LOTraffic); LASE (PeCo)			
Radio waves	Chambers Electronics (RadioBeam)	~$5600 (2007, converted from NZD)		
Video – manual analysis			Roughly 3 people-hours per hour of counts.	Davis, CA; Washington, D.C.; Vancouver, BC; Montreal, QC
Video – automated analysis	Miovision (Scout); Reveal; Cognimatics (Trueview); Video Turnstyle; Traficon			

PRACTITIONER SURVEYS AND INTERVIEWS

This section summarizes the results of the practitioner survey, follow-up interviews, and large-scale program survey conducted during the course of the project. These activities were intended (*a*) to develop a picture of the state of the non-motorized counting practice in the U.S., (*b*) to identify communities where particular counting technologies were being used, and (*c*) to identify interesting counting programs that could be used as case studies for the guidebook developed by this project.

Practitioner Survey

Outreach

Two methods were used to inform the non-motorized counting community of the existence of the survey. First, over 400 individual practitioners were contacted directly by e-mail. This group included:

- Persons on the NCHRP 07-17 (Pedestrian and Bicycle Transportation along Existing Roads) survey mailing list,
- Bicycle Friendly Community contacts,
- Walk Friendly Community contacts,
- Members and friends of the Bicycle and Pedestrian Data Subcommittee,
- State pedestrian and bicycle coordinators, and
- State motorized count program contacts that could be identified through state department of transportation (DOT) websites (26 in all).

The second method was to contact specific organizations with an interest in bicycle and/or pedestrian counting to ask them to inform their membership about the existence of the survey (typically by direct e-mail or through a mention in the group's e-newsletter). The following organizations were contacted; an asterisk following the organization name indicates that the organization confirmed that contacted their members:

- League of American Bicyclists (*)
- Association of Pedestrian and Bicycle Professionals (*)
- Association of Metropolitan Planning Organizations
- Complete Streets Coalition
- ITE Pedestrian and Bicycle Council
- National Association of ADA Coordinators
- National Association of City Transportation Officials
- National Association of Counties
- National Association of Development Organizations (*)

- National Center for Bicycling and Walking
- National Park Service
- NCUTCD Bicycle Technical Committee
- Partnership for the National Trails System
- Safe Routes to School National Partnership (*)
- TRB Statewide Multimodal Transportation Planning committee members
- TRB Pedestrian Committee members
- TRB Bicycle Transportation Committee members (*)

Persons choosing to answer the survey were self-selected (i.e., not selected randomly), and members of the groups that publicized the survey will likely be over-represented in the pool of respondents. Therefore, the results presented here should be interpreted as "percent of those responding" and not "percent of U.S. agencies." Nevertheless, as discussed below, the survey was successful in obtaining responses from a broad cross-section of organizations that conduct or are considering conducting bicycle and pedestrian counts.

The survey opened October 3, 2012, and results were downloaded on November 1, 2012. A total of 471 surveys were started, and 269 complete responses were identified after cleaning the data. The survey form is provided in Appendix A; supplementary tables of survey responses (e.g., written comments) are provided in Appendix B.

Respondent Location

Survey respondents represented 44 states plus the District of Columbia within the United States, along with six other countries. Respondents are summarized by country in Table 2-17. As can be seen, the vast majority of respondents reside in the United States, which is to be expected given the origin of this research being in the US.

Table 2-17. Respondent Locations by Country

Country	Number of Respondents
Canada	8
India	1
Israel	1
New Zealand	1
Switzerland	1
United Kingdom	1
United States	256

A state-by-state distribution of U.S. respondents is shown in Figure 2-11, along with a supplemental table in Appendix B. The largest share of the responses (approximately one-third) came from California, North Carolina, Colorado, and Oregon.

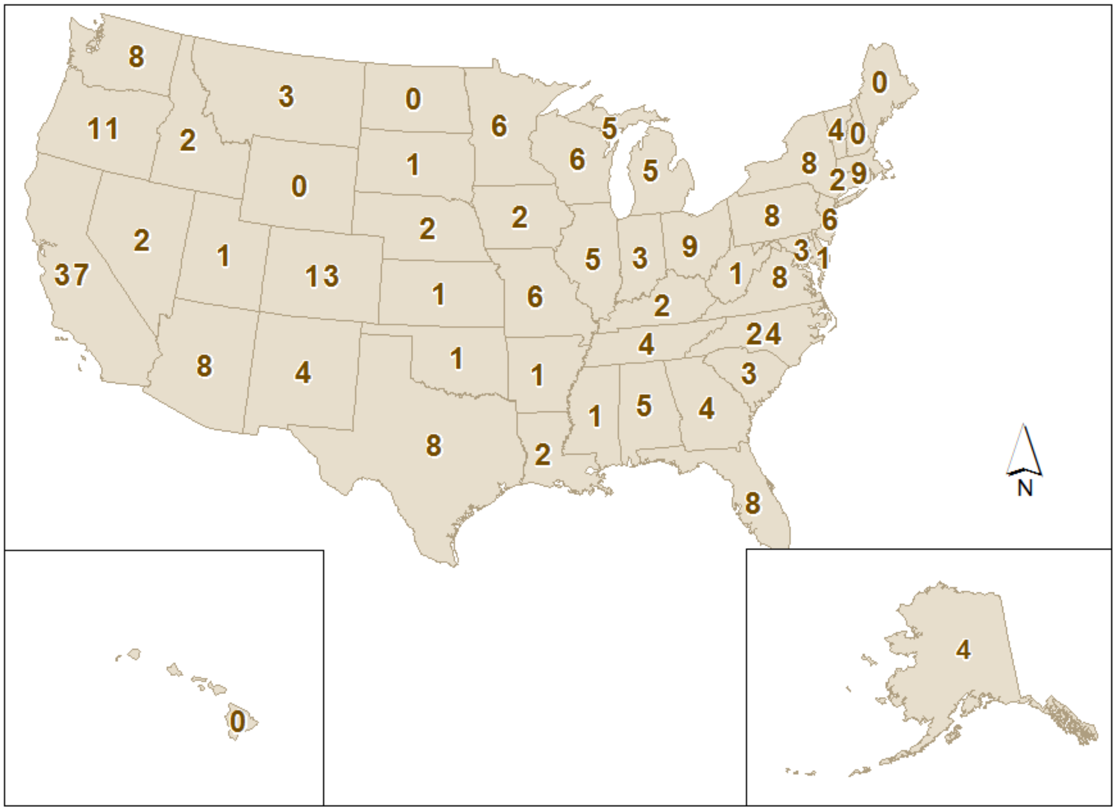

Figure 2-11. State-by-State Distribution of U.S. Respondents

Pedestrian vs. Bicycle Counts

To determine whether pedestrian or bicycle counting programs were more common among respondents, the number of organizations reporting using one or more pedestrian-only or combined count sites within the past 2 years were compared to the same metric for bicycle counts. Under this definition, 67 responding organizations pedestrians (in stand-alone or combined counts), and 90 count bicycles. Hence, bicycle counting programs are more common among respondents than pedestrian counting programs. Additionally, 66 of the 67 organizations that count pedestrians also count bicycles (either alone or as a component of combined counting efforts).

Organization Type

A variety of organizations were represented in the sample (Figure 2-12). The most common organization types were: U.S. cities, Metropolitan Planning Organizations (MPOs)/Regional Planning Commissions (RPCs), Non-profits/advocacy groups, and state DOTs. “Other” responses include various commissions and committees, non-U.S. agencies, and some responses specifying a category that had been given as an option (e.g., writing in “state DOT” under “Other”).

Figure 2-12. Survey Respondents by Type of Organization

Community Size

The survey included two separate questions pertaining to community size, as some respondents were presumed to be answering on behalf of agencies for which they serve as consultants.

Upon reviewing the responses for these two questions, however, it became evident that most respondents had only answered one of the two questions, and those that had answered both had provided the same answer for both. Accordingly, the two responses were merged into a single field for community size (as measured by population served by respondents' organizations). Table 2-18 gives a summary of community size, stratified by whether or not pedestrian and/or bicycle counts are performed within the community, and if so whether they take place periodically, project by project, or both. Approximately 35% of responding communities do not currently collect pedestrian or bicycle data, 45% collect pedestrian/bicycle counts periodically, and 40% do so on a project-by-project basis (respondents could provide more than one answer).

Table 2-18. Pedestrian/Bicycle Count Frequency by Community Size

Community Size (Population served by responding organization)	Yes, both periodically and project by project	Yes, on a periodic basis	Yes, project by project	No	Grand Total
1-4,999	0	1	0	0	1
5,000-10,000	0	0	2	5	7
10,000-50,000	4	6	2	9	21
50,000-100,000	4	9	3	6	22
100,000-500,000	12	16	6	14	48
500,000-1,000,000	5	4	3	2	14
1,000,000+	11	9	1	11	32
(blank)	19	22	35	48	124
Grand Total	**55**	**67**	**52**	**95**	**269**

Manual Count Frequencies and Intervals

A large number of responding agencies conduct manual counts of pedestrians and/or bicyclists. This technique is frequently used due to its relative simplicity and lack of capital equipment expenses. Manual count efforts reported in the survey are shown in Table 2-19 (pedestrians) and Table 2-20 (bicyclists). The results are shown both in terms of how frequently they occur (on the vertical axis), and the duration over which they are conducted (on the horizontal axis).

Table 2-19. Pedestrian Manual Counts Summary

	Pedestrian Manual Count Duration					
Pedestrian Manual Count Frequency	**1 hour or less**	**1–2 hours**	**3–6 hours**	**7–12 hours**	**13–24 hours**	**Grand Total**
Less than 1 time per year	11	11	13	10	6	51
1 time per year	8	19	10	5	4	46
2 times per year	2	6	1	2	2	13
More than 2 times per year	7	10	5	4	1	27
Grand Total	**28**	**46**	**29**	**21**	**13**	**137**

Table 2-20. Bicyclist Manual Counts Summary

Bicyclist Manual Count Frequency	Bicyclist Manual Count Duration: 1 hour or less	1–2 hours	3–6 hours	7–12 hours	13–24 hours	Grand Total
Less than 1 time per year	17	15	11	9	8	60
1 time per year	5	27	6	4	3	45
2 times per year	1	10	1	4	1	17
More than 2 times per year	6	7	6	2	3	24
Grand Total	**29**	**59**	**24**	**19**	**15**	**146**

For both pedestrian and bicyclist counts, 1–2 hour duration counts are the most common, and counts in general tend to occur less than once per year at a given location.

Count Site Selection Factors

Survey participants were asked "How does your organization select sites to be counted?" as an open-response format question with no differentiation between pedestrian and bicycle count sites. The detailed responses can be found in Appendix B. Responses were also coded for major recurring themes, as summarized in Table 2-21.

Table 2-21. Count Site Selection Factors

Site Selection Decision Factors	Frequency
Volumes/traffic/major destinations	32
Public requests/committee recommendation/ "local knowledge"	35
Infrastructure or development projects/ warrant studies	59
Sites of auto counts	8
Crash rates	8
At dedicated facilities/bike routes/bridges	44
Geographical distribution	14
NBPD procedures	11
Other	36

The total number of factors cited here does not add up to the number of surveys completed because some respondents did not answer this question, and others included multiple factors that guide their decision-making process. Responses falling under the "other" designation include topics such as data for large event rides, research projects, and historical precedence, among others. The most commonly cited reasons for selecting count sites are: to gather data for specific upcoming projects, to gather data for particular facility types, to respond to public requests, and to quantify expected volume levels.

The number of sites where counts occur for each type of count is a good indicator of how well developed counting programs are. As can be seen in Figure 2-13, motor vehicle counting programs tend to be more thoroughly developed than bicycle or pedestrian counting programs, when an organization conducts motor vehicle counts. Organizations not reporting motor vehicle counts may simply not be responsible for gathering motor vehicle data. The largest share of responses for each count type indicate zero counts within the past two years. One convoluting factor here is an overlap between either bicycle or pedestrian counts and combined counts, i.e. agencies reporting combined counts may or may not report separate pedestrian or bicyclist counts, although they do conduct counts of these modes. It is important, therefore, to not attribute too much value to the apparently large number of "no sites" responses. In addition, organizations not currently conducting non-motorized counts were encouraged to complete the survey, to provide information about whether they were considering doing so in the future and, if so, how.

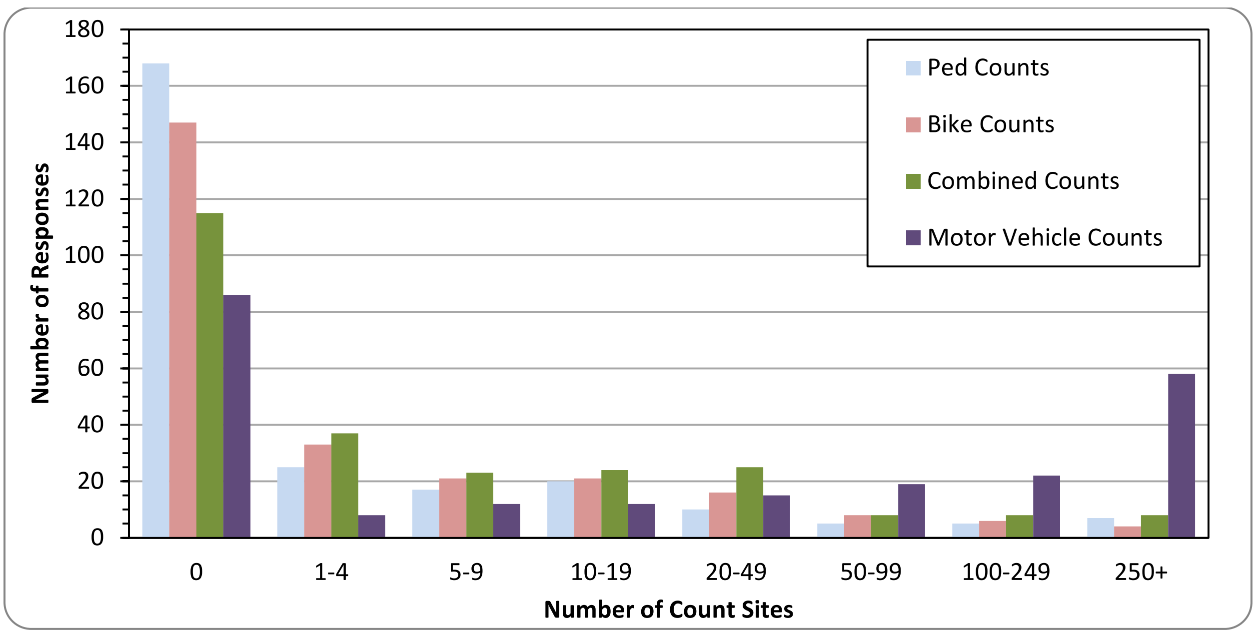

Figure 2-13. Number of Count Sites Used During the Past 2 Years

Adjustment Factors

Many respondents utilize some form of adjustment or correction factors with their count data. This accounts for inaccuracies with automated count results or variability in volume trends when extrapolating from short-term counts. In addition to the adjustment factors shown in Table 2-22, respondents mentioned simply recording information relevant to these factors without adjusting counts, avoiding counting during adverse conditions, and extrapolating spatially to fill in data at sites where counts do not take place.

Table 2-22. Adjustment Factors Used with Count Data

	Pedestrians	Bicyclists
No adjustment	72	88
Error correction factors	43	42
Temporal adjustment factors	33	35
Weather adjustment factors	30	33
Land use adjustment factors	24	24

Automated Counter Experience

This section focuses on presenting survey results regarding automated technology used to collect pedestrian and bicycle volume data and use of the count technologies based on survey respondents. It also includes examples of count programs in use as well as an evaluation of count technologies based on the literature review conducted as part of NCHRP 07-19.

Pedestrians

Manual counts, both in the field and based on video footage, are by far the most widely used methodologies for counting pedestrians (Table 2-23). This is likely due to these methodologies not requiring specialized or permanent technologies. Passive infrared, active infrared, and automated video counting all appear to have some market penetration based on our survey. However, automated video counting also has a high number of respondents reporting that they researched this technology but opted not to use it. The most common reasons given for opting not to use automated video devices related to cost concerns. Several respondents also mentioned anecdotal evidence that the technology is not yet good enough. Laser scanners and infrared cameras do not appear to be widely used for pedestrian counting.

Table 2-23. Experience with Automated Counters for Counting Pedestrians

Technology	Have used for less than 1 year	Have used for more than 1 year	Have discontinued use of this technology	Have neither researched nor used	Have researched but chose not to use
Manual counts with in-field staff or volunteers	6	87	3	3	1
Manual counts from video	11	33	1	35	14
Automated video counters	5	13	1	44	29
Passive infrared	3	17	0	46	19
Active infrared	0	13	0	57	18
Laser scanners	0	2	0	68	19
Infrared cameras	0	3	0	66	18

Bicyclists

Manual counts also appear to be the most commonly used method for counting bicyclists (Table 2-24). However, the more "advanced" technologies of inductive loops and pneumatic tubes are also fairly widely used, as well as (to a lesser degree) passive infrared, automated video, and active infrared. The relatively widespread adoption of pneumatic tubes and inductive loops probably arose because these technologies are already used extensively for the counting of automobiles.

Table 2-24. Experience with Automated Counters for Counting Bicyclists

Sensor Technology	Have used for less than 1 year	Have used for more than 1 year	Have discontinued use of this technology	Have neither researched nor used	Have researched but chose not to use
Manual counts	9	91	6	5	4
Pneumatic tubes	9	22	6	50	14
Piezoelectric strips	1	3	1	78	17
Inductive loops	2	25	0	58	15
Automated video counters	6	13	1	49	31
Passive infrared	4	18	1	55	17
Active infrared	2	10	0	69	19
Laser scanner	0	1	0	81	17
Infrared cameras	1	2	0	76	20
Fiber-optic pressure sensors	0	0	0	88	12

Use of Count Technologies

Each agency had the number of automated counting technologies that it has more than 1 year of experience with counted. These are cross-tabulated for bicycle and pedestrian counts in Table 2-25.

Table 2-25. Number of Agencies with Extensive Automated Counter Experience

Pedestrian Counters	Bicycle Counters						
	0	**1**	**2**	**3**	**4**	**5**	**Grand Total**
0	213	13	8	0	2	0	236
1	6	7	7	2	2	0	24
2	0	2	3	0	2	0	7
3	0	1	0	0	0	1	2
Grand Total	**219**	**23**	**18**	**2**	**6**	**1**	**269**

A small number of organizations reported extensive experience using automated counters for both bicyclists and pedestrians. The Delaware Department of Transportation has more than 1 year of experience with 5 different bicycle counters and 3 different pedestrian counters. The University of Colorado at Denver and Outdoor Chattanooga (Tennessee) both have experience with 4 different bicycle counting technologies and 2 different pedestrian counting technologies.

However, there are very few other similarities between these three organizations, suggesting that these extensive levels of experience are either happenstance or due to individual circumstances (e.g., political support, research needs).

Count Database Questions

When asked about data storage, of the 163 respondents who reported periodically collect non-motorized count data, 94 reported maintaining a database of non-motorized count data. Three respondents who reported not periodically collecting non-motorized count data claim to maintain a database, but upon closer inspection of the data, these respondents have all collected non-motorized counts within the past 2 years. Of the 97 respondents maintaining databases, the management responsibility and relation of the database to a motorized count database are summarized in Table 2-26.

The vast majority (85+) of reporting organizations who have a non-motorized count database maintain it themselves. Approximately 30% of the organizations with non-motorized count databases include these data with their motorized count databases, or in a parallel and easily linked database.

Table 2-26. Non-Motorized Count Database Maintenance Responsibilities

Who maintains your database?	Is your non-motorized count database linked to a database of motorized count data? No, it is completely separate	No, we do not have a database of motorized count data.	Yes, it can be linked easily through a unique ID field or other geographic identifier	Yes, it is part of the same database	Grand Total
A consultant does	1	1	0	0	2
Another public agency does	1	2	0	0	3
We do	42	14	10	19	85
Other	6	1	0	0	7
All of the above	1	0	0	0	1
Being built by our web development contractor	1	0	0	0	1
City and regional	1	0	0	0	1
PTA volunteers collect counts and submit them to city staff who keeps the records.	1	0	0	0	1
Rails to Trails Conservancy	0	1	0	0	1
We and a partner organization	1	0	0	0	1
(blank)	1	0	0	0	1
Grand Total	**50**	**18**	**10**	**19**	**97**

Participants were also asked about the software in which their database was maintained. The majority of respondents (58%) report using spreadsheets to store their database. Other responses are shown in Table 2-27.

Table 2-27. Software Used for Database Management

What type of software is used for your database?	Frequency
In-house customized software	9
Off-the-shelf desktop database software	3
Off-the-shelf server-based software	1
Spreadsheet	56
Vendor-specific product	15
Other	12
(blank)	1
Grand Total	**97**

A total of 78 databases include pedestrian counts and 93 include bicyclist counts. A total of 77 databases include manual count data, while 50 include automated count data. Of those including automated count data in their databases, 12 respondents said that the data is automatically uploaded from their counters, while the remaining 38 said it is not.

The survey also asked about how their count data are aggregated by time in their databases. The most frequent response was hourly, with 15-minute and daily also popular choices, as shown in Table 2-28.

Table 2-28. Time Period Summarization in Count Databases

What counting time periods are represented in the database?	Frequency
AADT	21
Monthly	21
Daily	42
Hourly	63
15 minute	45
5 minute	5

Deterrents

Respondents were asked about what factors deter their organization from collecting bicycle and pedestrian count data. In particular, they were asked both about collecting more data and starting data collection in general.

Deterrents to Collecting More Data

Survey participants were asked what factors prevent their organizations from collecting more pedestrian and bicycle volume data, the results of which are shown in Figure 2-14. The most significant factor across most respondents is a lack of staff time or money allocated to the task of pedestrian/bicycle data.

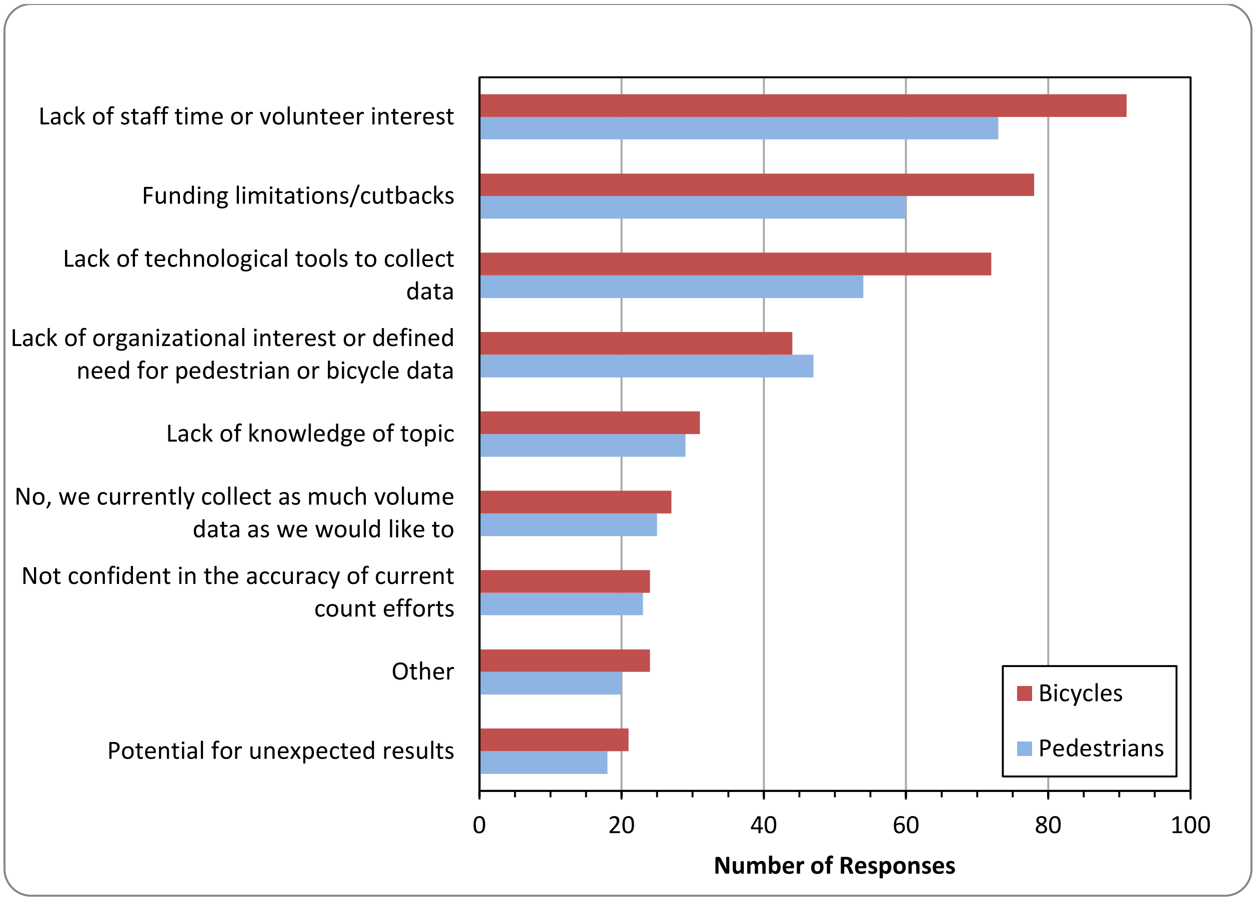

Figure 2-14. Factors Preventing Collection of More Data

In response to what "other" factors are preventing collecting more pedestrian volume data, responses included the following:

- "Confined to seasonal research & weather conditions"
- "Counts are based on project needs"
- "Never deemed essential"

When asked the same question pertaining to bicycle volume data, responses included:

- "Every dollar is spent on auto counts"
- "Few public requests for data"
- "We have had good success in use of volunteers; but, while p/b partners and some local munis see this data as valuable, there is still a HUGE disconnect in getting the DOT to accept the data as meaningful or useful. Still doesn't contribute to meaningful data about modal split. Has yet to have a meaningful impact on local decision making or project design."

Deterrents to Starting Bicycle/Pedestrian Data Collection

Figure 2-15 lists responses to the question on deterrents to starting a non-motorized count program. The most prominent themes among the "other" responses to this question included the costs of additional data collection and lack of funds, and suggestions that counting bicyclists or pedestrians does not fall under the responsibilities of the responding group. The "potential for unexpected results" category refers to possibilities such as counting fewer pedestrians and bicyclists than expected at a certain location or showing decreases in pedestrian or bicycle activity over time. The following are a selection of particularly interesting responses to this question:

- "Believe that agencies rather than non-profits should be collecting the data"
- "Concern the low numbers may adversely impact the justification for the facility"
- "Has not been a priority for organization in the past"
- "Lack of scientifically valid methodologies for selecting/sampling specific [locations] for data collection"

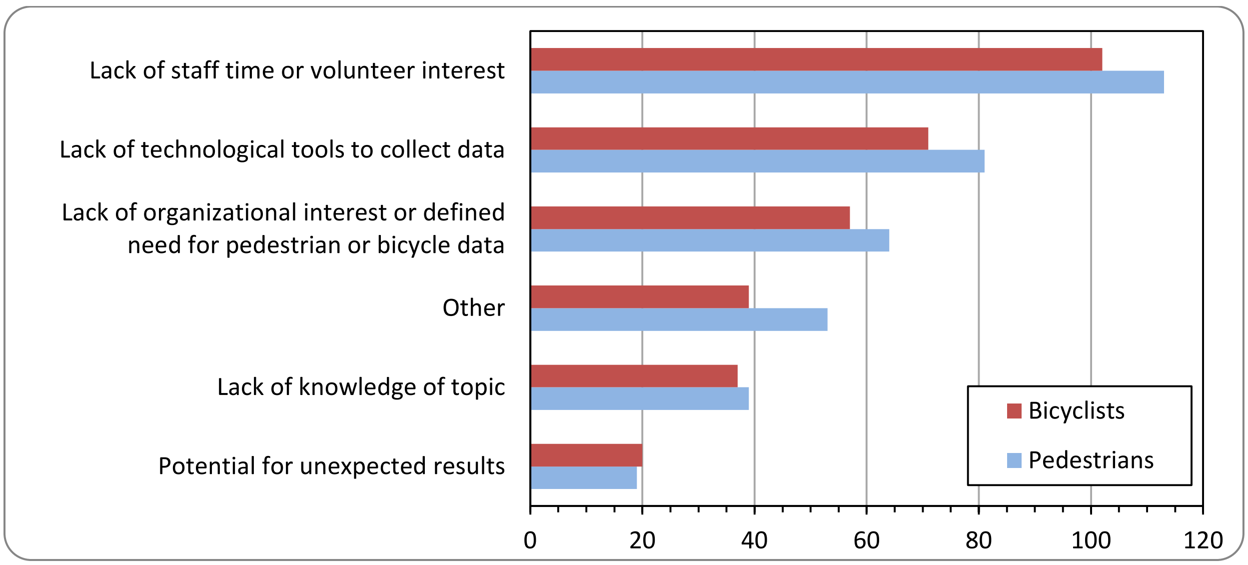

Figure 2-15. Factors Preventing Starting Data Collection

Satisfaction with Count Program

Respondents were asked whether they were satisfied with the process of data collection and analysis that their organization uses for pedestrian and bicycle counts, and to explain why or why not. A brief summary of responses is given below (many respondents did not answer this question):

- Satisfied with Pedestrian Data
  - Yes = 52
  - No = 47

- Satisfied with Bicycle Data
    - Yes = 53
    - No = 69

Among the respondents reporting satisfaction with their data collection and analysis, major themes included that the efforts meet the organization's needs and that current techniques are the most cost-effective option. Some examples of responses reporting satisfaction with pedestrian counting efforts include:

- "Because our pedestrian [infrastructure] is incomplete, we assume that if we build it, they will come. However, if we count them and find low numbers ([because] it is not currently safe to walk there), critics will complain that we shouldn't spend money where people are not already walking."
- "Most everything we do is in house or with academic research partners. We are happy with our processes and implementation to date."
- "Well, if by satisfied, you mean very excited, then yes. We think we are on to something. Certainly, our counters have very much enjoyed our approach so far, and we have had great feedback and anecdotal stories, our software programmers are very keen, the transportation engineers and statistical analysts that have consulted on the project have never seen anything like it and are equally as excited. One key component of the project is the ability for immediate public feedback via a digital map. Also the lack of processing time that will be required as compared to previous types. Also, our concept approaches that of a videogame - so we are hoping to build on people's "spare" time and a sense of competition to provide vast quantities of data. Even if some counts are only done for 10 minute intervals- it adds up."

Themes among unsatisfied responses focused around a desire to expand the amount of data available, establish a more formalized process of data collection and analysis, and increase the amount of count technology used, such as:

- "We would always like to collect more data and have better research to evaluate projects. We constantly run up against funding and time limitations, and as such, have not developed strong methodologies for counting."
- "Without data it is difficult to justify investments, especially when competing road projects have abundant data and analysis."
- "We collect counts regularly for specific projects, but that data is not [systematically] harvested for future use as a general purpose resource."
- "I wish we could automate the process for better long-term data".

Data Use

Finally, the survey asked what applications are pedestrian and bicycle count data used for. As shown in Figure 2-16, it appears that organizations tend to use data for a number of purposes simultaneously, while it might only be collected with one of these uses in mind. The most frequently reported uses of volume data were before-and-after studies of new infrastructure, project prioritization, and generally tracking activity trends over time. Open "Other" responses include level of service calculations, defense/justification for funding, "as needed for projects," and research, among others.

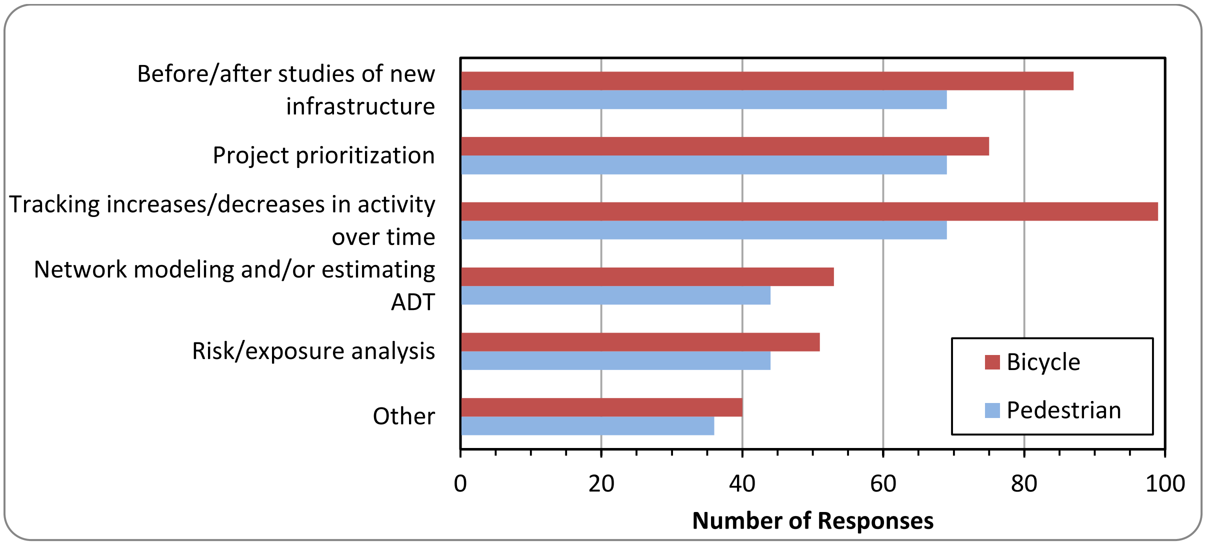

Figure 2-16. Uses of Volume Data

Follow-up Interviews

As a follow-up activity to the practitioner survey, 15 organizations that responded to the survey were contacted for more detailed interviews about their counting programs. The organizations were selected on the basis of providing a mix of organization types, sizes, geographic locations, counting technologies used, and overall experience with non-motorized counting, along their survey responses indicating something interesting about their counting program. The selected organizations consisted of:

- **Cities**
  - Calgary, AB
  - Chicago, IL
  - San Mateo, CA
- **Counties**
  - Alameda County (CA) Transportation Commission
  - Arlington County (VA) Division of Transportation

- **Regional Organizations**
  - Delaware Valley Regional Planning Commission (Philadelphia, PA)
  - Mid-Ohio Regional Planning Commission (Columbus, OH)
  - Midland Non-Motorized Transportation Advisory Committee (Bike/Walk Midland) (Midland, MI)
- **State Departments of Transportation**
  - Minnesota
  - Washington State
  - Wisconsin
- **Federal Highway Administration**
- **Other**
  - Advocacy group: Ada Bike Alliance (Boise, ID)
  - Consultant: DKS Associates (Portland, OR)
  - University: Portland State University (Portland, OR)

The following sections summarize the results of each interview.

Ada Bike Alliance

Background
Organization Type: Non-profit/advocacy
Population: 400,000
Location: Boise, Idaho (Ada County)
Climate: Four distinct seasons. Hot and dry summers with highs exceeding 100 °F. Winters are cold, with a January average of 30.2 °F. Snowfall averages 19 inches. Spring and fall are mild. Precipitation is usually infrequent and light, especially during the summer months
Bike to work rate: 1%
Walk to work rate: 2%

Summary
The ADA Bicycle Alliance (ADABA) was founded with the express purpose of conducting bicycle counts. Area agencies were not prioritizing counts and it was felt that having count data was critical not only for making funding decisions, but also for promoting bicycling as a significant mode. The ADABA is a completely volunteer-run organization—they have no funding. They have been able to establish a strong core of volunteers to conduct counts while also leveraging resources of other agencies and organizations. They have received some in-kind support from the Idaho Transportation Department (ITD) in the form of counting equipment. In addition, an ITD employee has volunteered time to map count locations using GIS. They are looking at ways to leverage a new program in transportation policy at Boise State University.

Key Takeaways

- Challenge to establish legitimacy among professionals working at the various transportation agencies. They feel like they are slowly establishing legitimacy as they continue to collect solid data. In fact, agencies are now requesting count data.
- Conducting counts in some key locations to establish more accurate average daily trip estimates.
- They have recruited homeowners in key areas where there is higher-than-average bike usage to conduct monthly counts from their front yards.
- ADABA does not have funding for automated technology, however, Idaho Transportation Department (ITD) has loaned pneumatic tubes to local agencies for a limited number of bike counts.

Count Information from Survey

Pedestrian Counts: Have not collected
Bike Counts: 100–249 locations in the last 2 years
Frequency: Not provided
Duration: Not provided
Locations: Multi-use trail, roadway intersection (intersection count)
Technology: Manual counts (used for more than 1 year), pneumatic tubes (currently planning), automated video counters (currently planning), infrared cameras (currently planning)
Combined Pedestrian and Bicycle Counts: 20–49 locations within the last 2 years
Motorist Counts: None

Alameda County Transportation Commission

Background

Organization Type: Countywide planning agency/congestion management agency
Population: 1,530,000
Location: San Francisco Bay Area, California (East Bay)
Climate: Average temperature in Oakland is 55 °F in winter and 71°F in summer**.**
Bike to work rate: 1.2%
Walk to work rate: 3.2%

Summary

The Alameda County Transportation Commission has been conducting counts for over a decade, but did not formally institutionalize counts until 2008 when they began to participate in a research study conducted by SafeTREC, a transportation safety research center affiliated with UC Berkeley. They rely primarily on manual counts, but have used automated counters for more project-based counts for about four years. They have been using count data, which shows significant year-over-year increases in bicycling and walking, as talking points for supporting active transportation modes and supporting a complete streets approach to transportation planning and design.

Key Takeaways

- The county is part of a "nested" approach to counting, which involves the Metropolitan Transportation Commission (MPO), the county, and cities. They have allowed MTC to procure contractors for all of their counting sites (both MTC sites within the county and the county's selected sites) because there were economies to doing so.
- The county has worked with agencies that build trails, for example, the East Bay Regional Park District, to get them to install counters during construction, which is more cost effective.
- The county has installed two in-pavement counters in the street and found it took a lot of staff oversight to ensure proper installation: "would be great if counter manufacturers could provide this service."
- Several entities collect data that are useful to the county and there is a lot of data sharing occurring among these entities. Kinks remain in terms of making sure all data are comparable.
- The regional parks district is changing vendors because they feel the new vendor's counters do a better job at distinguishing between pedestrians and bikes. This works out well for the county, which uses the same vendor. The county is considering a service that allows count data to be uploaded via cellular modem.
- They tried using volunteers for manual counts, but went back to using contracted professionals because they found it to be more efficient.
- They started with 30 count locations, currently have 63 (with partner agencies), and plan to expand to 100 locations in the future.

Count Information from Survey

Pedestrian Counts: 1–4 locations within the last 2 years

Frequency: Conducted 1 time per year
Duration: 2 hours
Locations: Sidewalk, intersection crosswalk
Technology: Manual counts (used for more than a year), passive infrared (used for more than 1 year)

Bike Counts: 20–49 locations within the last 2 years

Frequency: Conducted 1 time per year
Duration: 2 hours
Locations: On-street/sidewalk, roadway intersection (intersection count)
Technology: Manual counts (used for more than a year), passive infrared (used for more than 1 year)

Motorist Counts: Not provided

Arlington County Division of Transportation

Background

Organization Type: County
Population: 216,000
Location: Northern Virginia (Washington, D.C. area)
Climate: In winter, the average temperature is 38.4 °F and the average daily minimum temperature is 30.6 °F. In summer, the average temperature is 77.7 °F and the average daily maximum temperature is 86.5 °F. The total annual precipitation is about 39 inches.
Bike to work rate: 1.0%
Walk to work rate: 5.2%

Summary

The count program in Arlington County began based on staff identifying the "self-evident" need to have some data for pedestrian and bicycle travel. Initially staff identified existing tube counters not being utilized for street data collection and asked "Why not use these on trails?" In October 2009 they began collecting data at a known high-volume location with the existing tube counters. These counters were quickly able to provide interesting results with trend graphs about daily usage patterns. The initial impression from these data led the agency to find value in more data collection.

As interest grew, staff had some conversation with representatives from a vendor who had regularly presented their count technology at national conferences and offered to install a demonstration unit for Arlington County. Excitement about the new data quickly translated into piecing together a modest budget to purchase a number of counters over time. To date, the county has installed trail counters (loop and beam installations) at 16 locations, deployed 4 portable beam counters to collect short-duration counts at multiple locations, and recently completed installing 10 inductive loop counters at both trail and on-street locations.

Key Takeaways

- Successful demonstration sites lead to enthusiasm and support for count data at the agency level.
- The county has expanded the reach of data collection to adjacent jurisdictions to capture bridge traffic across the Potomac River entering the County on District of Columbia–owned roadways. Coordination and permitting is challenging but workable.
- The County is working to add count data to the dashboard of the community website to expand the availability of data to the public and other agencies.
- The success of demonstrating the value of these data has resulted in securing sustained funding for data collection technology. A recently passed bond issue in Arlington County now allocates $1 million annually from an $8/year vehicle registration fee for County residents; of this, $100,000 is directed to a technology budget for active transportation data collection.

- The data are currently used by the county in numerous ways, from reporting on trends to providing justification for improved maintenance or grant applications.

Count Information from Survey

Pedestrian Counts: 5–9 locations within the last 2 years

Frequency: 1 time per year

Duration: 2 hours

Locations: Sidewalk, multi-use trail, roadway intersection (turning count), intersection crosswalk

Technology: Manual counts (used for more than 1 year), manual counts from video (used for more than 1 year), passive infrared (used for more than 1 year), infrared camera (currently planning)

Bike Counts: 5–9 locations within the last 2 years

Frequency: 1 time per year

Duration: 2 hours

Locations: On-street/sidewalk, multi-use trail, roadway intersection (intersection count)

Technology: Manual counts (used for more than 1 year), pneumatic tubes (used for more than 1 year), piezoelectric strips (used for more than 1 year), inductive loops (used for more than 1 year), passive infrared (used for more than 1 year), infrared camera (currently planning)

Combined Pedestrian and Bicycle Counts: 20–49 locations within the last 2 years

Motorist Counts: Not provided

Calgary, Alberta

Background

Organization Type: Canadian city

Population: 1,100,000

Location: Calgary, Alberta

Climate: Long, cold, dry, but highly variable winters and short, moderately warm summers. Average winter temp is 27 °F, average summer temp is 75 °F.

Bike to work rate: 0.87%

Walk to work rate: 7%

Summary

Calgary has been collecting bicycle and pedestrian count data since the 1970s as part of its routine intersection traffic counts. They collect count data using custom-made counting devices that are operated by staff and seasonal contract workers. Data are stored and analyzed with custom software and GIS. They have used automated video counts on a limited basis and found that positioning is critical given their local weather conditions (cameras have been blown down or obstructed by snow). They tried using pneumatic tubes, but found it was difficult to get accurate counts, so they returned to video data collection.

Key Takeaways

- The city shares data on a request basis only and charges a fee for it. Data are provided in HTML format.
- They have traditionally conducted counts at intersections, but will do screenlines for projects (before-and-after evaluation) and on bridges, and conduct a cordon count of the CBD. The city is currently establishing baseline usage for the city's many pedestrian overpasses by conducting counts at those locations.
- Quality control involves four staff people looking over data to identify any anomalies and double-checking that the location is entered correctly before data are released or used.
- Having a large cache of historical data has proven useful for tracking mode share trends. The city still has a fairly low bicycle and pedestrian mode share.

Count Information from Survey

Pedestrian Counts: 10–19 locations within the last 2 years
  Frequency: Conducted less than 1 time per year
  Durations: 3–6 hours, 13–24 hours
  Locations: Sidewalk, multi-use trail, roadway intersection (screenline), intersection crosswalk, midblock crosswalk, bridges
  Technology: Manual counts (used for less than a year), automated video counters (used for less than a year), passive infrared (currently planning use), active infrared (currently planning use

Bike Counts: 20–49 locations within the last 2 years
  Frequency: Conducted less than 1 time per year
  Intervals: 3–6 hours, 13–24 hours
  Locations: On-street/sidewalk, multi-use trail, roadway intersection (screenline), roadway intersection (intersection count), midblock roadway crossing (intersection count), midblock roadway crossing (screenline), bridges,
  Technology: Manual counts (used for less than a year), automated video counters (used for less than a year), passive infrared (currently planning), active infrared (currently planning)

Combined Pedestrian and Bicycle Counts: 250+ locations within the last 2 years
Motorist Counts: 250+ locations within the last 2 years

Chicago DOT (Bike Program)

Background

Organization Type: City
Population: 2,700,000
Location: Chicago, IL
Climate: Chicago has distinct seasons. Summers are hot and humid, with a July daily average of 75.8 °F. Winters are cold, snowy, and windy, with some sunny days, and with a January

average temperature of 25.3 °F. Spring and autumn are mild seasons with low humidity.
Bike to work rate: 1.3%
Walk to work rate: 7%

Summary

Chicago began its counting program about 4 years ago as a way to collect before and after data when new bike lanes were added. With a new mayor, they wanted to expand that effort to gain a better understanding of bike movement, especially in and out of downtown where bikeways already existed and were being added. The city is especially interested in seeing the impact of the new "protected bike lanes" that have recently been added to the city's bicycle network.

Last year, a new approach was taken. The city conducted monthly bike counts at 6 locations outside of downtown, and also covered adjacent neighborhood locations (7–9 a.m., 4–6 p.m. every second Wednesday of each month through manual counts); gender and turning movements were recorded. Quarterly bike counts at 20 locations also began in 2011. These locations were located throughout downtown and consisted of a.m. and p.m. 2-hour counts (7–9 a.m., 4–6 p.m.).

Key Takeaways

- The monthly counts are done by staff, while the quarterly counts are conducted by volunteers.
- The 30 tube locations where counts were made in the summer 2009 and 2010 were dropped to make way for the new monthly and quarterly counts.
- The city has 5 interns who work part time on counting when counts are being conducted (they also have other duties) and 3 or 4 full-time equivalent staff who work approximately 5% on counts. The bike program also contracts with consultants for part of the program work, including counts.
- The city will be adding its first inductive loop for counting next year.

Count Information from Survey

Pedestrian Counts: Don't know
Bike Counts: 20–49 locations in the last 2 years
  Frequency: Not provided
  Duration: Not provided
  Locations: On-street/sidewalk, multi-use trail, roadway intersection (screenline), roadway intersection (intersection count)
  Technology: Manual counts (used for more than 1 year), pneumatic tubes (used for more than 1 year), inductive lops (currently planning), automated video counters (used for more than 1 year)
Combined Pedestrian and Bicycle Counts: No response
Motorist Counts: 50–99 locations within the last 2 year

Delaware Valley RPC

Background

Organization Type: Regional Planning Commission
Population: 5,626,000
Location: Philadelphia, PA
Climate: Cold winters, temperatures range from high teens to high 30s F; summers are warm and humid, with average highs 84–87° F and lows in the 62–67° F. The region experiences four distinct seasons.
Bike to work rate: 1.8% (Philadelphia)
Walk to work rate: 8% (Philadelphia)

Summary

DVRPC conducts counts of bicycles and pedestrians. Passive infrared counters are used for pedestrians and pneumatic tubes are used for bicycles. DVPRC does not use manual counting for data collection. Reasons for this include funding constraints, human fatigue, and credibility concerns (don't want advocates volunteering). They have been actively counting these modes since 2010. The RPC has identified 5,000 count sites throughout the region. Counts are generally conducted as part of before/after studies of new infrastructure, but some counts are done to help validate models.

Key Takeaways

- DVRPC will be installing permanent loop counters for bikes at approximately five sites as part of a grant obtained by a local health group that requires count data.
- All of the DVRPC data are accessible to the public. Maps are included on the agency's website, and members of the public can request electronic data files. Depending on the requested data volume, a fee may be applied. Most counts are conducted by request of a member jurisdiction. http://www.dvrpc.org/webmaps/pedbikecounts/

Count Information from Survey

Pedestrian Counts: 250+ locations within the last 2 years
  Frequency: Multiple times per year
  Durations: 24 hours for 1 week
  Locations: Sidewalk, multi-use trail
  Technology: Manual counts from video (currently planning), passive infrared (used more than 1 year)

Bike Counts: 250+ locations within the last 2 years
  Frequency: Multiple times per year
  Durations: 24 hours for 1 week
  Locations: Multi-use trail, midblock roadway crossing (screenline)
  Technology: Pneumatic tubes (used for more than 1 year), inductive loops (currently planning)

Motorist Counts: 250+ locations within the last 2 years

DKS Associates

Background

Organization Type: Consulting firm
Location: Portland, Oregon

Summary

DKS Associates' Portland, Oregon office has conducted bicycle and pedestrian counts for various agencies around the Portland region, including Metro (the MPO), for more than a decade. They use a variety of technologies and have a partnership with Portland State University to develop a publicly accessible online data warehouse (for more information, see the Portland State University case study). DKS has used a range of technologies and developed a preference for using automated counters that allow for 24/7 counts whenever possible.

Key Takeaways

- Using data from pedestrian push buttons at traffic to get a relative measure of pedestrian activity (does not capture actual volumes).
- Inductive loops have worked fairly well at intersections. Infrared does not work at intersections.
- Video is not all the way there in terms of being able to accurately count bicyclists. Somewhat concerning because many agencies are moving towards video—a lot of work needs to be done in terms of evaluating the accuracy of video data.
- Agencies are often reluctant to use new technologies because they see it as another product they have to stock and service.

Count Information from Survey

Pedestrian Counts: 20–49 locations within the last 2 years
Frequency: Less than 1 time per year
Durations: 2 hours, 3–6 hours, 13–24 hours
Locations: Manual counts (used for more than 1 year), manual counts from video (used for more than 1 year), passive infrared (currently planning), active infrared (currently planning), infrared camera (used for more than 1 year)
Technology: Not provided
Bike Counts: 20–49 locations within the last 2 years
Frequency: less than 1 time per year
Durations: 2 hours, 3–6 hours, 13–24 hours
Locations: On-street/sidewalk, multi-use trail, roadway intersection (intersection count)
Technology: Manual counts (used more than 1 year), inductive loops (used for more than 1 year), passive infrared (used more than 1 year), active infrared (used for more than 1 year)
Combined Pedestrian and Bicycle Counts: 250+ locations in the last 2 years
Motorist Counts: 250+ locations in the last 2 years

Federal Highway Administration

Background

Organization Type: Federal agency

Location: Washington, D.C.

Summary

FHWA does not directly collect pedestrian and bicycle data. The agency has responsibility to oversee the administration of federal transportation policy and funding that includes pedestrian and bicycle infrastructure across the nation. The FHWA released a policy statement in 2010 to reflect the program goals of the US Department of Transportation, which includes integration of active transportation networks in the nation's highway system. The USDOT Policy statement on bicycle and pedestrian accommodations is included below.

> *The DOT policy is to incorporate safe and convenient walking and bicycling facilities into transportation projects. Every transportation agency, including DOT, has the responsibility to improve conditions and opportunities for walking and bicycling and to integrate walking and bicycling into their transportation systems. Because of the numerous individual and community benefits that walking and bicycling provide — including health, safety, environmental, transportation, and quality of life — transportation agencies are encouraged to go beyond minimum standards to provide safe and convenient facilities for these modes.*

Included in this policy statement are recommended actions aimed to encourage states, local governments, professional associations, community organizations, public transportation agencies, and other government agencies, to adopt similar policy statements on bicycle and pedestrian accommodation. Among the recommended actions are two key provisions related to data collection and performance measures.

- *Collecting data on walking and biking trips: The best way to improve transportation networks for any mode is to collect and analyze trip data to optimize investments. Walking and bicycling trip data for many communities are lacking. This data gap can be overcome by establishing routine collection of non-motorized trip information. Communities that routinely collect walking and bicycling data are able to track trends and prioritize investments to ensure the success of new facilities. These data are also valuable in linking walking and bicycling with transit.*
- *Setting mode share targets for walking and bicycling and tracking them over time: A byproduct of improved data collection is that communities can establish targets for increasing the percentage of trips made by walking and bicycling.*

These policy recommendations reflect a renewed emphasis on active transportation based largely on the success of federal transportation programs initiated since the Intermodal Surface Transportation Equity Act (ISTEA) in the early 1990s. ISTEA and subsequent transportation bills have provided direct investments in non-motorized infrastructure through programs such as Transportation Enhancements and Recreation Trails, while establishing broad flexibility for other program funds to bicycle and pedestrian accommodations in most surface transportation projects.

More recently the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU), which was enacted by Congress in 2005, expanded to include two new programs: the Safe Routes to School Program (Section 1404) and the Nonmotorized Transportation Pilot Program (Section 1807). Both of these programs were enacted with an emphasis on documenting changes in active transportation use associated with these investments. The results of both programs have increased the awareness of the need to improve data collection for non-motorized travel modes and develop consistent standards for reporting of data.

In 2012, FHWA initiated an effort to update the Travel Monitoring Guide to allow for agencies to report pedestrian and bicycle data in conjunction with the required reporting of vehicle miles of travel data for federal aid highway facilities.

Midland Non-Motorized Transportation Advisory Committee (Bike/Walk Midland)

Background

Organization Type: City advisory committee
Population: 42,000
Location: Midland, MI
Climate: average 27.4 inches of rain per year, winter temperatures range from mid teens to mid 20s °F, summer temperatures range mid 50s to mid 80s °F
Bike to work rate: Not known
Walk to work rate: 2.7%

Summary

Pedestrian and bicycle counts are organized by Bike/Walk Midland, the city's non-motorized transportation advisory committee that was formed approximately six years ago. They are a subcommittee of the City Plan Committee and are overseen by the Planning Director. The group is mostly citizen volunteers. They have undertaken counting to provide better information and data for making infrastructure requests. At this point the count program is entirely a volunteer effort, and all counts are conducted manually. The group is adhering to the national count dates and using the forms provided by the National Bicycle and Pedestrian Documentation Project. Because of the difficulty of staffing volunteer stations, they have not been able to conduct as many counts as they would like. Given the limited data that they do have, they have not yet been able to identify any trends.

Key Takeaways

- There is currently no budget or funding for the count program. Bike/Walk Midland receives some support from the city for printing and making copies of forms.
- The count program is completely reliant on volunteers, making it difficult to accumulate significant levels of data.

- The data collected to date have not been shared outside of the committee and the city planning director's office.
- Midland is representative of smaller communities that are increasingly beginning to recognize the importance of collecting bicycle and pedestrian data.

Count Information from Survey

Pedestrian Counts: 10–19 locations within the last 2 years
  Frequency: Not provided
  Duration: Not provided
  Locations: Not provided
  Technology: Not provided

Bike Counts: 10–19 locations within the last 2 years
  Frequency: Not provided
  Duration: Not provided
  Locations: Not provided
  Technology: Not provided
  Motorist Counts: 10–19 locations within the last 2 years

Mid-Ohio Regional Planning Commission

Background

Organization Type: Regional Planning Commission (RPC)
Population: 1,513,000
Location: Columbus, OH
Climate: Summers are typically hot and humid throughout the state, while winters generally range from cool to cold. Precipitation in Ohio is moderate year-round.
Bike to work rate: 0.7% (Columbus)
Walk to work rate: 3.0% (Columbus)

Summary

The Mid-Ohio Regional Planning Commission has been conducting pedestrian and bicycle counts since around 2002. They recently conducted and analyzed detailed trail usage and pedestrian volume counts. The trail counts were done in partnership with the City of Columbus and Rails to Trails (RTT). The pedestrian counts were done in partnership with the Capital Crossroads Special Improvement District and utilized Trail Masters counters.

The counts are meant to serve as a baseline to document changes over time, while also assisting with grant applications, providing information to elected officials, and supporting/justifying budget decisions. The trail counts inform the process of evaluating whether to widen selected trails, and the pedestrian counts also serve as a marketing tool for potential incoming businesses. The locations for the counts were selected to be consistent with previous counts and also to capture perceived high-activity locations; however, the selection process was relatively informal. Broadly, the data management process involved downloading the data from the counters, querying and manipulating the data in Microsoft Access, and then exporting the data to Microsoft Excel.

The City of Columbus has also participated in the National Bicycle and Pedestrian Documentation Project methodology since 2005. They conduct the counts two times a year at over 20 locations; however, it was noted that the resulting counts tend to be relatively small and it can be difficult to draw definitive conclusions from them. The RPC also has tube counters but they don't use them often, in part because of limited staff resources.

Key Takeaways

- Count data contributes to an increasing interest in performance measures.
- One issue with their counters is the limited memory that fills up quickly, requiring frequent field visits to download data and reset.
- Emphasis on advantages of Access over Excel for data management, due to the ability to aggregate by hours or times of day for a variety of count times.
- The Downtown Special Improvement District provided $5,000 to support the most recent downtown count.
- Count data can be useful for developing volume predictions and calibrating bicycle and pedestrian demand models.
- The RPC sees itself as a natural repository for regional bicycle and pedestrian data based on its existing role as a repository for motorized traffic counts.

Count Information from Survey

Pedestrian Counts: 10–19 locations within the last 2 years

Frequency: 2 times per year
Duration: 2 hours
Locations: Sidewalk, multi-use trail
Technology: Not provided

Bike Counts: No bicycle-only counts conducted
Combined Pedestrian and Bicycle Counts: 20–49 locations within the last 2 years
Motorist Counts: Not provided

Minnesota DOT

Background
Organization Type*: State department of transportation*
Population: *5,345,000*
Location: *Minnesota*
Climate*: Cold winters, hot summers. Mean average temperatures range from 37 °F to 49 °F. average annual precipitation ranges from 19 to 35 inches.*
Bike to work rate*: 0.86%*
Walk to work rate*: 2.99%*

Summary

MNDOT is in the midst of a research project to study methods and technologies for bicycle and pedestrian counting. Interest was triggered by the large number of inquiries made to MNDOT from communities wanting direction on the counting methodology they should be using. A research study was funded internally with two main purposes: (1) to get a model counting protocol in place so that communities within the state collect data consistently and (2) to decide how and what would be incorporated into the MNDOT traffic counting system. The study is being conducted by the University of Minnesota. It consists of three phases: Phase 1: background research and manual counts for 42 communities using the National Bicycle and Pedestrian Documentation Project collection forms; Phase 2: trial of different counting equipment including inductive loops, tubes, etc.; Phase 3: how to incorporate into TRADAS (MNDOT's traffic data processing, analysis, and reporting system).

Key Takeaways

- 42 communities reported counts from the first statewide count effort in September 2012. MNDOT teamed with the Minnesota Department of Health's Active Communities program to coordinate the counts and to find volunteers.
- There has been a statewide effort building off of other efforts in Minnesota.
- Counting efforts in Minnesota and Minneapolis have been coordinated with counts conducted as part of the Non-motorized Transportation Pilot Program, administered by Transit for Livable Communities and known locally as Bike Walk Twin Cities.
- The City of Minneapolis Department of Public Works (DPW) and Transit for Livable Communities, Bike Walk Twin Cities (BWTC) have conducted annual counts in the Twin Cities since 2007, including over 400 count locations and 43 annual benchmark locations. The counts are based off the National Documentation Project Protocol and conducted annually by volunteers during the second week of September.
- DPW and BWTC also collect data using automated counters. DPW collects bicycle data from three automated counters along the Midtown Greenway and BWTC collects counts at 5 locations using portable pyro-electric counters.
- The University of Minnesota collects data using automated counters at several trail locations in Minneapolis.
- The Three Rivers Parks District has also conducted counts along the Twin City region's trail network.

Count Information

Pedestrian Counts: 100–249 during the last 2 years

Frequency: 1 time per year
Duration: 2 hours
Locations: Sidewalk, multi-use trail, intersection crosswalk, mid-block crosswalk
Technology: Manual counts (used for less than 1 year)

Bike Counts: 100–249 during the last 2 years

Frequency: 1 time per year

Duration: 2 hours, 7–12 hours

Locations: On-street/sidewalk, multi-use trail, roadway intersection (screenline), mid-block roadway crossing (intersection count), midblock roadway crossing (screenline)

Technology: Manual counts (used for less than 1 year)

Combined Pedestrian and Bicycle Counts: No response

Motorist Counts: 250+ during the last 2 years

Portland State University

Background

Organization Type: University

Location: Portland, Oregon

Climate: Mild, damp/wet winters and relatively dry, warm summers. Precipitation averages 37.5 inches per year. The city's wet reputation comes from the fact that the rain tends to fall as a drizzle or light rain over several consecutive days at a time.

Summary

Portland State University has been extensively involved with pedestrian and bicycle research, including data collection, for a number of years. PSU does not routinely collect bicycle and pedestrian data, rather they perform data collection and evaluate technology in conjunction with ongoing research projects on a regular basis. PSU compiles all of the data generated from project-based counts and from the City of Portland's manual and automated counts, acting as a regional repository for these data.

The University manages the PORTAL website that archives traffic data for the Portland metro area (http://portal.its.pdx.edu), including the suburbs in Washington state. The site has archived traffic, transit, and roadway network data since 2002. Beginning in 2012, PSU has begun a pilot effort to include pedestrian and bicycle data that are obtained from traffic signal loop detectors in bicycle lanes and pedestrian signal actuators from a small subset of signalized intersection in Portland. When complete, this effort will result in having pedestrian and bicycle data integrated into the traffic data management system. Future work with the portal will be focused on developing standards and formats to add the remainder of pedestrian and bicycle count data, but this effort will require significant work to normalize the data and develop adjustment factors to be consistent with other travel data housed in the portal.

Key Takeaways

- There is a growing excitement for pedestrian and bicycle data research at PSU and a strong partnership with the City of Portland to improve the collection and utilization of count data.

- PSU's work includes harvesting existing technology for new data, such as developing bicycle counts from existing bicycle loop detectors at traffic signals, and counting pedestrian push button activations at traffic signals.
- There are significant challenges in developing pedestrian and bicycle data on a par with existing vehicular and transit data.

Count Information from Survey

Pedestrian Counts: 1–4 during the last 2 years

Frequency: No response

Duration: No response

Locations: Intersection crosswalks

Technology: Manual counts (used for more than 1 year), manual counts from video (used for more than 1 year)

Bike Counts: 10–19 during the last 2 years

Frequency: No response

Duration: No response

Locations: Screenlines

Technology: Manual counts (used for more than 1 year), manual counts from video (used less than 1 year), inductive loops (used for more than 1 year)

Combined Pedestrian and Bicycle Counts: No response

Motorist Counts: 1–4 during the last 2 years

San Mateo

Background

Organization Type: City

Population: 98,000

Location: San Mateo, CA (San Francisco Bay Area)

Climate: Winter temperatures range from mid 40s to low 50s °F, summer temperatures range from mid 50s to mid 70s °F, 60 days of rain annually.

Bike to work rate: 2.1%

Walk to work rate: 4%

Summary

The City of San Mateo began conducting pedestrian and bicycle counts as a result of a Bicycle Master Plan developed in 2010. They will use these counts to evaluate bike and pedestrian mode share. They also see counts as important for putting biking and walking on equal footing with motor vehicles. The counts "add legitimacy" to these modes. The city collects count data through manual counts (currently at 17 locations) conducted by staff and volunteers. However, they also get data generated by private developers, who are required to conduct counts as part of a traffic impact studies. Routine count locations were identified in master plans and grouped into Tier 1 (high priority) and Tier 2. The City hopes to conduct counts at all 20 Tier 1 locations next year and get into some Tier 2 locations as well. The City also conducts routine tube counts, which are integrated into their larger database.

The City doesn't have a dedicated budget for counts, but estimates it costs less than $3,000 because it is built into what they do. They openly share data and have plans to post on the city website. They have also shared the data with NPBD, CalTrans, the Metropolitan Transportation Commission, and SafeTREC (UC Berkeley).

Key Takeaways

- The city conducts quality control for manual counts by providing training and performing tally-checks.
- They stopped using pneumatic tubes for a period, but have begun using them again. The key is making sure that the tube is pulled all the way to the far edge of the roadway so that bikes are counted.
- They researched using automated video counters, but chose not to use them because optical characteristics software did not seem bug-free at the time (several years ago). Mainstream opinion is that the technology has improved and may be worth revisiting.
- They have researched passive/active infrared and will likely use at some trail locations.
- The city uses the count data to produce an annual report card.

Count Information from Survey

Pedestrian Counts: 20–49 locations within the last 2 years
  Frequency: Conducted 1 time per year
  Intervals: 2 hours
  Locations: Roadway intersection, intersection crosswalk
  Technology: Manual counts (used for more than 1 year)
Bike Counts: 20–49 locations within the last 2 years
  Frequency: Conducted 1 time per year
  Intervals: 2 hours
  Locations: Roadway intersection (intersection count)
  Technology: Manual counts (used for more than 1 year)
Combined Pedestrian and Bicycle Counts: 20–49 locations within the last 2 years
Motorist Counts: 20–49 locations within the last 2 years

Washington State DOT

Background

Organization Type: State department of transportation
Population: 6,830,000
Location: Washington
Climate: An wetter oceanic climate predominates in western Washington, and a much drier semi-arid climate prevails east of the Cascade Range. The average annual temperature ranges

from 51°F on the Pacific coast to 40°F in the northeast. Western Washington is known for its mild climate, frequent cloud cover and long-lasting drizzles in the winter, and sunny and dry summers.
Bike to work rate: 0.91%
Walk to work rate: 3.4%

Summary

WSDOT initiated statewide pedestrian and bicycle counts because this was identified in the Statewide Pedestrian and Bicycle Plan as a key step towards moving forward with planning for active transportation modes. WSDOT also has a strong performance-measurement program and it was clear that pedestrian and bicycle volume data were major missing pieces for that effort. While WSDOT initiated the counting effort, the agency now plays more of coordination and reporting role, due to a significant growth in local community participation after 5 years of statewide counts. The biggest challenge has been getting unincorporated county areas to participate in counts. Participating communities have begun regularly using this data for their own planning purposes.

Data collection is done using volunteers, which are most often recruited and coordinated by local agencies and/or advocacy groups. WSDOT has streamlined the collection process by creating an online data entry portal where volunteers enter their tallies.

Key Takeaways

- WSDOT now requires all agencies receiving funding for local transportation projects to conduct pedestrian and bicycle counts. These data are integrated into a larger database.
- WSDOT has its own criteria for choosing count locations, but has found it to be most productive to allow local agencies or advocacy groups to choose or modify locations.
- New sites are always being added, but they keep collecting data at the original 23 sites.
- WSDOT and its partners have made it very clear to volunteer counters (many of which are advocates) that it does not work in their favor to bias data (over count) because through their quality control process they can easily identify anomalies and those counts are often thrown out.
- The goal is to be able to cross-check data whenever possible by using more than one collection method, and not just rely on one data collection method. WSDOT sees this as important for validating data.
- Data are stored in a master database using Excel, and can be ported to GIS. The key is to keep both the data and the database simple so that their use can be maximized.
- WSDOT started collecting gender and helmet use data a couple years ago.
- Data are shared openly with the public (posted on web) and with other departments and agencies. The goal is to have data used for concrete purposes (i.e., planning and design decisions) and not just for reporting, which seems to be the case.

- In terms of technology, WSDOT uses inductive loop detectors on some trail and bridge facilities and automated video detection at a limited number of sites. A decision-making matrix that an agency could go through to help choose the appropriate technology would be useful—for example, are they looking to develop planning or project data, and what site conditions exist?

Count Information from Survey

Pedestrian Counts: 250+ locations in the last 2 years

- **Frequency**: 1 time per year
- **Durations**: 2 hours, 3–6 hours
- **Locations**: Sidewalk, multi-use trail, roadway intersection (turning count), intersection crosswalk, mid-block crosswalk
- **Technology**: Manual counts (used for more than 1 year), manual counts from video (used for more than 1 year), passive infrared (currently planning, active infrared (currently planning), laser scanners (currently planning), infrared cameras (currently planning)

Bike Counts: 250+ locations in the last 2 years

- **Frequency**: 1 time per year
- **Duration**: 2 hours
- **Locations**: On-street/sidewalk, multi-use trail, roadway intersection (intersection count), roadway intersection (screenline), mid-block roadways crossing (intersection count) mid-block roadway crossing (screenline)
- **Technology**: Manual counts (used for more than 1 year), Pneumatic tubes (used for more than 1 year), piezoelectric strips (currently planning), inductive loops (used for more than 1 year), passive infrared (currently planning), active infrared (currently planning), laser scanner (currently planning), infrared camera (currently planning), fiber-optic pressure sensors (currently planning)

Combined Pedestrian and Bicycle Counts: 250+ locations within the last 2 years

Wisconsin DOT

Background

Organization Type: State department of transportation
Population: 5,712,000
Location: Wisconsin
Climate: Cold, snowy winters and warm summers. The average annual temperature varies from 39° F in the north to about 50° F in the south. Wisconsin also receives a large amount of snowfall, averaging around 40 inches in the southern portions of the state, with up to 160 inches annually in the Lake Superior Snowbelt each year.
Bike to work rate: 0.74%
Walk to work rate: 3.38%

Summary

Wisconsin DOT began counting bicyclists and pedestrians around 2005, starting with 10 manual counts. In 2008 they purchased two pyro-electric counters. In 2010 they added four more counters—two passive infrared and two tube counters. The counts were initially collected to help assess the validity of estimated counts submitted with transportation enhancement projects. Counts submitted with projects were compared to similar facilities with established counts. The counters were made available to communities to count use on their own paths and bike lanes. In 2012, WisDOT conducted a study to be more strategic about the use and placement of the equipment and to establish a basis for conducting statewide bicycle and pedestrian counts.

Key Takeaways

- Wisconsin currently uses no volunteers to help collect data. Most of the support comes from the WisDOT bicycle and pedestrian coordinators (central office and regional staff).
- Since Madison, Sheboygan County, and the Wisconsin Department of Natural Resources are currently collecting counts 24 hours/365 days a year, there is potential for extending the statewide counting program through coordination efforts.
- Sheboygan County counts have been conducted in conjunction with the Nonmotorized Transportation Pilot Program, administered by the Sheboygan County Planning Department.

Count Information from Survey

Pedestrian Counts: 5–9 locations in the last 2 years

Frequency: Less than 1 time per year

Intervals: 1 hour or less

Locations: Intersection crosswalk

Technology: Manual counts (used for more than 1 year), manual counts from video (used for less than 1 year), passive infrared (used for more than 1 year)

Bike Counts: 5–9 locations in the last 2 years

Frequency: Less than 1 time per year

Intervals: 1 hour or less

Locations: Multi-use trail, roadway intersection (intersection count)

Technology: Manual counts (used for more than 1 year), pneumatic tubes (used for more than 1 year), passive infrared (used for less than 1 year)

Motorist Counts: 250+ locations in the last 2 years

Additional Agency Surveys

An additional written survey was sent to existing large-scale automated pedestrian and bicycle counting programs, some of whom had also been included in the initial survey and follow-up interview, to obtain more insights about how non-motorized counting programs grow over time. This survey was sent to transportation professionals working at seven agencies currently operating such programs, with six agencies responding. These agencies were:

- City of Vancouver, Canada;
- Delaware Valley Regional Planning Commission (DVRPC);
- Colorado Department of Transportation (CDOT);
- City of Ottawa, Canada;
- Arlington (Virginia) County Department of Transportation; and
- San Francisco Municipal Transportation Agency (SFMTA).

The remainder of this section summarizes notable differences and similarities between counting programs, common trends and methods used by most agencies, anomalies and original answers, and additional information that was deemed interesting and relevant to the purpose at hand. The following bullet points cover the answers to each of the 12 questions included in the survey, although not necessarily in the order in which these questions were originally presented.

- The six automated pedestrian and bicycle counting programs on which information was gathered all started between 2008 and 2010. This is probably due to the commercialization of automated sensors with acceptable counting performance during that period of time. Although the automated counting programs are fairly new, they have been around long enough for agencies to assess their strengths and limitations.
- Most agencies seem to devote the bulk of their time and resources to bicycle counting, as opposed to pedestrian counting. In fact, the number of bicycle counters owned by each transportation agency surveyed is significantly larger than the number of pedestrian counters owned.
- Some of the programs started out as elaborate, region-wide manual counting programs many years (even decades) ago, and only recently evolved into large-scale automated counting programs. The manual counts were traditionally performed by trained volunteers. However, due to their resource-intensive and time-consuming nature, these manual counts could only be performed for a few hours per year at each given location.
- The most common significant factors in developing, sustaining, and growing the programs included: sufficient available funding, dedicated support from management, success of pilot projects, and pressing need or requests for more accurate, reliable, and extensive data.
- After a few years of running their automated programs, most agencies consider their personnel to be very qualified in the installation and calibration of their counting equipment. However, agencies also admit that their engineers and technicians lack the knowledge required to install and operate new types of innovative sensors, and point out the need to rely on vendor expertise when implementing new technologies. Also, most agencies now consider their personnel to be very comfortable with the interpretation and analysis of the collected data.

- Table 2-29 presents some statistics describing the distribution of automated pedestrian and bicycle counters available to the agencies surveyed. It also lists the types of sensors and counting devices currently used by these transportation agencies.

Table 2-29. Distribution of Automated Counters Available to Surveyed Agencies

Travel Mode	Mean Number of Counters Used	Range in Number of Counters Used	Types of Counters Used
Pedestrians	8	2 to 20	Infrared, video
Bicycles	24	10 to 46	Inductive loops, infrared, pneumatic tubes, piezoelectric sensors

- The agencies surveyed use pedestrian and bicycle data collected by their automated technologies to:
    - Evaluate the impact of projects and improvements to existing facilities (before/after studies)
    - Allow for better-informed decision-making and planning of future projects
    - Track trends in mode split over time
    - Develop metrics to track the progress of goals and objectives included in official transportation plans or other planning documents
    - Promote walking and cycling as efficient and reliable modes of transportation
    - Assist developers with the design of new developments which encourage and facilitate walking and cycling
    - Help staff advocate for increased attention to trail and street conditions. (e.g. snow clearing, creating buffered bike lanes in busy corridors, supporting continuing investment in infrastructure, etc.)
    - Lend support to regional bike-share programs
- Securing sufficient funding to purchase and install counters is one of the main challenges facing transportation agencies. The availability and clarity of official manuals and documents which highlight the importance of pedestrian and bicycle data is important when trying to persuade decision-makers to allocate resources to automated counting programs. One example of such a document is Chapter 4 of the *Traffic Monitoring Guide* (TMG) (FHWA 2013), which makes a convincing argument for the need for more pedestrian and bicycle data.
- When it comes to their future goals and objectives, most transportation agencies focus on their desire to expand their program to additional counting locations. For example,

the Arlington County Department of Transportation currently has 30 counters, and has a goal of increasing that number to 50 over the next two years.

- In addition to increasing the number of locations at which they have counters installed, some agencies are also looking to gain knowledge and expertise in dealing with new innovative counting technologies, and thereby diversify their sensor inventory. For example, the City of Vancouver is currently looking into Bluetooth, cellphone, video, and microwave technologies to assist in monitoring pedestrians and cyclists on roadways and shared facilities on a continuous basis.
- Funding that is obtained to pay for initial investments, such as the purchase and installation of counters, often does not cover obvious future maintenance and operating costs. To assure that funds are available in later phases of the program, agencies can use their initial results and collected data to adjust strategies outlined in their official transportation plans. Therefore, they can increase the likelihood that the plan's objectives will be met. This can convince decision-makers of the usefulness of the program, and facilitate their decision to unlock necessary maintenance and operating funds. This approach has been used by the City of Vancouver, which, coincidentally or not, operates the program that benefits from the most funding.
- Based on their responses, most agencies do collaborate, to different extents, with other organizations and government institutions. For example, the Arlington County DOT has counters installed at locations that fall under the jurisdictions of other agencies. Also, many different organizations operate counters in San Francisco, and a coordinated approach is planned to improve the sharing of the collected data between the SFMTA and those other organizations. Furthermore, Vancouver and Ottawa also collaborate with universities and transportation government agencies. On the other hand, the DVRPC and the CDOT do not collaborate with any other organizations. In the case of the DVRPC, collaboration is made impossible due to none of the neighboring agencies owning any of the material necessary to conduct automated pedestrian and bicycle counts.
- The CDOT and the DVRPC perform very few manual counts, and the data that they do collect manually are only used to assure the validity of their automated counts. The other agencies surveyed, which do perform some manual counts, usually report them on an annual basis, separately from their automated counts. Since the extent to which manual counts are performed is very small (usually 2 hours per year at each location), they are hardly compatible for integration with automated counts. While most agencies show little interest in integrating both types of data, the Arlington County DOT is hoping to develop an appropriate method to allow it to perform such integration in the relatively near future.
- Most agencies store the collected data both internally, on their servers, and externally, through the counting equipment vendors. Even when the data storage is handled by the vendors, it remains property of the transportation agency, as is the case in Arlington. Most agencies also make their data available to the general public, either as web maps,

GIS files, or other types of data files. Note that the DVRPC is the first agency in the U.S. to share some of the data it collected with the FHWA. It is, however, common for some agencies to share their data with academic groups and other state or federal organizations.

- To transfer data collected by their sensors to their database, some agencies rely on on-site download of the data to a PDA, followed by its transfer to a PC and its upload to the database. Most of the organizations that still rely on these manual methods are, however, planning on buying counters equipped with wireless modems in order to remotely retrieve their data and transfer it to the database via GSM. Some agencies already use cellular modems to transfer data from many of their counters (90% in the case of the CDOT) to their database. The SFMTA clearly states that all of the counters it intends to purchase in the future will include modems, which make it much easier to retrieve the data collected by the counters. The transportation agencies surveyed also mentioned using fiber optic networks and Bluetooth links to retrieve their data.

Chapter 3: Research Approach

This section describes the approach used for testing various automated non-motorized volume counting products and sensing technologies. Chapter 4 presents the results of this testing. Consistent with NCHRP guidelines, no product names or manufacturers are described here by name. Rather, when more than one product was tested representing a particular technology, the products are referred to as "Product A," "Product B," etc. Furthermore, the objective of testing different products was not to rate individual products, but rather to identify whether different vendors' implementations of a particular technology appeared to have a bearing on the observed count error.

TECHNOLOGY TESTING OBJECTIVES

The literature review showed that most existing pedestrian and bicycle counting technologies have been tested for short periods of time under a limited set of conditions. The effectiveness of some technologies has only been described anecdotally. Other technologies have been evaluated through internal testing by manufacturing companies or small-scale academic studies, but few of these studies have applied consistent measures of effectiveness across a broad set of conditions. Therefore, this research was designed to test pedestrian and bicycle counting technologies in a range of conditions, emphasizing the evaluation of technologies that had not been tested rigorously in the literature, along with technologies that have improved since last being tested.

The main purpose of testing automated non-motorized counting devices was to determine their accuracy under a variety of conditions. Good measurements of accuracy can be used to develop correction factors to account for regular under- or over-counting by specific sensor technologies under specific conditions. One of the most common sources of error for devices that detect users from a distance is the tendency to undercount due to *occlusion,* or one traveler blocking another from the counting device's field of view. Devices that detect users through contact or close-proximity movement (e.g., pneumatic tubes and loop detectors) may have other sources of error, such as not detecting enough pressure, not detecting certain materials, or counting motor vehicles in addition to bicyclists. Other counting device characteristics were also evaluated, including:

- Ease of installation,
- Labor requirements,
- Security,
- Maintenance requirements,
- Software requirements,
- Power requirements,

- Impact of weather conditions,
- Cost (e.g., purchase, installation, and other costs related to obtaining and activating devices),
- Coverage area (versatility), and
- Flexibility to use data outputs for various applications, including matching the TMG format (FHWA 2013).

Some of the criteria above (e.g., ease of installation, impact of weather conditions) were thought likely to apply to all counting devices (products) representing a given sensor technology. Others (e.g., power requirements, software, data outputs, cost) were thought to more likely be product-specific than technology-specific.

SENSOR TECHNOLOGY SELECTION

As part of the literature review effort, the research team identified the types of pedestrian and bicycle counting technologies on the market, along with individual products and their vendors. We also contacted a number of vendors to learn more about their products and the possibility of testing them as part of this project; in particular, whether equipment could be borrowed or leased. As an inducement, we offered to share the testing results for a given product with its manufacturer, and we noted that individual products were not going to be named in the published test results.

After discussing the available technologies with the panel, the following counting technologies were selected for testing:

- **Passive infrared.** Passive infrared devices detect pedestrians and cyclists by comparing the temperature of the background to the infrared radiation (heat) patterns emitted by persons passing in front of the sensor. They require placing a passive infrared sensor on one side of the facility being counted. Passive infrared sensors are widely used and have undergone multiple tests that have been reported in the literature. However, many of these tests are not recent and used various evaluation approaches, so it was thought to be interesting to see how the technology has improved.
- **Active infrared.** Active infrared devices count pedestrians and bicyclists using an infrared beam between an emitter and a receiver located on opposite sides of a traveled way (e.g., path, sidewalk). When the beam is broken for a set period of time by an object crossing it, a detection is recorded. An existing active infrared counter was available to the research team and was included in the test.
- **Pneumatic tubes.** This technology is applied by stretching one or more rubber tubes across the roadway or pathway. When a bicycle or other vehicle passes over a GPC tube, a pulse of air passes through the tube to a detector, which then registers a count. Bike-specific counters have a smaller profile and are specifically designed to count bicyclists.
- **Inductive loops.** Both in-pavement loops (requiring sawcuts) and temporary loops that can be placed on top of the pavement (without sawcuts) were selected. Inductive loops

generate a magnetic field when an electric current is passed through them. These counters detect changes in the field produced when metal parts of a bicycle pass over the loops.

- **Piezoelectric sensor.** Piezoelectric sensors are not used extensively for bicycle counting efforts in the U.S. However, they are quite common in other parts of the world, particularly Australia and New Zealand. Reports of this technology are generally very positive, so the technology was felt to be worth looking into more rigorously. Piezoelectric materials emit an electric signal when physical deformed, so counters using this technology typically consist of two strips embedded in the pavement across the travel way.
- **Radio beam**. Radio beam devices have not been formally tested in the literature to date, but have been anecdotally reported as working well. Radio beam counters use a transmitter and receiver positioned on opposite sides of the facility. A radio signal is sent from the transmitter to receiver; when the beam is broken, a user is detected.
- **Combination**. Combination devices use one counting technology (e.g., passive infrared) to detect all users (pedestrians plus bicyclists) and another technology (e.g., inductive loops) to detect bicyclists only. Therefore, the device can output pedestrian and bicycle counts separately.

Automated counting from video was desired to be included in the testing, but ended up not being evaluated. Although this technology has been the subject of a number of academic research projects, the one commercial application of it operates as a service, where clients send videos to the vendor to be counted. According to the vendor's website, its staff conduct quality-control checks of the counts, so any evaluation we would have performed would have been of the service (which may involve a combination of automated and manual data reduction) and not necessarily of the automated technology itself. Furthermore, an agency that we had planned to partner with to test the service experienced budget cuts during our testing period and was not able to conduct counts as planned using the service.

The following technologies were not selected for testing, due to one or more of the following: (1) minimal U.S. use to date, (2) limited application to outdoor use, (3) non-availability in the U.S. market, or (4) lack of vendor interest when contacted by the research team:

- **Thermal.** Thermal devices generate infrared images by detecting body heat. One vendor with a thermal device just coming onto the market as the testing program was wrapping up expressed interest in testing the product, but the project schedule did not permit adding the product to the testing.
- **Fiber-optic pressure sensor.** This technology was available commercially in Europe, but only the fiber-optic sensors themselves were available in the U.S.; a complete counting product incorporating these sensors was not offered in the U.S.
- **Radar.** Anecdotal evidence from Europe suggested that radar counters may be accurate at counting bicyclists, but tests of these devices have not been reported in the literature.

- **Laser scanners.** Laser scanners emit laser pulses in a range of directions and analyze the reflections of the pulses to determine characteristics of the device's surroundings, including the presence of pedestrians or bicyclists. According to a vendor, this technology is best suited for locations with electrical connections, although it could be used for short-term counts on battery power. The requirement for an electrical connection greatly limited the potential sites where the technology could be tested and would have involved greater installation costs than other technologies being considered.
- **Pressure and acoustic sensors.** Pressure and acoustic pads are installed in-ground, either flush with or under the surface. Pressure pads detect a change in force (i.e., weight) on the pad. Acoustic pads detect the passage of energy waves through the ground caused by feet, bicycle tires, or other wheels. These technologies would have required digging up and replacing sidewalks or off-street pathways (or finding a location where a pathway was about to open), which would have involved significantly greater installation costs and permitting requirements.

SITE SELECTION

Region Selection

The research team identified a pool of candidate jurisdictions that have been actively collecting and applying pedestrian and bicycle counts, and recommended to the panel that testing occur in the following five regions:

- Davis, California;
- Minneapolis, Minnesota;
- Portland, Oregon;
- San Francisco Bay Area, California; and
- Arlington, Virginia and Washington, D.C.

These regions were selected on the basis of:

- Providing the range of environmental conditions desired by the panel:
  - Foggy and rainy in the winter and hot and dry in the summer in Davis,
  - Cold and snowy in the winter in Minneapolis,
  - Rainy in the winter and spring in Portland,
  - Rainy in the winter and foggy in the summer in San Francisco, and
  - Rainy in the winter and hot and humid in the summer in Washington, D.C.;
- Presence of facilities with high volumes of bicycles and/or pedestrians, to allow a broad range of volume conditions to be tested;

- Proximity to one or more research team members, to facilitate monitoring the test sites over the course of a six-month test and to facilitate interactions with participating agency staff; and
- Agency willingness to have counting devices installed and to facilitate other logistical aspects of conducting the test (e.g., permitting, sawing pavement to install sensors).

The data collection budget allowed for a total of 12 individual sites to be counted, so each study region was planned to have two or three data collection sites. An initial set of potential sites was presented to the panel, with the recognition that some sites would end up not being used after a more detailed evaluation of the their appropriateness for the counting technologies and products being considered for each site.

Individual Site Selection

Potential count sites in each region were identified in conjunction with local agency pedestrian and bicycle planning staff, with the goal of finding sites that both met the project's needs for a diversity of conditions and that would provide useful data to the agency. In a number of cases, more detailed evaluations of the potential sites identified issues—generally relating either to counting product specifications or to local permitting requirements—that required selecting an alternative site. This section describes the process used to select sites in each region.

Portland, Oregon

The project team initially identified two sites in Portland, shown in Figure 3-1.

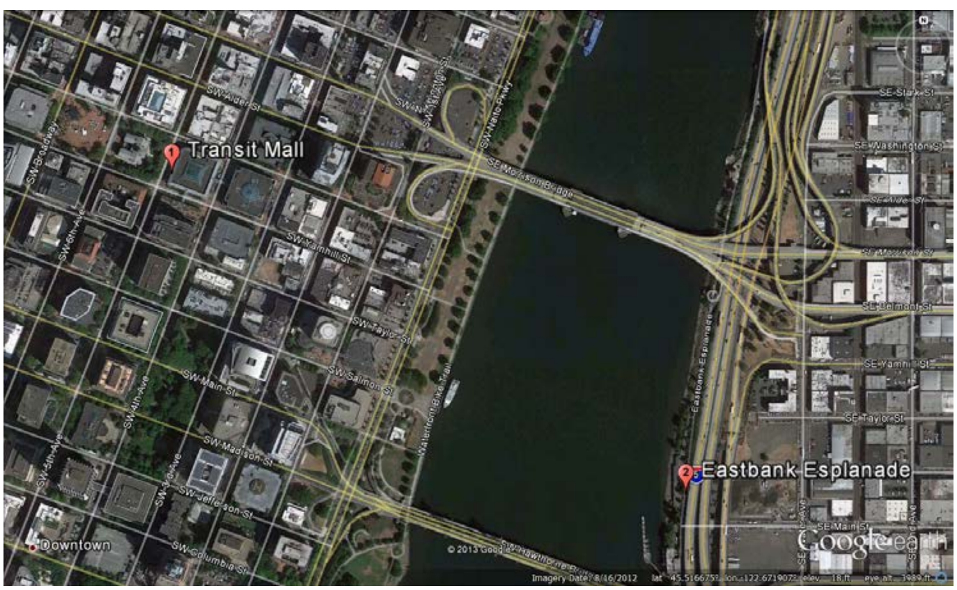

Figure 3-1. Original Portland Sites (Aerial View)

Source: ©2013 Google.

The first original site (Figure 3-2) was a sidewalk along the southbound transit mall (SW 5th Avenue) between SW Yamhill and SW Morrison Streets, adjacent to a major downtown shopping complex. This sidewalk is located on the opposite side of the street from the transit stops and is therefore not impacted by waiting transit passengers. The Portland Bureau of Transportation owns the sidewalk. However, one of the devices planned to be tested (a radio beam device) required mounting a receiver on the building wall. The building's owner decided that the receiver's enclosure was unattractive and declined to give permission to mount it. As a result, a different location needed to be found.

Figure 3-2. Transit Mall (Ground View)

The second site (Figure 3-3) was located along the Eastbank Esplanade multi-use path, a popular recreational and commuter route located between the Willamette River and the I-5 freeway. The site was located just north of the Hawthorne Bridge, the busiest bicycle facility in the city. The path was owned by the Portland Parks Bureau. It was originally planned to test a combination counter at this site, which involved sawcutting the pavement, but the Parks Bureau eventually declined to grant a permit for sawcutting. It was also planned to test a radio beam device at this site, but after receiving the device, it was discovered that the maximum vendor-recommended separation between transmitter and receiver was less than previously specified and, therefore, the device would not be usable at this site. As a result, a different location had to be found.

Figure 3-3. Original Eastbank Esplanade Site (Ground View)

Two replacement sites were selected, farther south on the transit mall at the Portland Building (the main office building for the City of Portland) and farther north on the Eastbank Esplanade at a narrower location where the radio beam device could be installed. These locations are mapped in Figure 3-4.

The City of Portland owns both the sidewalk and the adjacent building at the replacement transit mall site (Figure 3-5), which simplified the process of getting permission to install the counters. The counters installed at this site consisted of a passive infrared device and a radio beam device. Table 3-1, provided later in this section, summarizes the counters installed at each site by sensor technology and product.

The replacement Esplanade site (Figure 3-6) was at a location where the path splits into two narrower sections, which allowed the installation of the radio beam device. Although one would not normally install a counter at this location, as path users could bypass the counter using the other half of the path, the location met this project's needs, which was to test counter accuracy. A passive infrared counter and a radio beam counter were installed at this site. In addition, pneumatic tubes were installed during periods when videotaping occurred that would be used to establish ground-truth counts.

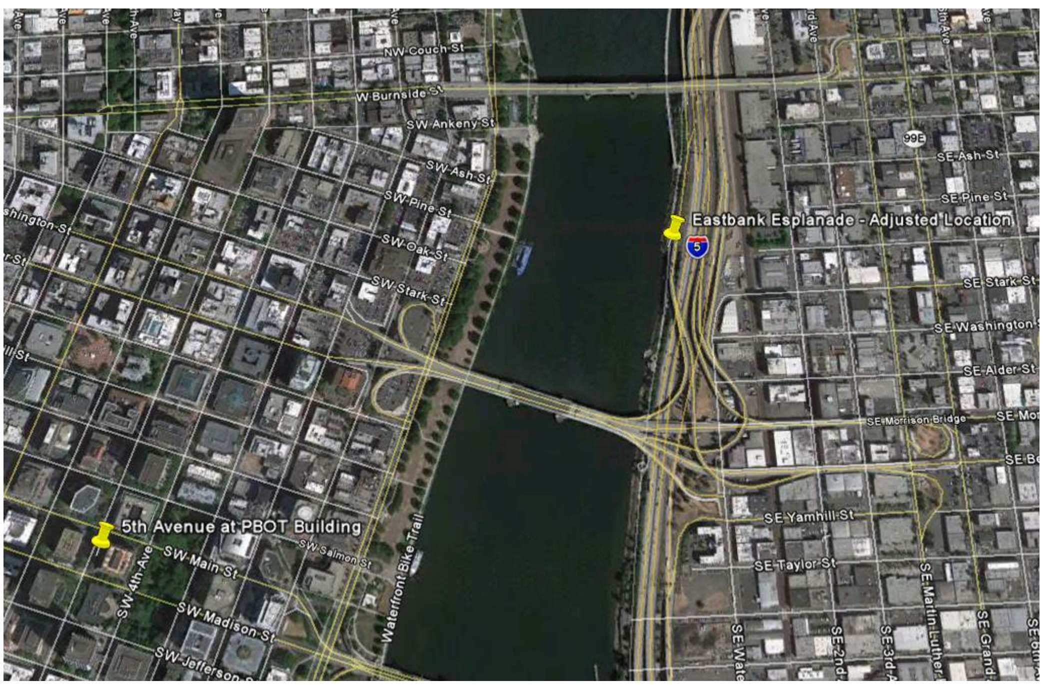

Figure 3-4. Final Portland Sites (Aerial View)

Source: ©2013 Google.

Figure 3-5. Final Transit Mall Site (Ground View)

Figure 3-6. Final Eastbank Esplanade Site (Ground View)

San Francisco, California

The project team identified two sites in San Francisco, shown in Figure 3-7.

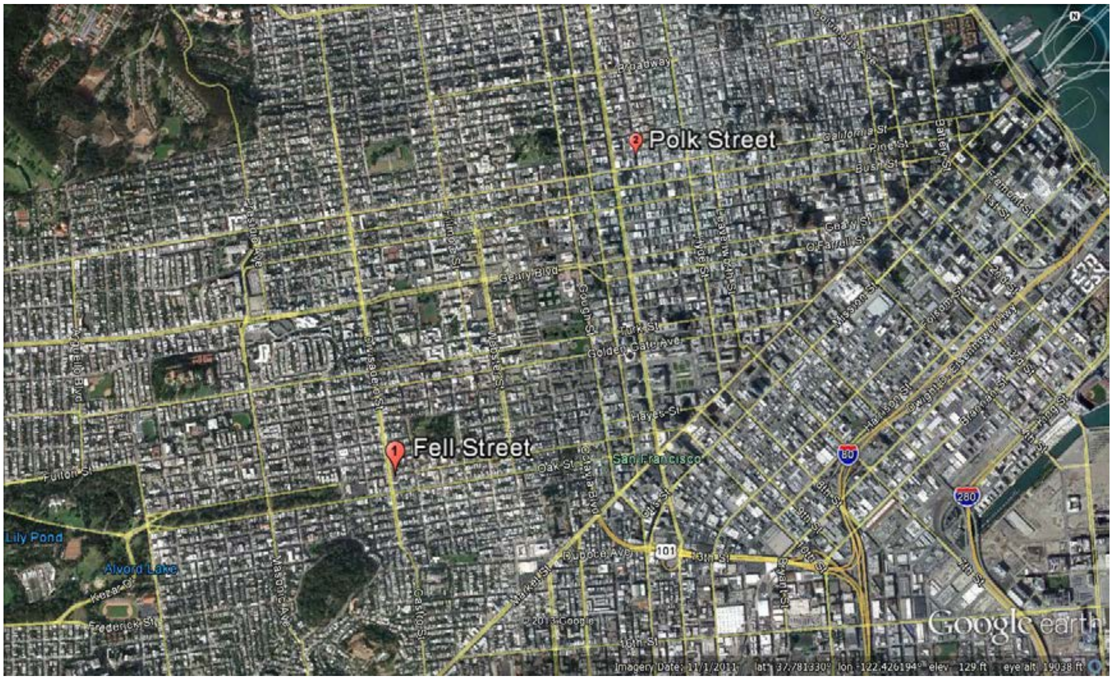

Figure 3-7. San Francisco Sites (Aerial View)

Source: ©2013 Google.

The first site was located on Fell Street west of Scott Street (Figure 3-8). A city-owned inductive loop counter already existed in the left-side bike lane at this site, which was supplemented by pneumatic tubes during periods when ground-truth videotaping occurred. In addition, a passive infrared device was installed to count the adjacent sidewalk.

The second San Francisco site was to be located on Polk Street south of Sacramento Street (Figure 3-9). The intent of this site was to provide an opportunity to count bicycles in mixed traffic, as well as to count the adjacent sidewalk. Unfortunately, the City of San Francisco's Department of Public Works required posting a $25,000 bond to cover potential pavement damage, and the San Francisco Municipal Transportation Agency (our contact) was not able to obtain a waiver. Therefore, it was infeasible to install an inductive loop counter at this location. In addition, a vendor never supplied one of the passive infrared devices we had planned to use to count the sidewalk here. As a result, just one long-term counting device remained (a passive infrared counter from another vendor, to count the sidewalk), along with the potential for installing penumatic tubes temporarily in the traffic lanes. As both of these devices were planned to be tested elsewhere, the research team decided not to use this site.

Figure 3-8. **Fell Street (Ground View)**

Figure 3-9. **Polk Street (Ground View)**

Davis, California

The research team worked with local agency staff to identify the two sites in Davis shown in Figure 3-10.

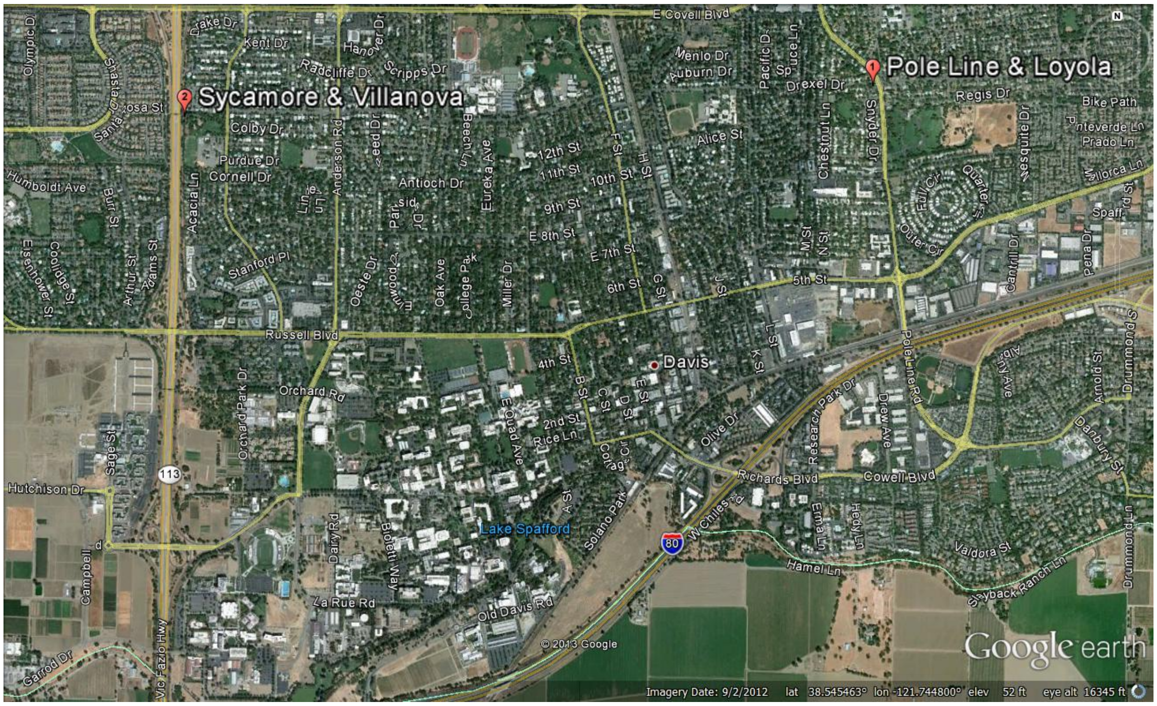

Figure 3-10. Davis Sites (Aerial View)

Source: ©2013 Google.

The first Davis site was a multi-use path located near the intersection of Loyola Drive and Pole Line Road (Figure 3-11). A passive infrared counter and a temporary (i.e., surface-mounted) inductive loop counter were installed at this location. In addition, a combination passive infrared and piezoelectric device for counting both pedestrians and bicyclists was ordered, but never delivered by the vendor. The temporary inductive loop counter was re-installed in a different loop configuration between the first and second rounds of data collection, to better match the manufacturer's installation recommendations.

Figure 3-11. Loyola and Pole Line (Ground View)

The second Davis site (Figure 3-12) was a multiuse path located west of the intersection of Sycamore Lane and Villanova Drive. A combination passive infrared and inductive loop device (for counting both pedestrians and bicyclists) was installed here, along with a passive infrared device from a different vendor (which was stolen during the course of testing). A radio beam device was also planned for this location, but as with the original Eastbank Esplanade site in Portland, the path proved to be too wide when the actual device (and revised specifications) were received. As a result, the radio beam device was moved to a site in Berkeley, California (discussed next).

Figure 3-12. Original Sycamore and Villanova Site (Ground View)

Berkeley, California

A site was added on the University of California at Berkeley (UC Berkeley) campus to accommodate testing of the radio beam sensor originally planned for Davis. The site was located on a narrow bridge on a shared-use path on the campus (Figure 3-13). In addition to the radio beam sensor, a passive infrared sensor was installed here.

Figure 3-13. UC Berkeley Site (Ground View)

Minneapolis, Minnesota

Two sites were identified in Minneapolis, as shown in Figure 3-14.

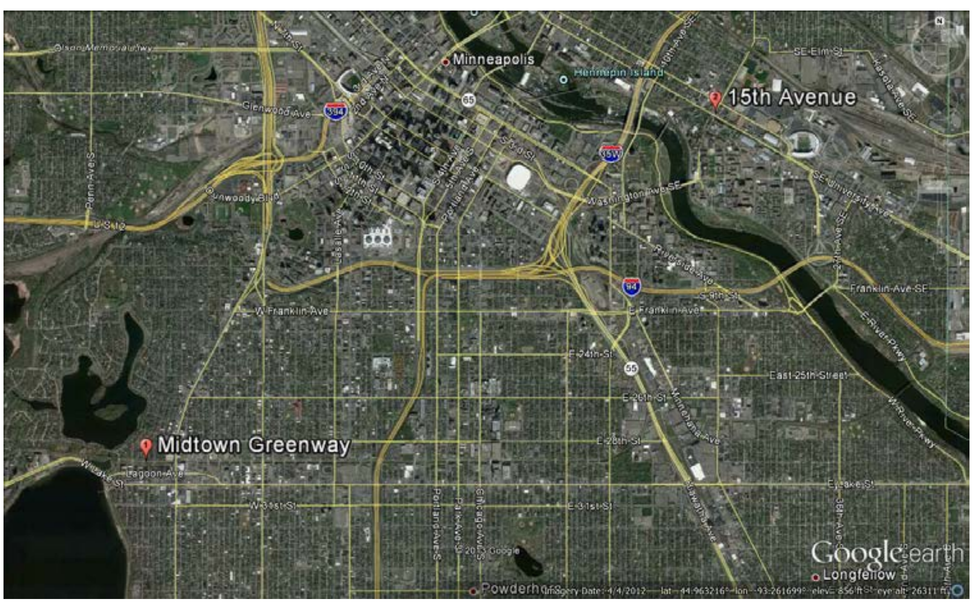

Figure 3-14. Minneapolis Sites (Aerial View)

Source: ©2013 Google.

The first site was on the Midtown Greenway multi-use path east of Humboldt Avenue (Figure 3-15). Two counting devices already existed at this location: a passive infrared device and a radio beam device, which we were able to use courtesy of the Three Rivers Park District and the University of Minnesota, respectively. These counters were supplemented by a radio beam device from a second vendor and permanent and temporary inductive loops. In addition, a combination passive infrared and piezoelectric counter planned for this site was ordered, but never received.

The second site was on 15th Avenue SE, north of University Avenue (Figure 3-16). A passive infrared counter was installed to cover the eastside sidewalk at this location. In addition, pneumatic tubes were placed in the adjacent northbound bicycle lane during the periods that ground-truth videotaping occurred.

Figure 3-15. Midtown Greenway (Ground View)

Figure 3-16. 15th Avenue (Ground View)

Arlington, Virginia and Washington, D.C.

Four potential sites were identified in Arlington, Virginia and Washington, D.C., as shown in Figure 3-17.

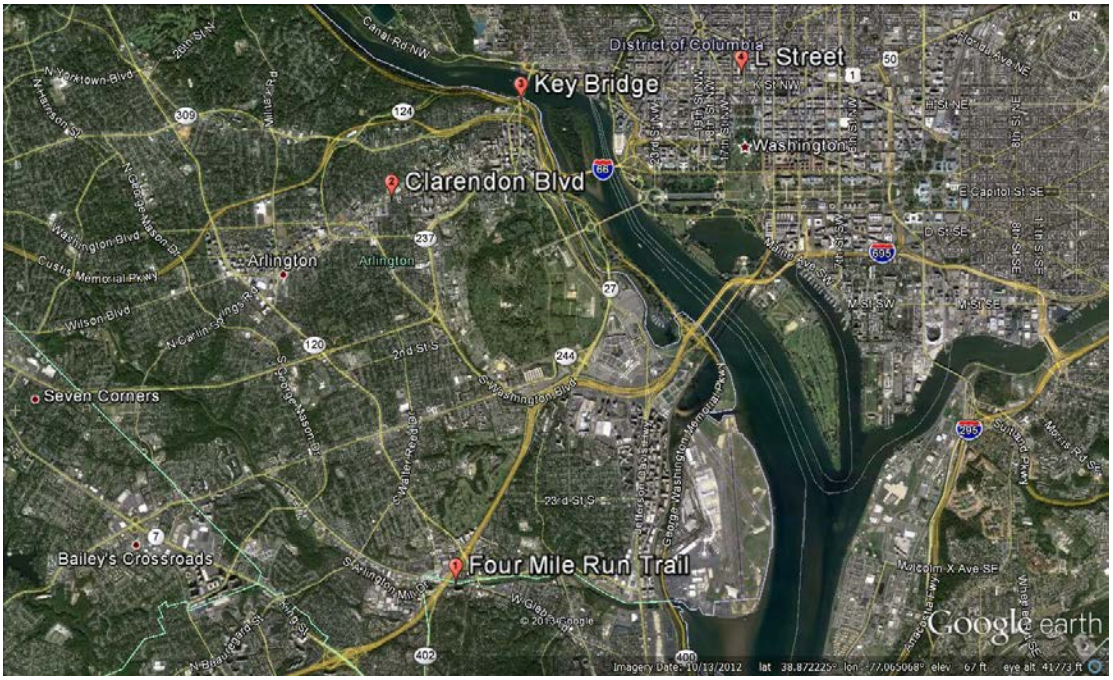

Figure 3-17. Arlington/Washington, D.C. Sites (Aerial View)

Source: ©2013 Google.

The first Arlington site was located on Four Mile Run Trail east of I-395 (Figure 3-18). Two counting devices, installed by Arlington County, already existed at this location: a piezoelectric counter and a passive infrared counter. These were supplemented with a passive infrared counter from a second vendor (moved from the Key Bridge site after the first round of testing), and a combination passive infrared/piezoelectric device from a third vendor. Unfortunately, neither the researchers nor the vendor were able to get the piezoelectric component of the combination device to communicate, and the vendor was never able to deliver the passive infrared component.

The second site was located on Clarendon Boulevard east of Danville Street (Figure 3-19). Arlington County already had an inductive loop counter installed at this location. This counter was supplemented with pneumatic tubes during one round of ground-truth videotaping. Due to low bicycle volumes at this site, a second round of testing was not performed.

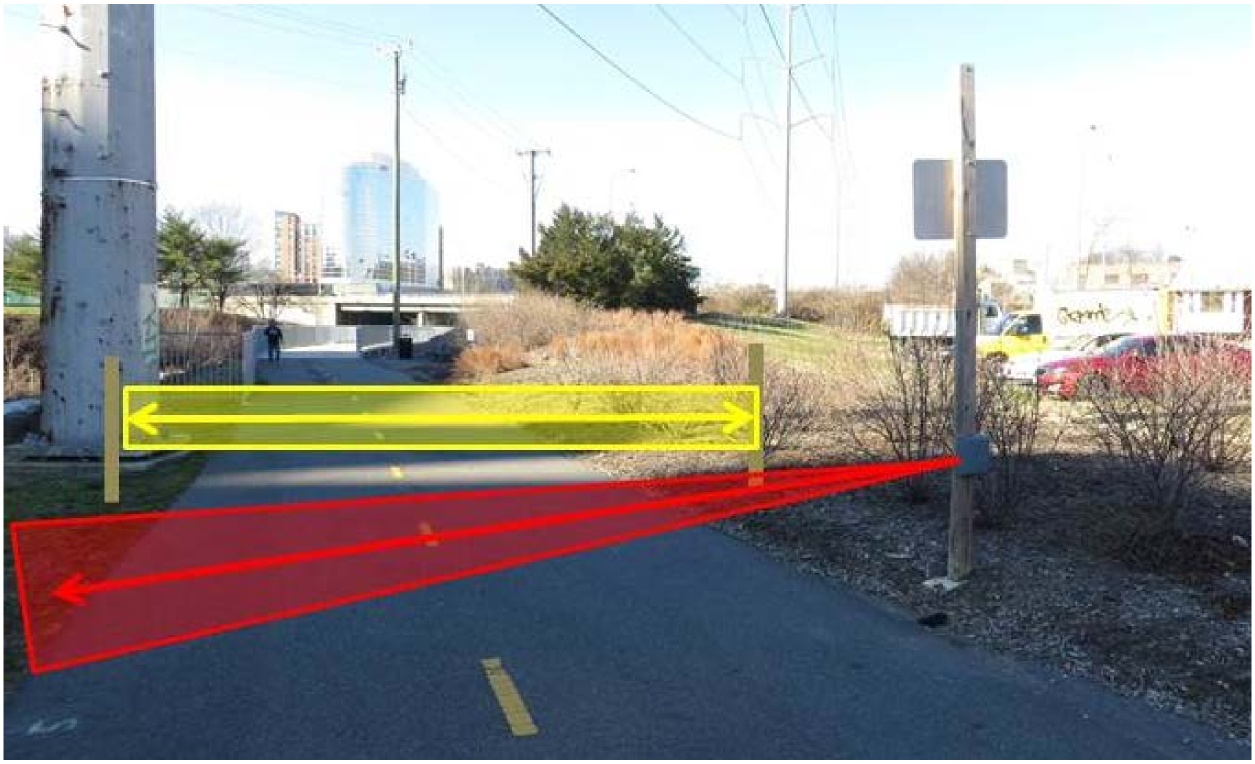

Figure 3-18. Four Mile Run Trail (Ground View)

Figure 3-19. Clarendon Boulevard (Ground View)

The third site was the Arlington end of the Key Bridge over the Potomac River (Figure 3-20). The bridge itself is owned by the District of Columbia. Arlington has partnered with the District DOT to install a combination passive infrared and inductive loop counter at this location to count pedestrians and bicyclists separately. A passive infrared device from a second vendor was installed by the research team for the first round of ground-truth videotaping and then moved to the Four Mile Run site. Pneumatic tubes were also installed here during periods when ground-truth videotaping occurred.

Figure 3-20. Key Bridge (Surface View)

The final site was located in Washington, D.C., along L Street east of 16th Street NW (Figure 3-21). A passive infrared counter was installed to cover the sidewalk, and pneumatic tubes and surface-mounted inductive loops were installed in the bicycle lane during periods when ground-truth videotaping occurred.

Figure 3-21. L Street (Ground View)

Montreal, Canada

The research team experienced delays in receiving the counting devices to be installed at the Minneapolis count sites. As Minneapolis had been picked to provide cold-weather testing of counting devices, the team desired to obtain data from another cold-weather site early in the testing process, and therefore began collecting data from existing automated count sites in Montreal to which a team member had access (Figure 3-22).

Three sites on bi-directional cycle tracks—Avenue du Parc, Rue Rachel, and Boulevard de Maisonneuve—had existing inductive loop detectors operated by the City of Montreal. A fourth site on Rue University, also on a bi-directional cycle track, was counted using surface-mounted inductive loops and pneumatic tubes from two different vendors. Finally, a fifth site along Rue Milton where McGill University has installed passive infrared counters on both sidewalks was counted. Pneumatic tubes from two different vendors were installed in the adjacent bicycle lane at this site.

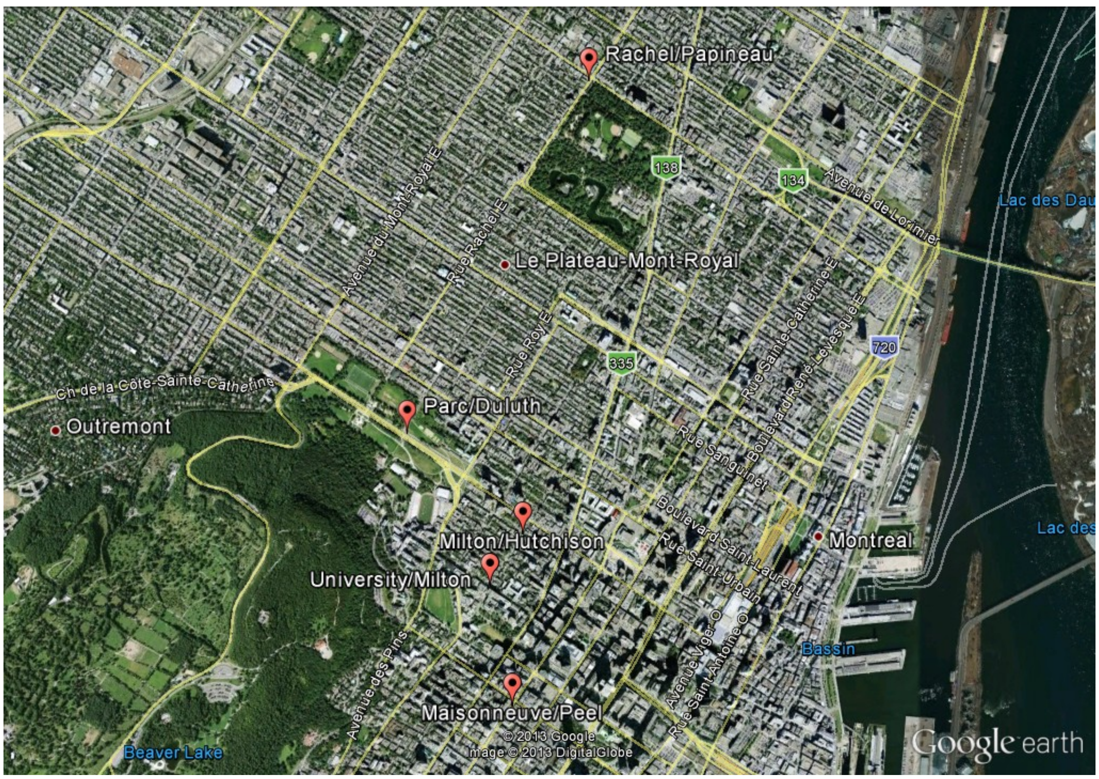

Figure 3-22. Montreal Sites (Aerial View)

Source: ©2013 Google.

SUMMARY OF TEST SITES AND TECHNOLOGIES

Table 3-1 summarizes the counting technologies and products tested at each site.

Table 3-1. Summary of Test Sites and Technologies

		Minneapolis		Arlington/D.C.				Portland		San Francisco		Davis		Berkeley	Montreal				
Technology Category	**Product**	**Midtown Greenway**	**15th Avenue SE**	**Four Mile Run Trail**	**S end of Key Bridge**	**Clarendon Blvd**	**L Street**	**Eastbank Esplanade**	**5th Avenue PBOT Building**	**Fell Street**	**Polk Street§**	**Loyola Path**	**Villanova Path**	**UC Berkeley**	**Rue University**	**Rue Milton**	**Avenue du Parc (N of Avenue Des Pins)**	**Rue Rachel**	**Boulevard de Maisonneuve**
Passive infrared	A		C	E			C		C	C		C		C	C	C	C	C	C
	B			C															
	C	E		C	C			C					C						
Active infrared	A	E																	
Radio beam	A	C							C										
	B	E																	
Pneumatic tubes	A		C		C	C	C			C					C	C			
	B							C							C	C			
Inductive loops	A	C				E				E					E		E	E	E
	B	C					C					C			C				
Piezoelectric sensor	A			C															
	B			E															
Passive infrared + loop	A				E								C						
Radio beam high/low freq.	A							C						C					

Notes: E = existing device, C = completed installation by research team.
Pneumatic tubes and surface-mounted inductive loops were only installed during the weeks when video ground-truth data were collected.
Inductive loop Product A is an embedded loop, while Product B is a surface loop.

EVALUATION METHOD

Evaluation Criteria

Pedestrian and bicycle counting technologies were evaluated according to several performance measures. The primary evaluation criterion was accuracy. However, ease of installation, labor requirements, security, maintenance requirements, software requirements, cost, flexibility of data, and other characteristics were also evaluated.

Accuracy

Accuracy was determined by comparing data generated by the automated counting devices with ground-truth pedestrian or bicycle volumes generated from manual counts taken from video recordings. This method of generating ground-truth counts was selected primarily because it is believed to be the most accurate, as the data reducers can play back the videotape at a suitable speed for making sure all pedestrians or bicyclists are recorded, and can rewind the tape if necessary to check that no pedestrian or bicyclist was missed. This method also had the benefit of allowing a relatively large amount of video to be collected, from which the researchers could select only the time periods with environmental conditions (e.g., rain, darkness) or non-motorized volumes of interest to be counted. Finally, the method allowed data to be collected at a different time from when it was reduced, which helped spread out the use of research team labor. The process used to generate the ground-truth counts is described in a subsequent section.

With the exception of the Montreal sites, which were added to the testing program to provide more cold-weather observations, counting technologies with the capability of being used in a permanent installation were installed for a period of approximately 6 months. Technologies intended to be used for short-duration counts—pneumatic tubes and surface-mounted inductive loops—were generally installed only during the periods when cameras were collecting ground-truth video for the ground-truth counts. (In a few cases, tubes and surface-mounted loops were left in place for longer periods of time—up to 5 months—to test their durability.)

The intent of installing equipment for 6 months was to allow sufficient time to try to capture the environmental conditions and volume levels of interest, and to evaluate the counters' short-term durability, including evaluating whether their accuracy changed over time.

Ground-truth counts were generally collected at two points in time, with the first round of data collection occurring in May and June 2013, and the second round generally occurring in September 2013. In some cases (Portland and Minneapolis), a second or third round of data collection occurred in November 2013 to capture desired rain and snow conditions. The Clarendon site was counted only once, due to low bicycle volumes. The Berkeley site was also only counted once; it was a late addition to the testing program to accommodate a device that required relatively narrow paths. The project budget permitted generating an average of 24 hours of ground-truth data for each study location.

As described in detail in Chapter 4, correction factors were developed by comparing the ground-truth counts to the counts produced by each device that was tested.

Other Characteristics Evaluated

In addition to accuracy, the following factors were evaluated:

- **Ease of installation.** Potential installation difficulties include the need for specialized equipment (e.g., ground cutters), the need for specialized knowledge, difficult-to-reach mounting points (e.g., points high above the ground), difficulties with calibration, or long installation times. The level of assistance required from vendors to install and calibrate the technologies was noted (i.e., how easy was the technology to install "out of the box"?).
- **Labor requirements.** Labor requirements include installation, maintenance, data cleaning, and data analysis.
- **Security from theft and tampering.** Security was evaluated based on both inspection of any potential shortcomings of the device, as well as recording any damage sustained while the device is in place. Some possible problems that were anticipated included theft, coverage of optical devices (lenses) with foreign objects (e.g., chewing gum, paint), disconnection of componentry (e.g., pneumatic tubes removed from logger), and opened device cases.
- **Maintenance requirements.** Maintenance requirements included regular site visits for data downloads, re-calibration of the device to maintain accuracy, optical lens cleaning, or removal of obstructions. Anything requiring a site visit after installation to continue accurate data collection was documented as a maintenance requirement. Costs associated with ongoing maintenance were considered.
- **Flexibility of data produced.** The data formats exported by the counter were evaluated, along with compatibility with the FHWA's *Traffic Monitoring Guide* format (FHWA 2013).
- **Cost.** Cost refers to the monetary cost of purchasing and installing the device, including any additional accessories or software necessary for count data collection and analysis, as well as replacing batteries and any charges associated with telemetry.
- **Durability.** Durability refers to the useable life of a device and its ability to withstand wear and tear.
- **Weather tolerance.** Technologies were evaluated based on their ability to operate and maintain accuracy under a range of climates and weather conditions (e.g., heat, cold, rain, fog).

These factors were evaluated largely from a qualitative standpoint, except for in cases where a quantitative approach was feasible (e.g., times and costs).

Contingency Plans

Contingency plans were developed in case potential problems arose during the testing effort. The following problems occurred, and were addressed as follows:

- **Vendor stops providing support.** One vendor was unable to provide the equipment we ordered, except for one device that could not output data after it was installed. These devices were removed from the test. Due to a lack of alternative vendors for the technology in question and (in any event) the long lead times needed to procure equipment, we did not attempt to find replacement devices.
- **Device is stolen.** One device was stolen after the first round of ground-truth data was collected and was not replaced.
- **Problems with the device.** We worked with the vendor, as needed, to identify the source of the problem and make corrections. Examples included pneumatic tubes that were knocked loose and surface-mounted inductive loops that were originally installed in a sub-optimal configuration. In one case, an installed device could not communicate with the vendor-supplied software needed to download its data and was removed from the test.
- **Necessary permits or permissions could not be obtained to install particular types of counters.** This issue primarily affected technologies requiring pavement sawcuts, although device aesthetics was an issue in a couple of instances. We attempted to resolve these problems in the following order: (1) find an alternative site nearby where the device(s) could be installed, (2) move the equipment in question to a test site in a different city, or (3) not use the site at all.
- **Data collection sites did not provide as broad a spectrum of conditions (e.g., weather, volume) as desired.** In these cases, we proceeded as originally planned. Although developing correction factors for a large variety of conditions would have been ideal, the project schedule and budget did not allow for selecting new sites and installing additional devices, and the data produced by this project still represents an improvement on the existing literature.

VIDEO DATA REDUCTION PROCESS TO GENERATE GROUND TRUTH COUNTS

All of the manual counts for NCHRP 07-19 were conducted based on video footage collected at the test sites. Videos were typically recorded for two five-day periods at each of the sites in the study, aiming to test the technologies under a diverse set of environmental conditions. For example, a set of test sites were selected in Davis, CA because it has hot weather and high bicycle volumes; a set of test sites were selected in Minneapolis because it has cold temperatures, etc. All dates of video collection are listed in Table 3-2.

Table 3-2. Dates of Video Collection for All Sites Used in NCHRP 07-19

City	Site	Video Data Collection Dates	Automated Counter Installation Dates
Berkeley	UC Berkeley	September 27–29, 2013 October 7–9	September 27, 2013 – January 16, 2014
Davis	Loyola & Pole Line	August 20–21* October 8–11	July 31 – January 25
	Sycamore Park	June 17–22 October 8–11	June 14 – ongoing (not removed at city request)
Minneapolis	Fifteenth Ave.	May 15–21* November 20–24	May 15 – December 24
	Midtown Greenway	June 26–30 November 20–24	June 18 – December 27 (Inductive loops left installed)
Montreal	Maissoneuve	March 27 April 23	Inductive loops permanently installed before study
	Milton	July 20 2012 (2 hours) July 23rd 2012 (1 hour)	Temporary installations during video collection
	DuParc	March 26th (5 hours) May 3rd (4 hours)	Inductive loops permanently installed before study
	Rachel	March 21st (5 hours)	Inductive loops permanently installed before study
	University	July 26, 2012 (1 hour) July 28, 2012 (2 hours) July 31, 2012 (5 hours) July 3–5 and July 8–12	Pneumatic tubes temporarily installed during video collection; inductive loops permanently installed before study
Portland	5th Avenue Transit Mall	July 16–22 September 10–14 November 15–20	July 15 – mid January
	Eastbank Esplanade	July 3–10 August 20–23 September 11–14 November 15–19	July 3 – mid January
San Francisco	Fell Street	May 6–10, 2013 August 27–29 September 3–5	May 2 – September 5, 2013 (inductive loops permanently installed before study)
Washington D.C./Arlington	Clarendon	May 25–29	May 24 – 30 (inductive loops permanently installed before study)
	Four Mile Run	June 1–5 September 24–29	May 31 – mid-December (piezoelectric strips permanently installed before study)
	Key Bridge	May 25–29 September 24–29	May 24th – mid-December (combination counter permanently installed before study)
	L Street	May 31–June 2 June 6–10 September 24–29	June 3 – mid-December

Notes: *Denotes time period with equipment difficulties.
All dates are in 2013 unless specifically noted otherwise.

Videos were shipped from the test sites on DVDs and flash drives, depending on the firm in charge of collecting video (which varied by city).

Two video reduction processes were tested. The initial system involved a piece of software that was developed internally at UC Berkeley by another research center. This set up had a video playback pane with digital buttons for up to 10 "events." When a button was pressed, a timestamp value was recorded. When a segment of video was completed, an output text file was generated with all of the timestamp values. This software would be ideal for testing equipment that outputs data in timestamp format, as every undercount or overcount could be explicitly identified. However, most of the devices in the study export data in an aggregate form (e.g., 15-minute bins, 1-hour bins), so this level of detail was unnecessary. In addition, a number of factors led the research team to develop a different video reduction protocol. In particular,

- The software was buggy, leading to occasional choppy video playback.
- Excessive pre- and post-processing were required. Videos had to be converted to a consistent format in order to use the software. Also, the timestamp counts had to be calculated.
- Clicking buttons with the mouse for every count was not very efficient and seemed more likely to lead to repetitive stress injuries than using keypad input.
- Video playback was more likely to become choppy if the playback speed was varied.

To deal with these issues, a revised approach was developed using freely available software. Video was played back using the VLC media player, which accommodates a variety of video formats. Keybinding is very easy for functions such as pause/play, speed up/slow down, and skip ahead/back at various increments. To conduct the counts, KeyCounter was run in the background. With KeyCounter, the user designates specific keys for the software to count. The numeric keys were selected to be consistent with our definitions of "Event 1," "Event 2," etc., and each keystroke represented one event. Student data collectors watched the video for the specified period of time (typically 15 minutes), and pressed the defined keys whenever a count should be recorded. Other keys could theoretically be used if this approach were used for a different data collection process. For example, turning movement counts could be performed with the same approach. One crucial component of this data collection approach is having the timestamp visible in the video so the analyst can stop playback exactly at the end of the data collection interval. Timestamps should preferably be at the second resolution (as opposed to minutes), so that the end of the period can be anticipated.

At each site, data collectors recorded each pedestrian or bicyclist who should have been detected by each technology. This was done by defining movements of each user through a specific detection zone area as a discrete "event." In many cases, "events" represented individuals passing through overlapping detection zones from more than one technology. For example, see the event definition diagram for the Midtown Greenway second data collection round (Figure 3-23). This site had 7 different counting devices and five counting events defined. To calculate the ground-truth volumes for each, the following equations were used:

- Inductive Loops (Purple) = [Event3]
- Inductive Loops (Green) = [Event4]
- Pneumatic Tubes (Red) = [Event2]
- Pneumatic Tubes (Blue) = [Event5]
- Active Infrared = [Event1] + [Event2]
- Radio beam = [Event1] + [Event2]
- Passive Infrared = [Event1] + [Event2]

This is the most complicated site in the study. In some cases (e.g., Key Bridge), only two events (number of pedestrians and number of bicyclists) were necessary to calculate ground-truth volumes for multiple devices.

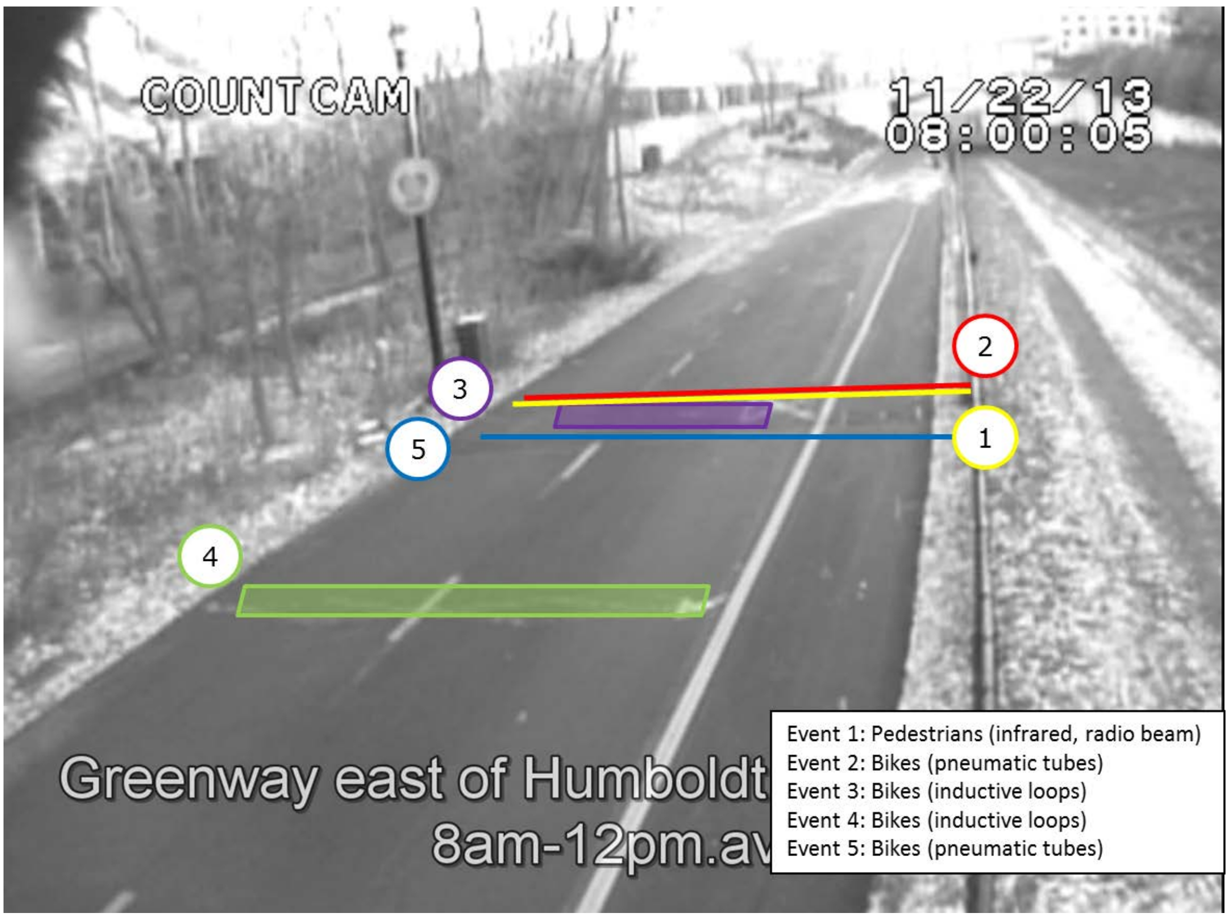

Figure 3-23. Example Counting Process Diagram from Midtown Greenway

Video reduction using this approach was found to be highly efficient. At most low-volume sites, the playback speed could be up to three times faster than normal speed (3x) while maintaining the ability to observe all pedestrians and bicyclists. If a large group passed, the video could easily be paused to identify each individual (using the spacebar by default). Video could also be skipped backward very easily (Shift + Left Arrow to move the video ~4 seconds back) if an individual's path through the frame was not easily seen on the playback screen. This was particularly important for devices with constrained detection areas, such as inductive loops. By comparison, counting pedestrians and bicyclists who passed screenline counters (e.g., passive infrared, radio beam) was a relatively simple task.

One important consideration in video reduction was camera placement. Cameras were typically placed approximately 10 to 20 feet from the automated counter detection zones at each study site. However, during the first round of data collection at one site (Midtown Greenway) the camera was located ~75 feet from the testing site. This was not a significant problem for the screenline devices at this site, but it proved problematic for the two inductive loop arrays because the detection zone was not clearly defined for the camera. As a result, data collectors' counts showed large overcounts for these two devices, which is inconsistent with findings from all other sites. These data points were deemed unreliable and removed from the analysis. Other data points that have been removed are described in the section "Data Cleaning" and are summarized in Table 3-5.

INTER-RATER RELIABILITY

In an attempt to determine whether manual data collectors were recording counts consistently, thirty 1-minute periods were selected from two sites and data collectors were given instructions to count a specified set of "events" for each of the video clips. Some of these events were contrived (i.e., no automated counter was actually present), and some clips were deliberately chosen to be difficult.

The fact that these reliability counts were performed on 1-minute clips of video makes it likely that high percentage differences might exist between data collectors even for minor errors (as the total counts in a given period are low). Additionally, some of these disagreements might balance out over a longer time period. However, having the data collectors each observe many 15-minute video clips would take more budget than was available, so this approach represented a reasonable compromise.

Table 3-3 shows the Concordance Correlation Coefficient (CCC) calculated for each pair of data collectors in the study (Lin et al., 2002). The CCC is a measure of agreement between two variables, which takes into account both accuracy and consistency, unlike Pearson's *r* which only considers consistency. A CCC value of 1 indicates perfect agreement, and a value of 0 indicates no agreement. All of the pairs of data collectors had CCC values greater than 0.8 for the inter-rater reliability testing, and only one data collector had values below 0.9 when compared with the other data collectors. Accordingly, the research team is confident in the reliability of the data collectors' abilities to accurately determine ground-truth volumes when reviewing video footage.

Table 3-3. Results of Inter-Rater Reliability Evaluation (Concordance Correlation Coefficients)

		Data Collector						
		1	2	3	4	5	6	7
Data Collector	1	1.000	0.991	0.963	0.993	0.802	0.979	0.994
	2	---	1.000	0.950	0.993	0.809	0.981	0.995
	3	---	---	1.000	0.958	0.809	0.951	0.960
	4	---	---	---	1.000	0.917	0.984	0.995
	5	---	---	---	---	1.000	0.912	0.919
	6	---	---	---	---	---	1.000	0.986
	7	---	---	---	---	---	---	1.000

DATA STORAGE

All data were stored in a series of spreadsheets joined together in an Access database. To select video periods for reduction, a query was run for each site pulling data from one or two automated counters (e.g., a count of pedestrians and a count of bicycles) for each time period for which video was available. The resulting tables thus had weather data and an estimate of the volumes during the interval so that particular conditions could be pursued (e.g., hot weather, high volumes).

After manual counts were conducted, a query was run for every site wherein a table was generated containing the environmental conditions, and automated counts, manual counts (calculated from the coded "events" as described above under "Data reduction process"), counting device description, and "Counter Issue" status for each device at the site. The "Counter Issue" field was used to tag any time periods known to have problematic data so that they could be excluded from analysis without being permanently removed from the dataset. A separate set of queries was then run first generating (from one site) and appending to (from the remaining sites) a table for each technology type. These tables (e.g., 'pyro', 'loops') were structured with each row representing a particular device-count period.

WEATHER DATA SOURCES

For all U.S. sites, weather data were downloaded from the National Climatic Data Center's Quality Controlled Local Climatological Data (QCLCD). The QCLCD was selected on the basis of a high level of temporal resolution. Data is recorded at each site in hourly increments. However, this comes at the cost of a lack of spatial resolution. In some cases weather data sites were up to 10 miles away from the count site. The effect of this is likely the strongest for the San Francisco site, where the weather data was collected at San Francisco International Airport (SFO) and the count data was collected near the center of the city. SFO is on the bay side of the peninsula, separated from San Francisco by a range of hills. Anecdotally, the count data site tends to be foggier than the area around the airport, but detailed data were not available to quantify this effect. The weather data collection stations used in NCHRP 07-19 are summarized in Table 3-4.

Table 3-4. Weather Stations Used as Sources of Weather Data for Equipment Testing

City	Weather Station	Weather Station ID
Washington D.C./Arlington, VA	Ronald Reagan International Airport	13743/DCA
San Francisco, CA	San Francisco International Airport	23234/SFO
Berkeley, CA	Oakland International Airport	23230/OAK
Davis, CA	Nut Tree Airport (Vacaville, CA)	93241/VCB
Portland, OR	Portland International Airport	24229/PDX
Minneapolis, MN	Minneapolis-St. Paul International Airport	14922/MSP
Montreal, QC, Canada*	Montreal International Airport	

Note: *Montreal weather data comes from the Government of Canada's National Climate Archives. (http://www.climate.weatheroffice.gc.ca/climateData/hourlydata_e.html?timeframe=1&Prov=QUE&StationID=51157&hlyRange=2013-02-13|2013-02-17&Month=2&Day=13&Year=2013&cmdB1=Go)

Temperatures were taken from the QCLCD dataset, using the average of temperatures observed during the hour of data collection. Precipitation was also taken from the QCLCD dataset. The database includes a field for "Weather Type" which is populated with coded values corresponding to specific weather events. For example, "-RA" is light rain, "RA" is moderate rain, and "+RA" is heavy rain. This field was used to determine whether it was raining, snowing, and whether there was a thunderstorm. In addition, a separate "Heavy" classification was used for heavy rain. The study time periods included few snow events, so rain was the only type of precipitation evaluated. Further, instances of heavy rain were few and far between (and pedestrian and bicycle volumes were predictably low in these periods), yielding insufficient data for a thorough evaluation.

The QCLCD dataset has a field for "Sky Condition" which gives a rated level of cloud cover (based on percentage cover, classified into 8 classes) at various altitudes. "Overcast" was calculated as a binary variable of whether the sky was completely overcast at any altitude.

Nighttime status (dark lighting condition) was determined for every 15-minute period based on the sunrise/sunset times provided by http://aa.usno.navy.mil/data/docs/RS_OneYear.php.

DATA CLEANING

The automated counters did not export data in a consistent format. Some devices exported counts in 15-minute bins, some exported counts in 1-hour bins, and some timestamped each individual count. The timestamp-stored values were converted to 15-minute bins to allow for consistent analysis. All data were then converted to 1-hour time periods for consistency of analysis. For the devices that output data in 15-minute intervals, this meant summing the automated and manual count values across the four component intervals of the hour. For the devices that output data in 1-hour format, the manual count values were summed across the four component intervals, and the automated count was taken from one of the intervals.

Some devices being tested performed in ways inconsistent with other devices of the same type installed at different sites. While attempts were made to not remove any data from the study without good reason, the sites summarized in Table 3-5 were excluded for the reasons shown. The research team felt that these periods of data collection were not representative of the overall accuracy of the technologies being tested (given their inconsistency with other devices of the same type), and hence that the observed problems were most likely a result of mis-installations that could be avoided in the future given the knowledge gained through the data reduction process.

Table 3-5. Summary of Data Removed from Analysis

Excluded Data	Reason
L Street inductive loops	Very high undiagnosed overcounts, inconsistent with performance at all other sites.
Midtown Greenway inductive loops (sensor counts only)	Difficult to tell where edges of detection zone are due to distant camera placement.
Midtown Greenway pneumatic tubes	These pneumatic tubes showed substantial undercounting when initially installed. A representative from the vendor adjusted the sensitivity setting remotely, after which the counter demonstrated a consistent pattern of overcounting. The consistent pattern of overcounting suggests that the tube could be adjusted again to achieve a more accurate count, but because the research team did not recognize that this was needed until after video had been collected, this counter was removed from the analysis to avoid an unfair representation of the device that would be avoided in practice by more careful adjustment of the device.
15th Avenue pneumatic tubes	These tubes substantially overcounted bicyclists, inconsistent with pneumatic tubes at other sites. Part of this could be attributable to poor validation video footage, as trucks and buses frequently obscured the detection zone from the camera.

SUMMARY OF DATA COLLECTED

Video data were collected twice for most of the sites in the study. Data collection periods were typically between 2 and 5 days long, and took place between March and November 2013, as described earlier in this chapter in Table 3-6. Specific hourly intervals were selected for reduction from these large batches of video. Videos were selected heuristically, with a focus on maximizing the amount of data under extreme conditions (e.g., high volumes, hot or cold temperatures, thunderstorms) and maximizing the amount of data for the technologies that were underrepresented in the study (active infrared, piezoelectric strips, and radio beam). The cleaned data are summarized in Table 3-5.

All of the variables denoted "hours" show the number of hours of automated counts with corresponding ground-truth counts under each of those conditions. The variables marked with (mean/SD) show the mean value and standard deviation of the variable in question across all hours of video used for analysis for a given technology.

Table 3-6. Summary of Data Collected During NCHRP 07-19

Condition	Passive Infrared	Active Infrared	Pneumatic Tubes	Inductive Loops	Inductive Loops (Facility)	Piezo-electric Strips	Radio Beam
Total hours of data	298	30	160	108	165	58	95
Temperature (°F) (mean/SD)	70 / 15	64 / 26	71 / 9	73 / 12	71 / 17	72 / 10	74 / 10
Hourly user volume (mean/SD)	240 / 190	328 / 249	218 / 203	128 / 88	200 / 176	128 / 52	129 / 130
Nighttime hours	30	3	10	13	19	15.75	3.5
Rain hours	17	0	4	7	7	0	6
Cold hours (<30 °F)	12	5	0	0	7	0	0
Hot hours (>90 °F)	11	0	0	5	5	3	4
Thunder hours	8	0	0	2	2	0	0

Note: SD = standard deviation.

Chapter 4: Findings and Applications

A major component of NCHRP 07-19 involved field testing a variety of commercially available pedestrian and bicycle counting technologies by comparing the counts produced by the technologies with manual counts on video footage. The manual counts were assumed to represent correct, or "ground truth," counts. Counting technologies were then evaluated for accuracy (average error rate across all time periods) and consistency (degree to which similar accuracy rates are repeated for different time periods) based on these manual count values. The term *precision* is also used to describe counting consistency.

All of the manual counts for NCHRP 07-19 were conducted based on videos taken at each test site. Videos were typically recorded for two five-day periods at each of the sites in the study, aiming to test the technologies under a diverse set of environmental conditions. For example, a set of test sites were selected in Davis, CA because it has hot weather and high bicycle volumes, and a set of test sites were selected in Minneapolis because it has cold temperatures. Videos were shipped from the test sites on DVDs and flash drives, depending on the firm in charge of collecting video (which varied by city).

DATA ANALYSIS

Data analysis involved three phases: graphical (exploratory) analysis, accuracy calculations, and correction functions.

Graphical Analysis

The first phase of the data analysis process involved plotting manual (ground-truth) versus automated counts for each technology. For example, the initial plots depict the manual count values on the x-axis versus the automated count values on the y-axis (at 1-hour resolution, which has been used for all of the analysis). The graphical analysis also shows patterns in the data in terms of accuracy and consistency. These plots all include a dashed diagonal line which can be interpreted as the "perfect accuracy" line.[5]

- The pneumatic tubes on the Midtown Greenway in Minneapolis had their sensitivity adjusted after the first two days of data collection. These tubes were initially intended for a mixed traffic situation, which requires different sensitivity settings than greenway sites. Accordingly, the first two days of data have been removed for analysis. Figure 4-1 depicts this effect.

[5] Note that when a data point falls on this line, undercounting and overcounting could be occurring that cancel each other out (e.g., 4 missed detections and 4 false positives), resulting in a count that matches the ground-truth count.

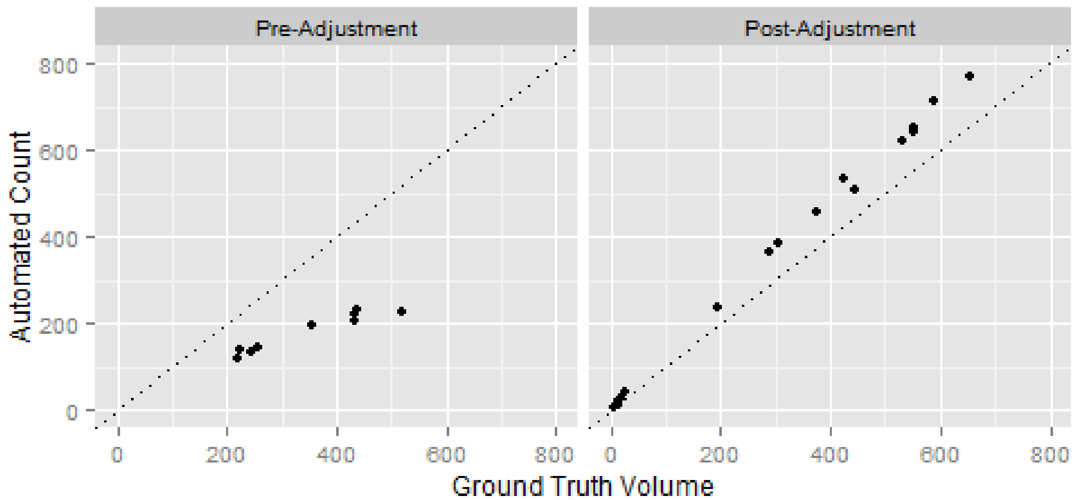

Figure 4-1. Before and After Comparison of Pneumatic Tube Accuracy with Sensitivity Adjustment

Accuracy Calculations

Four accuracy and consistency measures were calculated for each technology under a range of conditions: average percentage deviation (APD), average of the absolute percentage deviation (AAPD), weighted average percentage deviation (WAPD), and Pearson's correlation coefficient (*r*). These measures are described below. All analyses were carried out using the R statistical software package.

Average Percentage Deviation (APD)

Average Percentage Deviation (APD) represents the overall divergence from perfect accuracy across all data collected. This is calculated as

$$APD = \frac{1}{n}\sum_{t=1}^{n} \frac{A_t - M_t}{M_t}$$

where A_t is the automated count for time period t, M_t is the manual (ground-truth) count in period t, and n is the total number of periods analyzed.

This metric has the advantage of providing insight into how much to adjust counts from a given technology (as discussed in greater detail below), but does not provide as much detail on overall accuracy. In particular, overcounts and undercounts in different time periods can cancel each other out.

Average of the Absolute Percentage Deviation (AAPD)

AAPD helps to remedy the undercount/overcount cancelation problem with the APD.

$$AAPD = \frac{1}{n}\sum_{t=1}^{n} \left|\frac{A_t - M_t}{M_t}\right|$$

By taking the absolute values, over and under-counts of the same magnitude no longer balance each other out, but rather both count towards the total accuracy. However, this measure has the difficulty that percentage errors at low volumes can bias the results, as for example an overcount of 1 on a ground-truth volume of 1 is calculated as a 100% overcount, whereas an overcount of 1 on a ground-truth volume of 100 is calculated as a 1% overcount.

Weighted Average Percentage Deviation (WAPD)

To account for the low volume bias of the AAPD measure, a volume-weighted accuracy measure is also calculated, as:

$$WAPD = \sum_{t=1}^{n} \left(\left| \frac{A_t - M_t}{M_t} \right| \times \frac{M_t}{\sum_{j=1}^{n} M_j} \right)$$

Pearson's Correlation Coefficient (r)

Pearson's *r* tells how correlated two variables are with each other, where *r* = +1 is total positive correlation, *r* = -1 is total negative correlation, and *r* = 0 is no correlation. With automated counters, the value of *r* will ideally be +1 between the ground-truth volume and the automated count. That is, one perfectly predicts the other, although the two counts don't necessarily have to be equal. A correlation coefficient close to *r* = +1 suggests that one can fairly precisely estimate the volume by multiplying the automated count by a multiplicative adjustment factor. Pearson's coefficient is calculated as:

$$r = \frac{\sum_{t=1}^{n} (M_t - \bar{M})(A_t - \bar{A})}{\sqrt{\sum_{t=1}^{n} (M_t - \bar{M})^2} \sqrt{\sum_{t=1}^{n} (A_t - \bar{A})^2}}$$

Correction Functions

A number of accuracy correction functions were estimated for each technology and, for those technologies where multiple devices were tested, for each separate product. All of the correction functions were estimated using Ordinary Least Squares Regression, and are of the form

$$Manual = f(Automated, Environmental\ Factors)$$

In all cases, the environmental factors are only included as interaction terms with the automated count. For instance, equations such as the following were considered:

$$Manual = \beta 1 \times Automated + \beta 2 \times Automated^2 + \beta 3 \times Automated \times (Temperature > 90°F)$$

By considering factors in this way, the regression coefficients can be considered as adjustments to the correction factor being generated. In general, intercepts were generally not included to avoid equations that would predict non-zero ground truth volumes given an automated count of zero.

For each dataset, models were compared on the basis of the Akaike Information Criterion (AIC). The AIC is a measure of model fit which penalizes models based on the number of estimated parameters. For a given dataset, models with lower AIC values can be interpreted as fitting the data better. However, the AIC does not provide any information on absolute goodness-of-fit (as measures such as R^2 do). R^2 is not used in this evaluation because it is not reliable for models with no intercept term, which is true of most of the models. Models were also evaluated based on the significance (compared against 0 using a t-test) of individual parameter estimates.

ANALYSIS BY TECHNOLOGY TYPE

Passive Infrared

Qualitative Experience

Passive infrared sensors made up a significant proportion of the data in the study. Based on this project's practitioner survey, these sensors appear to be the primary technology currently used in practice for collecting pedestrian volume data in single-mode environments (e.g., sidewalks) and for collecting combined bicycle and pedestrian volume data in mixed mode environments. As documented in the literature review, there have been multiple studies to date evaluating the accuracy of passive infrared sensors.

Installation of passive infrared products varied by product, but was generally very easy. Temporary installations involved either bracketing a box with the sensor inside to an existing street sign pole, or screwing a small sensor into a wooden surface (which alternatively could be mounted inside an anti-theft box, considering that one of these devices was stolen during the study). Permanent installations typically involve sinking a wooden post into the ground alongside the facility being counted.

Care must be taken with installing the passive infrared sensors to not point them toward a background that is likely to trigger false detections. Examples of problematic backgrounds include heavy foliage, windows, or background traffic. One sensor during this study experienced significant overcounts due to the lens being directed at a planter box with a glazed window in the background. The problem became especially pronounced at high temperatures, which is attributed to the leaves on the plants heating up to temperatures approaching that of a human body. One member of the team has experienced similar overcounting events with this class of sensors due to light rail vehicles passing through the background.

Another difficulty with passive infrared sensors is undercounting due to occlusion. These counters were observed to perform worse at higher volumes, especially Product B.

Accuracy and Consistency

The findings on passive infrared sensors corroborate the findings of previous studies. The passive infrared sensors demonstrated an average undercount rate (APD) of 8.75% and an AAPD of 20.11%. A more accurate count rate was observed with one product compared to the other, as demonstrated in Table 4-1 and in Figure 4-2. Both products appear to follow a roughly linear profile, but one seems to have a lower slope, suggesting that counts for this product propagate with volumes at a higher rate than the other product.

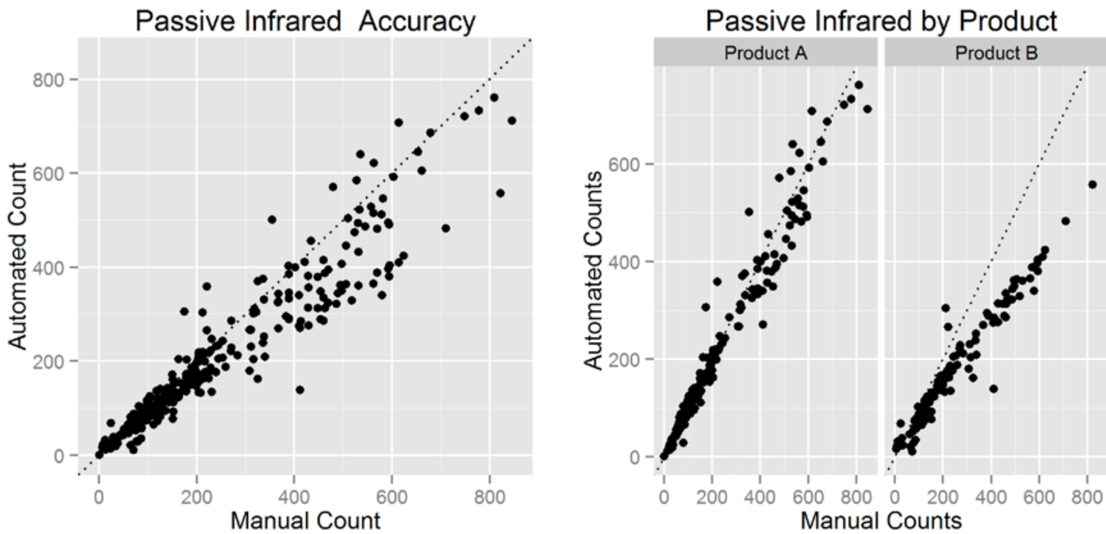

Figure 4-2. Accuracy Plots of Passive Infrared Sensors

The fact that the two products had different error rates indicates that a vendor's implementation of this technology plays an important role in the counter's accuracy. Furthermore, as can be inferred from Figure 4-2, both products produced consistent counts over a variety of volumes, which means that reasonably accurate volume estimates could be obtained from either product by simply applying a correction factor. However, the correction factor needed to adjust one product's counts is substantially different than the factor needed to adjust the other product's counts, which suggests the need for users to develop their own correction factors.

Device-Specific Accuracy and Consistency

Evaluating accuracy and consistency in aggregate is useful for providing factors for practitioners who do not have sufficient resources to develop their own, but it is worth calculating separate factors for each device that was tested. Table 4-1 demonstrates this for passive infrared sensors.

Table 4-1. Accuracy and Consistency Metrics on a Site- and Device-Specific Basis for Passive Infrared Sensors

Site	Product	APD	AAPD	WAPD	*r*	N	Average Hourly Volume
Overall Average	-	-8.75%	20.11%	18.68%	0.9502	298	240
Overall Product A	A	-3.12%	11.15%	10.66%	0.9804	176	236
L St	A	1.83%	11.01%	10.08%	0.8653	21	583
Four Mile Run	A	1.34%	8.85%	10.08%	0.8838	44	173
Fell Street	A	-4.68%	9.44%	8.97%	0.9677	27	43
15th Avenue	A	-4.80%	5.23%	4.57%	0.9956	18	345
Key Bridge	A	-12.38%	12.91%	13.62%	0.9882	31	351
Berkeley	A	-14.32%	14.32%	14.51%	0.9595	6	151
Sycamore	A	15.08%	16.01%	16.26%	0.9555	17	98
Loyola	A	-18.46%	19.47%	19.17%	0.8625	12	64
Overall Product B	B	-16.86%	33.05%	29.75%	0.9711	122	246
Midtown Greenway	B	5.61%	46.06%	31.90%	0.9809	30	328
Four Mile Run	B	-17.43%	27.07%	26.08%	0.7775	44	173
Key Bridge	B	-28.60%	28.60%	30.14%	0.9817	31	351
Sycamore	B	-33.66%	33.66%	31.31%	0.8642	17	98

Notes: APD = average percentage deviation, AAPD = average of the absolute percent difference, WAPD = weighted average percentage deviation, *r* = Pearson's Correlation Coefficient, N = number of detectors, Average volume = hourly average pedestrian and bicycle counts based on video observation.

Correction Functions

The various correction function forms that were tested for passive infrared counters are presented in Table 4-2. These functions are presented here both for the data as a whole, and for each product separately, as the two seem to have quite divergent accuracy profiles.

For all of the passive infrared data combined and for each of the products analyzed separately, the lowest AIC values occur for models including the automated count, the square of the automated count (divided by 10^4 to bring the parameter value closer to 1), and the facility width. The quadratic term has a negative coefficient, indicating an upward increasing trend in the correction function equation. However, the effect is very slight: note that the squared term has been divided by 10^4. Worse performance is seen with wider facilities when considering all of the data pooled, but better performance is seen with wider facilities when considering each product independently. These factors are modest: approximately 1.5 missed detections per 100 true events for each additional foot of facility width. Note also that all facilities were considered pooled, including sidewalks and multi-use paths, and with no distinction for solid backgrounds. Temperature, darkness, and rain were tested as binary factors in the correction function, but none appeared to be significant.

Table 4-2. Regression Correction Functions Tested for Passive Infrared Sensors

Dataset	Intercept	Automated Count	Automated ^2 / 10^4	Auto-mated × Hot (>90 °F)	Auto-mated × Cold (<30 °F)	Auto-mated × Night	Auto-mated × Rain (≥0.01 in/h)	Auto-mated × Facility Width (ft)	AIC
All Data	---	1.137 (0.000)	---	---	---	---	---	---	3288
	13.9 (0.012)	1.096 (0.000)	---	---	---	---	---	---	3284
	---	1.313 (0.000)	-3.995 (0.000)	---	---	---	---	---	3258
	---	1.136 (0.000)	---	0.054 (0.809)	---	---	---	---	3290
	---	1.156 (0.000)	-3.674 (0.000)	-0.117 (0.568)	-0.007 (0.891)	-0.112 (0.208)	-0.0578 (0.478)	0.014 (0.000)	3243
	---	1.125 (0.000)	-3.358 (0.000)	---	---	---	---	0.015 (0.000)	3237
Product A	---	1.037 (0.000)	---	---	---	---	---	---	1792
	2.602 (0.573)	1.030 (0.000)	---	---	---	---	---	---	1794
	---	1.074 (0.000)	-0.765 (0.175)	---	---	---	---	---	1792
	---	1.037 (0.000)	---	-0.007 (0.965)	---	---	---	---	1794
	---	1.036 (0.000)	---	-0.007 (0.968)	0.007 (0.845)	---	---	---	1796
	---	1.357 (0.000)	-1.319 (0.020)	0.055 (0.726)	-0.086 (0.030)	-0.065 (0.315)	-0.089 (0.163)	-0.026 (0.000)	1776
	---	1.262 (0.000)	-0.979 (0.070)	---	---	---	---	-0.019 (0.000)	1776
Product B	---	1.412 (0.000)	---	---	---	---	---	---	1270
	-14.29 (0.044)	1.468 (0.000)	---	---	---	---	---	---	1268
	---	1.265 (0.000)	4.721 (0.003)	---	---	---	---	---	1263
	---	1.411 (0.000)	---	0.385 (0.276)	---	---	---	---	1271
	---	1.411 (0.000)	---	0.385 (0.275)	-0.965 (0.243)	---	---	---	1271
	---	1.309 (0.000)	5.563 (0.002)	0.516 (0.135)	-0.784 (0.330)	0.014 (0.933)	-0.077 (0.528)	-0.005 (0.163)	1267
	---	1.307 (0.000)	5.459 (0.001)	---	---	---	---	-0.005 (0.186)	1263

Note: AIC = Akaike Information Criterion. Numbers in parentheses are P values; coefficients with a P value of 0.050 or less are significant at a 95% confidence level.
Hot, cold, rain, and dark are indicator variables that are 1 when the condition is met and 0 otherwise. Night is defined as the starting time for the counting period being between sunset and sunrise.

Environmental Condition Effects

For passive infrared counters, we hypothesized the following effects of weather and other environmental conditions, and came to the conclusions enumerated below:

Worse performance at higher volumes, due to a higher incidence of occlusion

This appears to be more of a problem with Product B than Product A. Product A actually has negative coefficients in the automated count, which suggests that performance is slightly better at high volumes. The magnitude of this term is small, however. Product B, on the other hand, demonstrates a stronger adverse effect of high volumes. This is a problem that has been documented for passive infrared counters in previous literature (Schneider et al. 2012, Ozbay et al. 2010), but it appears that it is a surmountable problem, given Product A's high accuracy even with high volumes.

Worse performance at temperatures approaching that of a human body, due to difficulties distinguishing people from the background

This effect was not observed, as demonstrated in Figure 4-3. In this plot, "Cold" refers to temperatures below 30 °F, "hot" refers to temperatures above 90 °F, and "mid" refers to anywhere in between. One difficulty in assessing this problem is that high temperatures have a depressing effect on non-motorized volumes, such that most of the data in the high temperature regime did not have very high volumes. It is therefore difficult to tease out any differences in accuracy. However, based on including temperatures in the correction functions, the effect does not appear to be present.

Likewise, no effect was seen of freezing temperatures on detection accuracy, even at very high volumes. This is in conflict with recent research (Andersen et al. 2014) conducted at very cold temperatures and high volumes, where many missed detections occurred, which was attributed to heavily insulating clothing. It is suspected that this effect was not observed in the current research because the temperatures witnessed were not low enough to warrant heavy-enough clothing to have an effect—temperatures did not drop much below 10 °F.

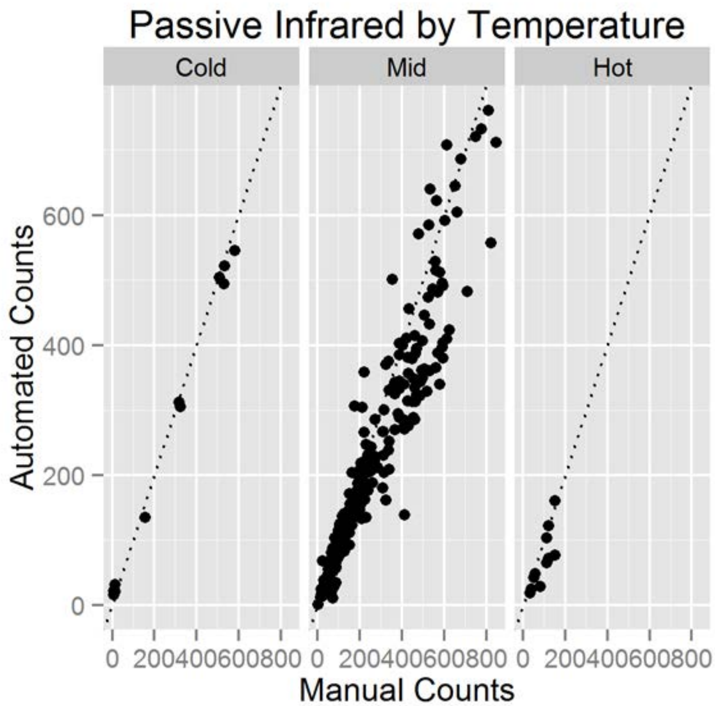

Figure 4-3. Passive Infrared Accuracy as a Function of Temperature

Despite this project's findings, conversations with another research team have suggested anecdotal evidence for a high temperature effect with passive infrared sensors.

Worse performance on wider facilities, due to a higher incidence of occlusion

Including facility width in the correction function produces a statistically significant parameter estimate, but the sign is inconsistent between the pooled data from both products and considering the two products separately. When considered separately, it appears that accuracy is actually *higher* on wider facilities. This is counter-intuitive. One possible cause is the lack of consideration of the backgrounds for each sensor (i.e., what lies beyond the facility). For example, the sensors installed at Sycamore Park in Davis were directed towards an open field, which could produce false positives, whereas the sensor installed on Fell Street in San Francisco was directed at a solid wall.

Worse performance in heavy rain and/or snow due to false positives

The data collected by NCHRP 07-19 were unfortunately sparse for heavy rain and snow, as indicated in Figure 4-4.

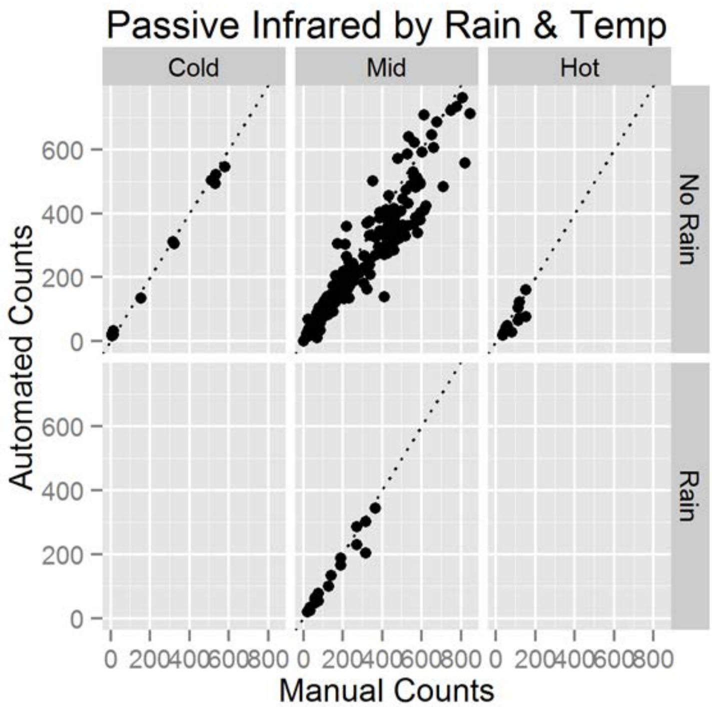

Figure 4-4. Accuracy Comparison for Passive Infrared Sensors by Rain and Temperature

However, during periods of rain, no substantial overcounts were observed. This appears to refute the proposition that rain triggers false detections on passive infrared sensors. There were insufficient snowy weather observations to determine whether snow has an effect. It seems unlikely, given that passive infrared sensors operate based on detecting body heat. The only plausible mechanism for error with snow is that if there is very heavy snow, the snowflakes could have an occluding effect on people walking by. To the research team's knowledge, this has not been documented.

Including rain in the correction function estimation did not produce statistically significant parameter estimates.

Active Infrared

Qualitative Experience

The testing only included one active infrared sensor, a loan from Dr. Greg Lindsey at the University of Minnesota. This device appeared to function fairly accurately, with very high consistency. This experience fits well with Professor Lindsey's previous experience with the technology.

The active infrared sensor is moderately easy to install (no ground cutting required), although the transmitter and receiver have to be installed separately and aligned with each other.

Accuracy and Consistency

The active infrared sensor has fairly high accuracy with very high consistency, as shown in Figure 4-5. In particular, volume estimates were found to be very precise (APD = -9.11%, AAPD = 11.61%, WAPD = 11.90%, r = 0.9991) with a gradually increasing undercount. These values are based on 30 hours of data.

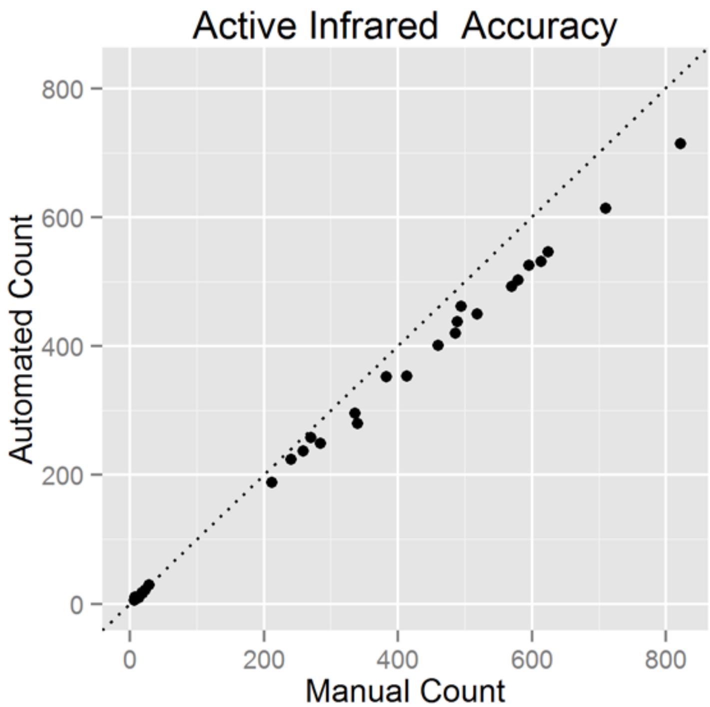

Figure 4-5. Accuracy Plot for Active Infrared Sensor

Regression Corrections

Based on visual inspection, it appears that the active infrared accuracy function is extremely linear. Including the square of the automated count in the correction function and an interaction between temperature and the automated count produces the best fit model for the active infrared sensor.

Table 4-3. Correction Functions for Active Infrared Sensor

Intercept	Automated Count	Automated ^2 / 10^4	Automated × Temperature (°F)	Automated × Night	AIC
---	1.139 (0.000)	---	---	---	232
-3.935 (0.251)	1.148 (0.000)	---	---	---	233
---	1.100 (0.000)	0.787 (0.065)	---	---	230
---	1.443 (0.000)	---	-0.004 (0.002)	---	223
---	1.426 (0.000)	0.854 (0.017)	-0.004 (0.000)	-0.249 (0.387)	220
---	1.413 (0.000)	0.868 (0.015)	-0.004 (0.001)	---	219

Note: AIC = Akaike Information Criterion. Numbers in parentheses are P values; coefficients with a P value of 0.050 or less are significant at a 95% confidence level.
Night is an indicator variable that is 1 when the starting time for the counting period is between sunset and sunrise, and 0 otherwise.

Effects of Different Conditions

Because only one active infrared sensor was tested in this study, there was not enough variation in the data to ascertain whether any site-level factors have an impact on the accuracy. Further, the inclement-weather data for this counter was quite sparse. The following factors were hypothesized to have an effect:

Occlusion effects that increase with increasing volumes

Occlusion does appear to be a factor with increased volumes, given that undercount rates increase with volume. However, these effects appear to be highly linear.

False positives in heavy precipitation

Unfortunately no time periods with rain or snow were captured on camera for the site with the active infrared sensor, so no conclusions can be drawn on this topic from this study. Conversations with Dr. Lindsey's team suggest that their active infrared sensors do face difficulties in these conditions, wherein extremely high overcounts occur. These faulty data can easily be identified by comparing the count record with weather data, which can work for estimating long-term patterns, but is a problem if data on wet-weather activity patterns are desired.

Temperature

Including an interaction between temperature and the automated count reveals slightly improved accuracy as temperature increases. However, the range of temperatures observed in developing this correction function was fairly small, so further research is needed to verify whether this effect is meaningful.

Pneumatic Tubes

Qualitative Experience

Pneumatic tubes were tested primarily on multi-use paths or bicycle lanes in this study. Bicycle-specific pneumatic tubes, thinner and smaller than vehicle counting tubes, were used. Ideally more mixed (with motor vehicles) traffic testing would have been conducted, but two mixed-traffic sites were dropped due to difficulties in procuring other equipment intended for those sites.

One site (15th Avenue in Minneapolis) proved problematic in multiple ways. First, during the initial data collection phase, the tube nails came out of the ground. After the tubes were re-installed, they did not appear to function well, as shown in Figure 4-6. These data are from two sets of pneumatic tubes, one installed in each bicycle lane. It is difficult to say what exactly is the problem with these data. 15th Avenue has fairly high bus and truck traffic, and these large vehicles occasionally occluded the camera's view of the counter for 1–2 minutes in a 15-minute count period. However, this does not seem like the sole explanation, given the severity of both under- and overcounting. These sensors have been omitted from all following analysis (and the overall data plot in Figure 4-7) as the cause of the errors is uncertain.

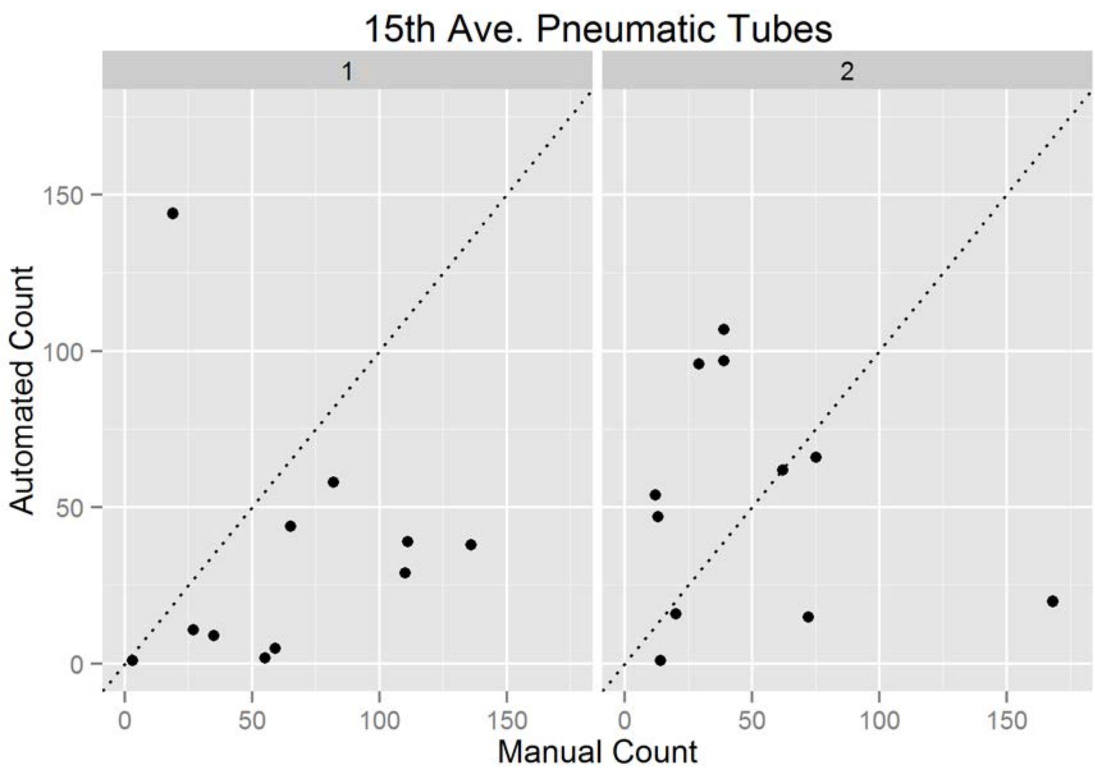

Figure 4-6. Accuracy Plot for Pneumatic Tubes at 15th Avenue Site

Accuracy and Consistency

Figure 4-7 plots accuracy results for all tubes that were tested (minus the 15th Avenue site), Figure 4-8 plots accuracy results by the two products tested, Figure 4-9 plots accuracy results by product and site, and Table 4-4 provides accuracy and consistency statistics for all tubes.

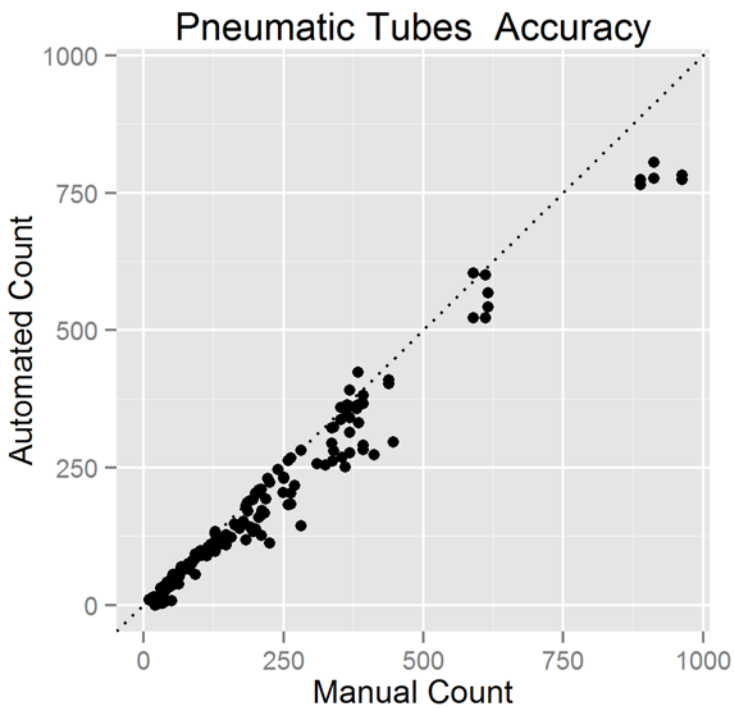

Figure 4-7. Accuracy Plot for Pneumatic Tubes

The pneumatic tube data present a number of distinct patterns, in contrast with the other tested counter technologies. This result suggests that there are strong site- and device-specific effects at work. It can be seen in Figure 4-9 that the sites with the highest diversion from the equality line are Fell Street in San Francisco, Rue Milton in Montreal, and Product B on Rue University in Montreal. Rue Milton is the only mixed (with motor vehicle) traffic facility on which pneumatic tubes were tested, and it also has the highest observed bicycle volumes. Therefore, it is difficult to determine whether the discrepancies between the automated count and the ground truth are due to the mixed-traffic conditions, the very high bicycle volumes, or a combination. On Fell Street, the pneumatic tubes were installed within the bicycle lane but not into the shared-use lane. For this site, it was sometimes difficult for data collectors to determine whether the bicyclist rode over the pneumatic tubes or not because the tubes were at the edge of the field of view, and many bicyclists' trajectories crossed close to the end of the tubes.

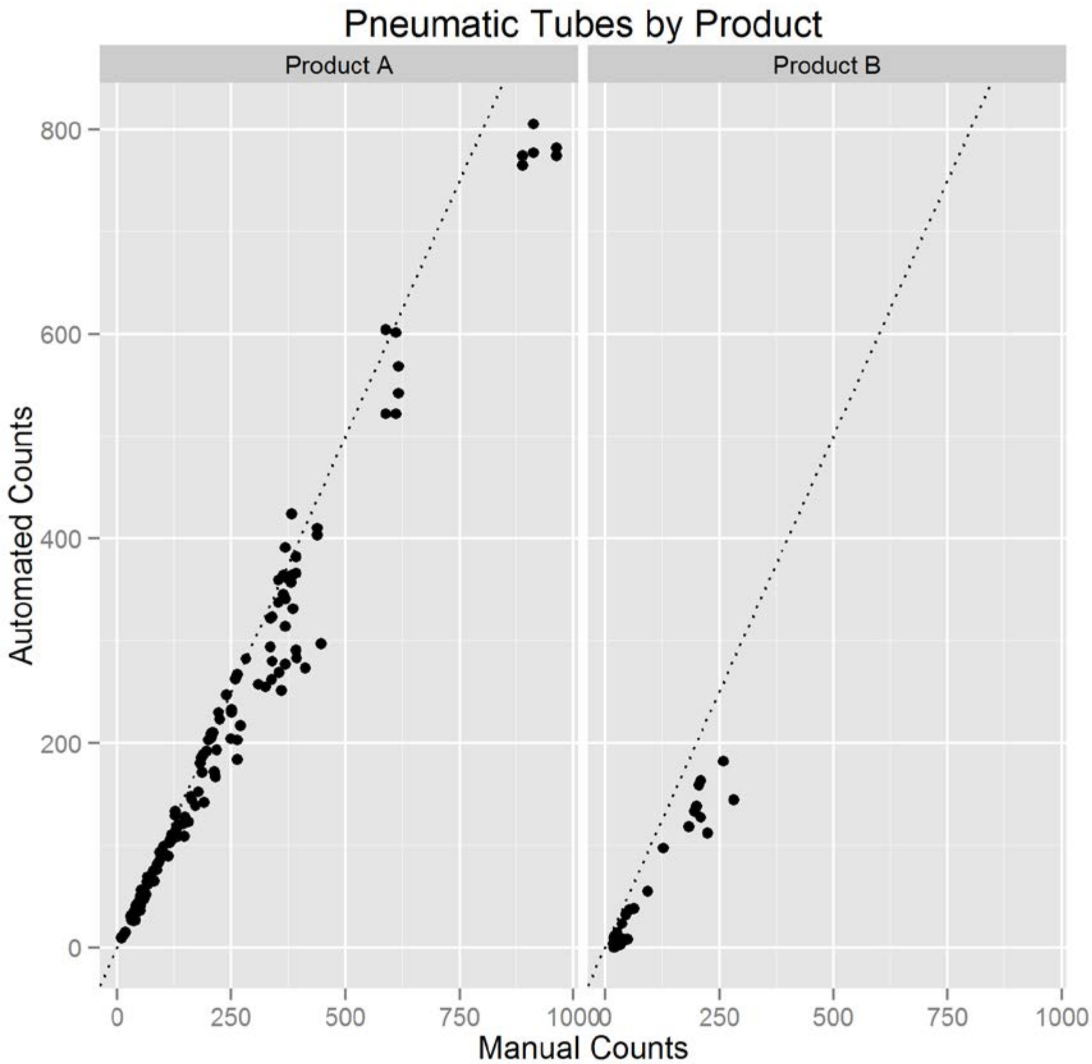

Figure 4-8. Accuracy Plot for Pneumatic Tubes by Product

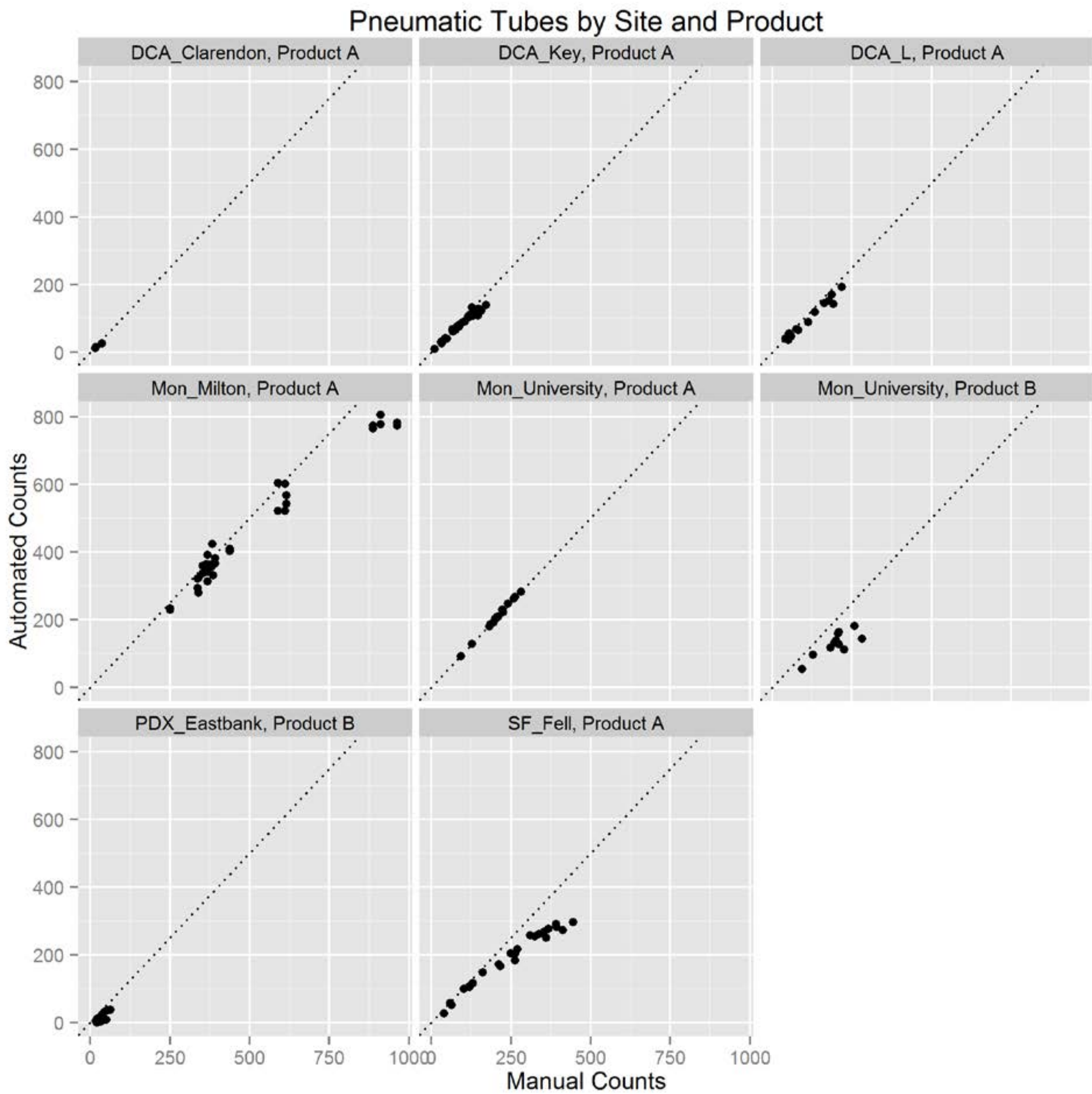

Figure 4-9. Accuracy Plot for Pneumatic Tubes by Product and Site

Table 4-4. Accuracy and Consistency Values for Pneumatic Tubes by Product and Site

Site	Product	APD	AAPD	WAPD	*r*	N	Average Volume
Overall Average	-	-17.89%	18.50%	14.15%	0.9864	160	218
Overall Product A	A	-10.54%	11.27%	11.94%	0.9884	132	244
University	A	0.52%	1.17%	1.23%	0.9979	17	206
Key Bridge	A	-10.51%	10.95%	13.04%	0.9839	31	92
L Street	A	-12.00%	12.54%	13.61%	0.9895	21	92
Fell Street	A	-20.58%	20.58%	23.40%	0.9863	24	249
Clarendon	A	-21.06%	21.06%	22.86%	0.9986	3	23
Milton	A	-7.37%	8.55%	9.80%	0.9863	36	497
Overall Product B	B	-52.55%	52.55%	39.93%	0.9704	28	99
University	B	-34.27%	34.27%	34.82%	0.8045	11	199
Eastbank	B	-64.38%	64.38%	59.38%	0.7809	17	34

Notes: APD = average percentage deviation, AAPD = average of the absolute percent difference, WAPD = weighted average percentage deviation, *r* = Pearson's Correlation Coefficient, N = number of detectors, Average volume = hourly average pedestrian and bicycle counts based on video observation.

Effects of Environmental Conditions

Frozen tubes

It is hypothesized that pneumatic tubes will become less sensitive in very cold temperatures, as the rubber in the tubes hardens. However, very little data were available in cold temperatures (below 30 °F), so these conditions were not extensively tested. It bears mentioning that in many cases, these conditions should not be experienced anyway, as pneumatic tubes are very difficult to install in cold weather (nails must be driven into frozen ground or mastic tape must be used, which sticks better when hot), and caution must be taken when snowplows are active as tubes can easily be destroyed or dislodged by plows.

Reduced accuracy due to aging tubes

The rubber components of a pneumatic tube sensor system are a consumable that must be periodically replaced as they wear out. Tubes can develop cracks, holes, and weak spots that result in miscounts. Cases of total failures are fairly obvious to detect—no counts are produced. However, it was suspected that tubes might lose some accuracy as they age. To test this, one set of tubes was left installed on the Midtown Greenway for the duration of the study (~5 months). Accuracy rates were not substantially worse for this set of tubes than for others in the study.

Reduced accuracy in mixed traffic

Pneumatic tubes installed in mixed traffic settings are suspected to have false positives. Tubes classify vehicles based on axle spacing and speed, which presents a difficult problem computationally if multiple vehicles (e.g., bicycle and automobile) cross the tubes at roughly the same time.

Two sets of pneumatic tubes were tested at a single mixed-traffic site in this study, Rue Milton in Montreal. A total of 36 hours of data were collected at this site, with APD = -7.37%, AAPD = 8.55%, and Pearson's $r = 0.9863$. These values reflect higher accuracy and consistency than pneumatic tubes in general, despite a very large range of bicycle volumes. It is worth noting that this is a relatively low motor-vehicle traffic street, so future research should explore the accuracy rates of pneumatic tubes on shared-use lanes with higher motor vehicle volumes and speeds.

Regression corrections

Table 4-5 provides the parameters associated with the various regression models that were tested. There are a number of factors that must be taken into account when interpreting the parameters presented in this table. First, "facility width" is measured edge-to-edge on multi-use paths but just as the width of the lane for bicycle lanes. As bicycle lanes are typically narrower than multi-use paths, an apparent higher accuracy is seen for wider facilities, which could simply be a result of bicyclists who are riding toward the edge of the bike lane being counted by manual counters but missing detection on the pneumatic tubes. Additionally, as noted above the "shared lane" variable only refers to a single site, which limits the generalizability of these findings. Because of these confounding factors, the simple function only including the automated count is recommended for pneumatic tubes.

Table 4-5. Correction Functions for Pneumatic Tubes

Dataset	Intercept	Automated Count	Automated ^2 / 10^4	Automated × Temperature (°F)	Automated × Facility Width (ft)	Automated × Shared Lane	AIC
All Data	----	1.135 (0.000)	---	---	---	---	1584
	8.196 (0.034)	1.111 (0.000)	---	---	---	---	1581
	---	1.121 (0.000)	0.027 (0.541)	---	---	---	1585
	---	1.500 (0.000)	---	-0.005 (0.001)	---	---	1575
	---	1.363 (0.000)	0.276 (0.000)	---	-0.030 (0.000)	---	1531
	-1.429 (0.759)	1.217 (0.000)	---	---	---	-0.101 (0.001)	1571
	---	1.152 (0.000)	0.272 (0.000)	---	---	-0.199 (0.000)	1547
	---	1.483 (0.000)	0.240 (0.000)	-0.005 (0.002)	---	-0.192 (0.000)	1539
Product A	---	1.127 (0.000)	---	---	---	---	1293
	-0.912 (0.833)	1.130 (0.000)	---	---	---	---	1295
	---	1.086 (0.000)	0.082 (0.057)	---	---	---	1291
	---	1.643 (0.000)	---	-0.008 (0.000)	---	---	1270
	---	1.319 (0.000)	0.313 (0.000)	---	-0.028 (0.000)	---	1233
	---	1.596 (0.000)	0.052 (0.196)	-0.007 (0.000)	---	---	1271
	---	1.118 (0.000)	0.290 (0.000)	---	---	-0.175 (0.000)	1258
	---	1.569 (0.000)	0.249 (0.000)	-0.006 (0.000)	-0.163 (0.000)	---	1237
Product B	---	1.520 (0.000)	---	---	---	---	262
	16.65 (0.008)	1.384 (0.000)	---	---	---	---	256
	---	1.951 (0.000)	-3.050 (0.071)	---	---	---	260
	---	0.769 (0.444)	---	0.010 (0.453)	---	---	263
	---	3.1595 (0.081)	-3.895 (0.067)	---	-0.135 (0.489)	---	262
	---	1.015 (0.293)	-3.237 (0.058)	0.012 (0.316)	---	---	262

Note: AIC= Akaike Information Criterion. Numbers in parentheses are P values; coefficients with a P value of 0.050 or less are significant at a 95% confidence level.
Shared lane is an indicator variable that is 1 when both motorized vehicles and bicycles cross the tubes and 0 otherwise.

Radio Beam

Qualitative Experience

The researchers faced significant difficulties evaluating the accuracy of the radio beam sensors. This was due to a specific implementation detail of the product being tested: namely, the counter defaulted to beginning its count immediately when initiated, rather than aggregating into bins beginning on the hour. This was a setting that could be altered, but required going into an "advanced settings" menu, which most of the installers did not realize. This meant that the automated counts collected corresponded to different time periods than the manual counts, as all other devices counted in 15-minute or 1-hour periods that began on the hour. However, this issue is not something that would be a big problem in terms of collecting volume data in general, and in fact this device had far more flexibility than the others tested (e.g., time bins of any integer number of minutes, delayed count starts).

Accordingly, counts had to be repeated for a number of radio beam counters, for example counting from 12:05–12:20, 12:21–12:35, 12:35–12:50, and 12:50–13:05. Additionally, one counter used in this study was accidentally set to count in 61-minute interviews, so manual counts for this site were redone using intervals corresponding to the same time periods.

Figure 4-10 shows the accuracy plot for radio beam counters. Two different products were tested here, one of which simply counts all people passing by (pedestrians and bicyclists combined) while the other counts pedestrians and bicyclists separately using two frequencies of radio beam. The counter distinguishing pedestrians from bicyclists (product A) had to be mounted on both sides of the facility with a maximum separation of 10 feet, so both of these devices were installed on bridges on multi-use paths. As can be seen in the plot, the volume range at these sites was fairly small (maximum of 200 pedestrians/hour and 50 bicyclists/hour), which partially limits the generalizability of these findings, but could also be an effect of the required 10-foot maximum facility widths. The other device (product B) could be mounted on one side of the facility, and hence was tested on a multi-use path and on a sidewalk.

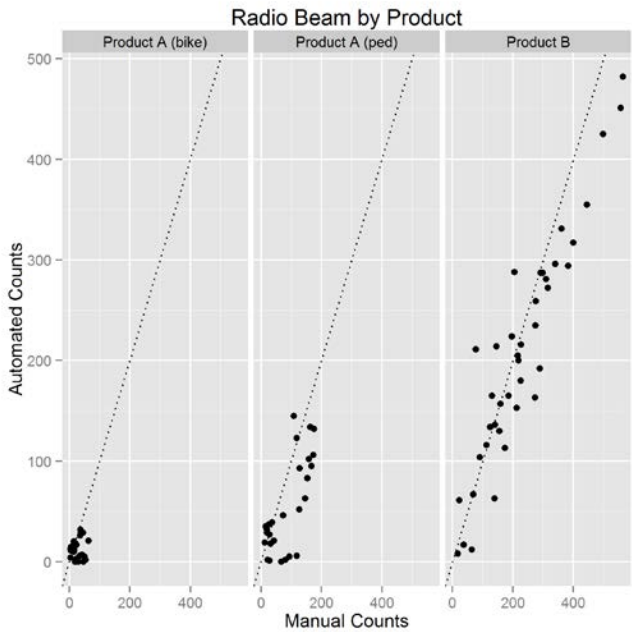

Figure 4-10. Accuracy Plots for Radio Beams by Product

Accuracy and Consistency

As can be seen in Table 4-6, Product B generally appears to function with higher accuracy and consistency than Product A. Product B is a simpler application, using a single-sided mounting. When used on a sidewalk with high hourly volumes (5th Avenue in Portland), Product B had very high consistency (Pearson's $r = 0.9779$) and reasonable accuracy (APD = -15.61%), while when installed on a multi-use path (Four-Mile Run in Arlington) the consistency was lower, which could be due to the mixed-mode nature of the facility. Product A, on the other hand, generally functioned with low consistency and low accuracy (high values of APD). The volumes for these sites were low, which result in high percentage errors occurring with small raw numbers of miscounts, but the results do not appear promising.

Table 4-6. Accuracy and Consistency Values for Radio Beam Sensor

Dataset	Product	APD	AAPD	WAPD	*r*	N	Average Hourly Volume
Overall Average	-	-18.18%	48.15%	27.41%	0.9503	95	129
Average Product A (bike)	A (bike)	-31.16%	72.55%	70.18%	0.1041	28	26
Berkeley	A (bike)	42.48%	62.88%	41.38%	0.7817	11	13
Eastbank	A (bike)	-78.81%	78.81%	77.43%	0.3763	17	34
Average Product A (ped)	A (ped)	-26.27%	52.50%	46.67%	0.7368	27	87
Berkeley	A (ped)	-26.48%	33.09%	33.50%	0.3383	11	142
Eastbank	A (ped)	-26.13%	65.84%	73.29%	-0.1118	16	48
Average Product B	B	-3.63%	28.13%	19.17%	0.9328	40	230
5th Avenue	B	-15.61%	15.61%	13.79%	0.9779	17	331
Four-Mile Run	B	5.23%	37.39%	27.59%	0.7394	23	156

Notes: APD = average percentage deviation, AAPD = average of the absolute percent difference, WAPD = weighted average percentage deviation, *r* = Pearson's Correlation Coefficient .

Effects of Environmental Conditions

The primary hypothesized source of error for radio beam sensors prior to this study was occlusion, as with all screenline sensors. Radio beams are not optical devices, so temperature, lighting, and rain were not suspected to be problems. During testing, there was insufficient variation in the weather to verify whether there was an effect of rain. As shown in Table 4-7, facility width appears to have an effect when considering the pooled data from all radio beam sensors. However, there were insufficient data in this study to evaluate those effects for the separate devices because each product was only installed at two sites. Including a squared automated count term did not generally improve fit for the model. Accordingly, the recommended correction function for radio beam sensors is the linear function with no intercept. Care should be taken when applying this factor, however, especially when using radio beam devices that distinguish pedestrians and bicyclists, as both of these counts have relatively low correlation between the manual count and the automated count (Pearson's *r* of 0.1041 for bikes and 0.7368 for pedestrians). Further research is warranted for radio beam sensors in adverse weather conditions, and for higher bicycle volumes when using radio beam counters that distinguish between modes.

Table 4-7. Correction Functions for Radio Beam Sensor

Dataset	Intercept	Automated Count	Automated ^2 / 10^4	Automated × Temperature (°F)	Automated × Hot (>90 °F)	Automated × Facility Width (ft)	AIC
Overall	---	1.130 (0.000)	---	---	---	---	987
	18.67 (0.001)	1.050 (0.000)	---	---	---	---	978
	---	1.087 (0.000)	0.142 (0.567)	---	---	---	989
	---	1.134 (0.000)	---	---	-0.094 (0.463)	---	988
	---	2.019 (0.000)	0.400 (0.137)	---	---	-0.073 (0.025)	985
	---	1.857 (0.000)	---	---	---	-0.053 (0.074)	986
	---	2.015 (0.000)	---	-0.002 (0.303)	---	-0.053 (0.073)	987
Product A (bike)	---	1.470 (0.000)	---	---	---	---	258
	23.95 (0.000)	0.177 (0.598)	---	---	---	---	239
	---	2.245 (0.031)	-34.59 (0.412)	---	---	---	259
Product A (ped)	---	1.323 (0.000)	---	---	---	---	287
	37.42 (0.004)	0.920 (0.000)	---	---	---	---	280
	---	2.151 (0.000)	-7.503 (0.063)	---	---	---	285
Product B	---	1.117 (0.000)	---	---	---	---	429
	-2.165 (0.897)	1.125 (0.000)	---	---	---	---	431
	---	0.978 (0.000)	0.446 (0.161)	---	---	---	429
	---	1.121 (0.000)	---	---	-0.081 (0.591)	--	431

Note: AIC = Akaike Information Criterion. Numbers in parentheses are P values; coefficients with a P value of 0.050 or less are significant at a 95% confidence level.
Hot is an indicator variable that is 1 when temperatures exceed 90 °F and 0 otherwise.

Inductive Loops

Qualitative Experience

Inductive loops were tested at a number of sites during this project, both on- and off-street facilities. Both permanent and temporary inductive loops were tested.

In evaluating inductive loops, a special type of error is specifically addressed: bypass errors. Bypass errors arise because of the sensor's spatially limited detection zone: loops do not always cover the entire width of the facility. Cyclists sometimes ride around the edge of the loops, which is likely a result of many micro-design elements of the facility.

First, consider Fell Street in San Francisco, shown in in Figure 4-11. This site is a green-painted bicycle lane on a one-way street. This site lies immediately after a bicycle route turns left onto Fell Street. The inductive loops are located in the bicycle lane. High bicycle volumes on this facility result in frequent passing maneuvers between bicyclists, which can result in bypass errors if the passing maneuvers occur at the loop sensor. Similarly, cyclists who have made a right turn onto Fell Street (or are continuing straight) instead of making a left turn sometimes ride on the right side of the street, which can also be considered a bypass error.

Figure 4-11. Inductive Loop Testing on Fell Street (San Francisco, CA)

Second, consider the Midtown Greenway in Minneapolis. This site is a very wide multiuse path, with marked separated pedestrian and bicycle zones. Two sets of inductive loops were installed at this site: a set of permanent loops and a set of surface loops. Both sets of inductive loops are centered in the bicycle facility, but have small gaps between their edges and the sides of the path, which yield bypass errors when bicyclists ride by at the edges of the facility (or in the pedestrian zone), which seems to occur more frequently at high volumes. Note that this effect was also problematic for data collection in terms of estimating the accuracy of the loops when bicyclists riding directly over them, in that it was difficult to determine where exactly the edge of the detection zone was based on camera footage.

Finally, consider the Key Bridge between Washington, D.C. and Arlington, VA, shown in Figure 4-12. The facility under question here is a shared use path on the side of the bridge. The path has a constrained width (8 to 10 feet), and the loops cover roughly the entire width of the path. Hence, this site does not experience substantial bypass errors.

Figure 4-12. Inductive Loop Testing on Key Bridge (Washington, D.C. and Arlington, VA)

Accuracy and Consistency

Figure 4-13 compares the differences in accuracy and consistency based on the detection zone volume and the overall facility volume (including bypass errors). It is important to note that these plots represent two slightly different data sets, due to the aforementioned difficulties with the Midtown Greenway data collection process. This is a very high-volume site (peak volumes observed of nearly 800 bicyclists per hour), which likely biases the accuracy downwards. However, even at lower volumes, the facility counts are undercounted. As expected, undercounting of the facility volume appears to increase with volume, whereas detection zone accuracy appears to be only very slightly affected.

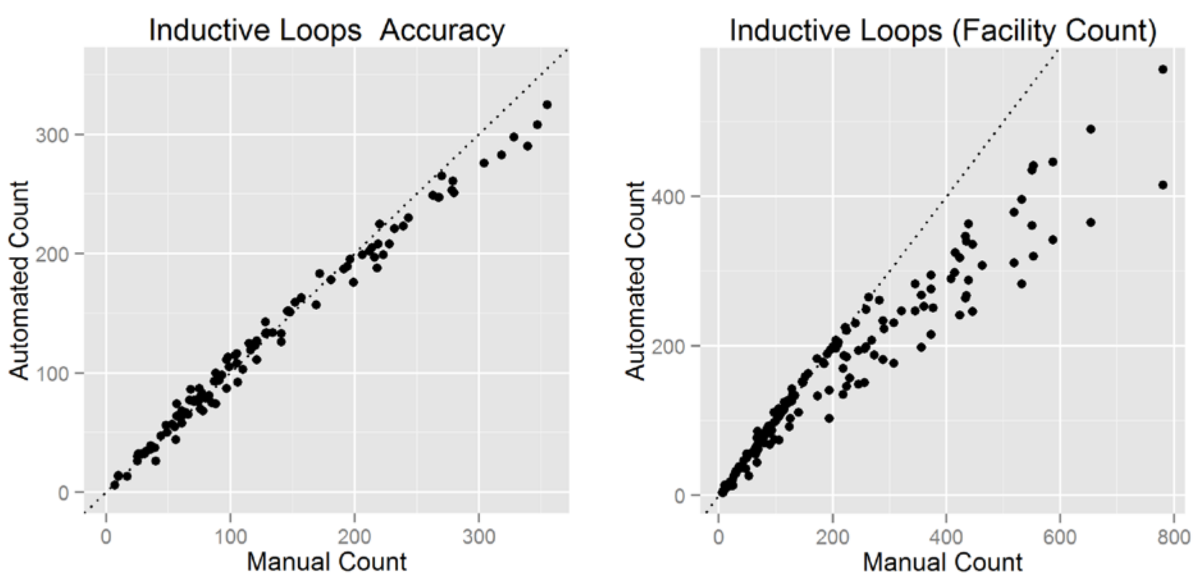

Figure 4-13. Accuracy Plots for Inductive Loops Including Bypass Errors

Table 4-8 provides the accuracy and consistency statistics for inductive loops, without bypass errors (i.e., considering only those bicycles that passed through a loop's detection zone). As shown in Table 4-8, inductive loop sensors are both very accurate and very precise. There does not appear to be a substantial difference between the surface inductive loops and the embedded inductive loops.

Table 4-8. Accuracy and Consistency Values for Inductive Loops (Detection Zone Accuracy)

Dataset	Type	APD	AAPD	WAPD	*r*	N	Average Hourly Volume
All Data	-	0.55%	8.87%	7.55%	0.9938	108	128
All Surface	S	0.32%	7.57%	5.70%	0.9968	29	145
Loyola	S	7.85%	10.84%	9.82%	0.9736	12	51
University	S	-4.99%	5.26%	5.00%	0.9878	17	211
All Embedded	E	0.63%	9.35%	8.36%	0.9929	79	122
Sycamore	E	7.91%	8.18%	7.70%	0.9729	18	81
Clarendon	E	-27.35%	27.35%	29.73%	1	3	25
Key	E	7.95%	8.13%	6.03%	0.9957	31	92
Fell	E	-9.52%	9.52%	9.51%	0.9981	27	194

Notes: APD = average percentage deviation, AAPD = average of the absolute percent difference, WAPD = weighted average percentage deviation, *r* = Pearson's Correlation Coefficient .

Table 4-9 presents accuracy and consistency statistics for inductive loops when considering facility volumes (i.e., including bypasses) as the "ground-truth." The facility volume was defined on a site-by-site basis. For multi-use paths, all bicyclists were counted while riding on the path. For bicycle lanes, the volume included all bicyclists riding along the street. Accordingly, the facility-level accuracy and consistency values presented here should not be taken as general truths, but rather as documentation of the range of values encountered for the sites on which inductive loops were installed in this study.

Overall consistency rates are fairly high (Pearson's $r > 0.95$ for all sites), while accuracy rates varied substantially between sites. The multi-use path sites and cycletrack site had high accuracy rates, particularly when the inductive loops spanned the entire path width. The Midtown Greenway's inductive loops were both narrower than the path, with the surface loops being narrower than the embedded loops, and hence these loops undercounted the total facility volume. Similarly, the on-street sites were subject to bypass errors from bicyclists riding outside of the bike lane. In order to account for these differences in accuracy rates, site-specific corrections should be developed to account for the traffic patterns at each site when inductive loops are used but do not span the entire facility.

Table 4-9. Accuracy and Consistency Values for Inductive Loops (Facility-Level Accuracy)

Dataset	Type	APD	AAPD	WAPD	*r*	N	Average Hourly Volume
All Data	-	-14.08%	17.62%	23.63%	0.9648	165	200
All Surface	S	-20.09%	21.55%	29.34%	0.942	59	222
Loyola	S	-1.56%	8.20%	8.35%	0.9766	12	56
University	S	-2.44%	2.80%	2.80%	0.9919	17	206
Midtown	S	-37.51%	37.51%	41.31%	0.9937	30	298
All Embedded	E	-10.74%	15.44%	19.86%	0.9904	106	187
Sycamore	E	7.91%	8.18%	7.70%	0.9729	18	81
Clarendon	E	-27.35%	27.35%	29.73%	1	3	25
Key	E	7.95%	8.13%	6.03%	0.9957	31	92
Midtown	E	-20.60%	20.60%	23.01%	0.9977	27	330
Fell	E	-25.50%	25.50%	26.05%	0.9904	27	237

Notes: E = embedded, S = surface.
APD = average percentage deviation, AAPD = average of the absolute percent difference, WAPD = weighted average percentage deviation, *r* = Pearson's Correlation Coefficient, N = number of detectors, Average volume = hourly average pedestrian and bicycle counts based on video observation.

The largest shortcoming with inductive loops is the aforementioned bypass error. This error can be mitigated in a number of ways, including selecting loops that are wide enough to cover most of the facility, and locating loops at a constrained point on the facility to minimize the possibility of bypasses. However, these measures cannot necessarily be taken with on-street facilities. Instead, site-specific correction factors should be developed to account for bypass errors and estimate the facility volumes.

Effects of Environmental Conditions

Table 4-10 provides the parameters for the regression models that were tested. Hot is an indicator variable that takes a value of 1 when temperatures exceed 90 °F and 0 otherwise.

Table 4-10. Correction Functions for Inductive Loops

Dataset	Intercept	Automated	Automated ^2 /10^4	Automated × Hot (>90 °F)	Automated × Facility Width (ft)	AIC
All data (Detection Zone)	---	1.050 (0.000)	---	---	---	829
	-9.580 (0.000)	1.105 (0.000)	---	---	---	805
	---	0.906 (0.000)	0.685 (0.000)	---	---	771
	---	1.050 (0.000)	---	-0.118 (0.290)	---	830
	---	1.116 (0.000)	0.325 (0.000)	---	-0.019 (0.000)	738
All data* (Facility Volumes)	---	1.346 (0.000)	---	---	---	1753
	-24.03 (0.000)	1.445 (0.000)	---	---	---	1739
	---	1.156 (0.000)	0.624 (0.000)	---	---	1739
	---	1.347 (0.000)	---	-0.325 (0.507)	---	1754
	---	1.018 (0.000)	0.199 (0.246)	---	0.021 (0.000)	1720
	---	1.044 (0.000)	---	---	0.024 (0.000)	1719

Notes: *Including bypass errors
AIC= Akaike Information Criterion. Numbers in parentheses are P values; coefficients with a P value of 0.050 or less are significant at a 95% confidence level.
Hot is an indicator variable taking a value of 1 when temperatures exceed 90 °F and 0 otherwise.

Age of Loops

The age of inductive loops has been suggested as a potential issue for loop accuracy. However, this was not detected in the NCHRP 07-19 testing. One set of embedded loops that was tested was 3½ years old and another was 2 years old. However, as shown in Figure 4-13, which includes data from all of the counters, no data seem to be of especially bad quality despite these older systems being included in the study.

Volume (especially for facility counts)

Higher volumes appear to very slightly affect the accuracy of the sensor when considering the detection zone volume, as shown by the statistically significant squared automated count term in the low-AIC correction functions for detection zone inductive loop volumes. Facility width also appears as a statistically significant term, but with a negative sign (indicating improved accuracy). This could be an effect of the inclusion of both multi-use paths and bicycle lanes (where the lane width was used). The bike lanes are narrower than multi-use paths, so this term could be interpreted as a proxy for multi-use paths (as opposed to bike lanes). At the bike lane sites, detection-zone accuracy could have been perceived as less accurate because of some ambiguity in the extent of the detection zone. Because of these doubts with the facility width term, the recommended correction function for the detection zone accuracy includes the automated count and square of the automated count (divided by 10^4) with no intercept.

When considering facility-level volumes, counts were less accurate for wider facilities, which fits with *a priori* expectations. However, the same concern with width measurement should be considered as with the detection zone correction function. More importantly, the facility-level volume correction functions developed here should not be applied to other sites without careful consideration because the extent of the inductive loops relative to the facility width have not been taken into account, nor have traffic patterns explicitly been considered. For example, on Fell Street bicyclists frequently are observed riding on the right side of the street (the bicycle lane is on the left) because they have recently made a right turn onto Fell. However, other bicycle lanes may not have such a high proportion of riders maneuvering in such a way. These corrections have been presented for the purposes of illustration.

Piezoelectric Strips

Qualitative Experience

The study's findings regarding piezoelectric strips were very limited due to difficulties in procuring equipment from the vendor. The initial plan was to install piezoelectric strips at three sites, in addition to the existing set at one site (Four Mile Run). However, only one of the three devices was delivered, and technicians were never able to establish a connection to the counter to download data. Hence, all of the findings described herein are drawn from a single counter that had been on-site for nearly 4 years, and was not installed with the oversight of the research team. Figure 4-15 presents the accuracy plot for this counter.

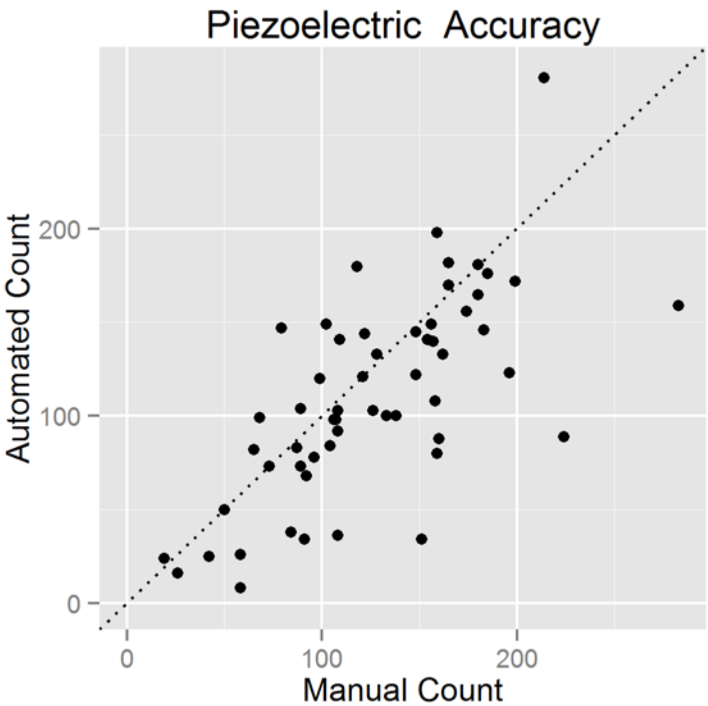

Figure 4-15. Accuracy Plot for Piezoelectric Strips

Accuracy Description

The piezoelectric device included in the study does not appear to be functioning very accurately or consistently. Because these data are only from one site with one counter, these results should be considered with caution, as there are many possible explanations, but the data are insufficient to isolate the specific accuracy problems. Table 4-11 provides the accuracy and consistency statistics for this device.

Table 4-11. Accuracy and Consistency Values for Piezoelectric Strips

Site	APD	AAPD	WAPD	*r*	N	Average Hourly Volume
Four Mile Run	-11.36%	26.60%	25.24%	0.691	58	128

Notes: APD = average percentage deviation, AAPD = average of the absolute percent difference, WAPD = weighted average percentage deviation, *r* = Pearson's Correlation Coefficient, N = number of detectors, Average volume = hourly average pedestrian and bicycle counts based on video observation.

Effects of Environmental Conditions

There were insufficient data to identify any effects of the environment on the counter's accuracy.

Regression Corrections

Table 4-12 shows the correction functions estimated for the piezoelectric strip counter tested in this study. The recommended correction function for this device includes the automated count and the squared automated count on the basis of significant parameter estimates, a low AIC, and no prediction of non-zero volumes based on observed automated counts of zero.

Table 4-12. Correction Functions for Piezoelectric Strips

Intercept	Automated	Automated ^2 /10^4	Automated x Hot (>90 °F)	AIC
---	1.059 (0.000)	---	---	607
53.58 (0.000)	0.667 (0.000)	---	---	590
---	1.562 (0.000)	-3.246 (0.000)	---	594
---	1.037 (0.000)	---	0.268 (0.441)	473

Note: AIC= Akaike Information Criterion. Numbers in parentheses are P values; coefficients with a P value of 0.050 or less are significant at a 95% confidence level.
Hot is an indicator variable taking a value of 1 when temperatures exceed 90 °F and 0 otherwise.

Combination Counter (Pedestrian Estimates)

Qualitative Experience

Combination counters use multiple sensors to generate separate estimates of pedestrian and bicycle volumes. In this study, the combination counters tested use passive infrared sensors and inductive loops. The tested devices output estimates of pedestrian and bicycle volumes by default. These sensors have been evaluated separately in the previous sections, considering the sum of the automated and pedestrian count as the passive infrared sensor's ground truth and considering the bicycle count as the inductive loop's ground truth volume. Qualitative experiences have already been discussed, but here the accuracy and consistency of the counters' inferred pedestrian volumes are discussed explicitly.

Accuracy Description

Figure 4-16 shows the pedestrian volume estimate accuracy based on data for both sites. Figure 4-17 distinguishes the data between the two sites, while Table 4-13 gives calculated accuracy and consistency metrics. These devices appear to work well on the whole, with a high consistency rate (Pearson's $r = 0.9916$). The Sycamore Park site in Davis, however, had a substantial net overcount percentage but low hourly volumes. As has previously been stated, the percentage deviation at this site is very high in part as a result of the low volumes—relatively few miscounts result in a high percentage difference.

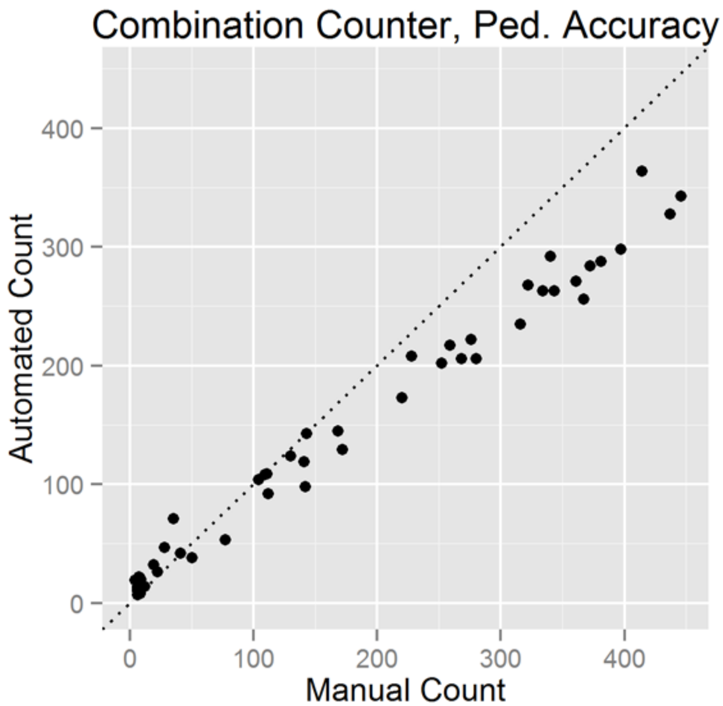

Figure 4-16. Accuracy Plot for Pedestrian Volumes Estimated from Combination Counters

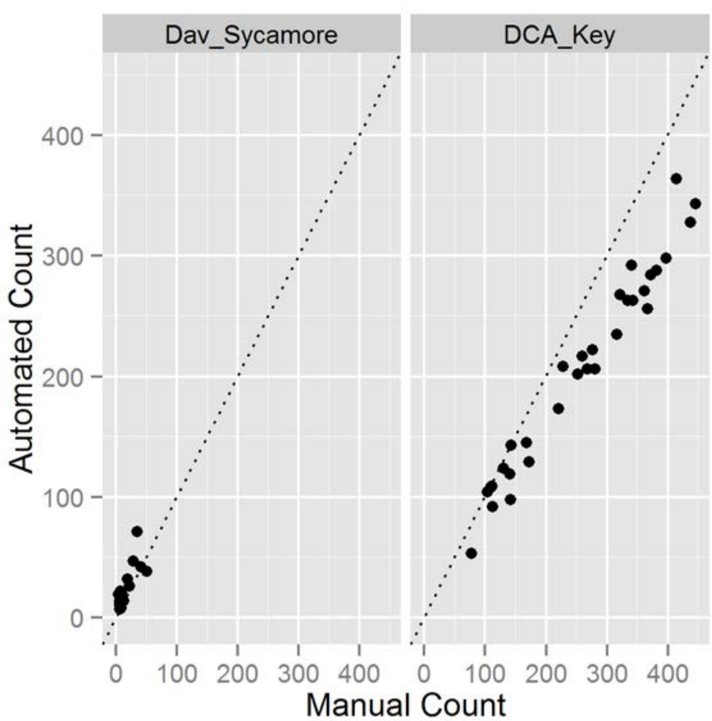

Figure 4-17. Accuracy and Consistency Plots for Pedestrian Volumes from Combination Counters Comparing Two Sites

The Key Bridge site, on the other hand, shows net undercounting as expected due to occlusion effects, with a high rate of consistency.

Table 4-13. Accuracy and Consistency Metrics for Pedestrian Volumes from Combination Counters

Dataset	APD	AAPD	WAPD	*r*	N	Average Hourly Volume
All Data	18.65%	43.78%	21.37%	0.9916	47	176
Sycamore	90.19%	93.19%	59.93%	0.7886	16	17
Key Bridge	-18.27%	18.27%	20.08%	0.9822	31	259

Regression Corrections

Table 4-14 shows the correction functions that have been developed for pedestrian volume estimates using correction counters. The models with the lowest AIC values here are the last two presented in the table. It can be seen from the coefficients that temperatures and rain appear to have a significant effect on accuracy, but in the opposite direction as expected, with accuracy improving under poorer-weather conditions. Rain and temperature could be significant because they are correlated with volumes. Accuracy appears to be worse at higher volumes, which do not generally occur during rain and high temperatures, so an apparent increased accuracy is seen under these conditions. A higher percentage of pedestrians in the traffic mix also appears to have an (adverse) effect on accuracy.

Despite these significant interaction terms, this dataset only has data from two sensors at two sites, with little variation in the weather data. These corrections are recommended to be revisited with additional data from sites at which pedestrian volumes do not decrease as substantially under conditions of rain.

Table 4-14. Correction Functions Estimated for Pedestrian Volumes from Combination Counters

Inter-cept	Automated	Automated ^2 / 10^4	Automated × Temper-ature (°F)	Automated × Key Bridge	Auto-mated × Rain (≥0.01 in/h)	Auto-mated × Traffic Mix (% peds)	AIC
---	1.256 (0.000)	---	---	---	---	---	424
-15.69 (0.002)	1.325 (0.000)	---	---	---	---	---	416
---	1.128 (0.000)	4.890 (0.046)	---	---	---	---	422
---	1.809 (0.000)	---	-0.008 (0.001)	---	---	---	415
---	1.455 (0.000)	0.006 (0.085)	-0.010 (0.000)	---	-0.171 (0.002)	0.644 (0.000)	382
---	1.349 (0.000)	2.772 (0.113)	-0.009 (0.000)	0.489 (0.000)	-0.236 (0.000)	---	382
---	1.314 (0.000)	---	-0.008 (0.000)	0.555 (0.000)	-0.258 (0.000)	---	383
---	1.233 (0.000)	---	-0.0084 (0.000)	0.344 (0.015)	-0.216 (0.000)	0.421 (0.017)	378
---	1.287 (0.000)	0.005 (0.170)	-0.009 (0.000)	0.309 (0.028)	-0.200 (0.000)	0.413 (0.018)	378

Notes: Key Bridge is an indicator variable taking a value of 1 when the count was from the Key Bridge and 0 otherwise.
Rain is an indicator variable taking a value of 1 when at least 0.01 in. of rain fell during the count period and 0 otherwise.
Traffic Mix is the percentage of pedestrians in the total ground-truth count volume.

SUMMARY

Table 4-15 provides a combined comparison of accuracy and consistency values by site, product, and counting technology.

Table 4-15. Accuracy and Consistency Values for all Technologies by Site and Product

Technology	Subset	APD	AAPD	WAPD	*r*	N	Average Hourly Volume
Passive Infrared	All data	-8.75%	20.11%	18.68%	0.9502	298	240
	Product A	-3.12%	11.15%	10.66%	0.9804	176	236
	Product B	-16.86%	33.05%	29.75%	0.9711	122	246
	Berkeley	-14.32%	14.32%	14.51%	0.9595	6	151
	Loyola	-18.46%	19.47%	19.17%	0.8625	12	64
	Sycamore (A)	15.08%	16.01%	16.26%	0.9555	17	98
	Sycamore (B)	-33.66%	33.66%	31.31%	0.8642	17	98
	Four Mile Run (A)	1.34%	8.85%	10.08%	0.8838	44	173
	Four Mile Run (B)	-17.43%	27.07%	26.08%	0.7775	44	173
	Key (A)	-12.38%	12.91%	13.62%	0.9882	31	351
	Key (B)	-28.60%	28.60%	30.14%	0.9817	31	351
	L Street	1.83%	11.01%	10.08%	0.8653	21	583
	15th	-4.80%	5.23%	4.57%	0.9956	18	345
	Fell	-4.68%	9.44%	8.97%	0.9677	27	43
	Midtown	5.61%	46.06%	31.90%	0.9809	30	328
Active Infrared	All data	-9.11%	11.61%	11.90%	0.9991	30	328
Pneumatic Tubes	All data	-17.89%	18.50%	14.15%	0.9864	160	218
	Product A	-10.54%	11.27%	11.94%	0.9884	132	244
	Product B	-52.55%	52.55%	39.93%	0.9704	28	99
	Clarendon	-21.06%	21.06%	22.86%	0.9986	3	23
	Key	-10.51%	10.95%	13.04%	0.9839	31	92
	L Street	-12.00%	12.54%	13.61%	0.9895	21	92
	Midtown 1[†]	4.33%	33.31%	29.98%	0.9012	30	298
	Midtown 2[†]	39.34%	39.34%	46.85%	0.9818	9	12
	University (A)	0.52%	1.17%	1.23%	0.9979	17	206
	University (B)	-34.27%	34.27%	34.82%	0.8045	11	199
	Eastbank	-64.38%	64.38%	59.38%	0.7809	17	34
	Fell	-20.58%	20.58%	23.40%	0.9863	24	249
	Milton 1	-6.58%	8.93%	9.76%	0.9786	18	497
	Milton 2	-8.17%	8.17%	9.85%	0.9961	18	497
Inductive Loops	All data	0.55%	8.87%	7.55%	0.9938	108	128
	Surface loops	0.32%	7.57%	5.70%	0.9968	29	145
	Embedded loops	0.63%	9.35%	8.36%	0.9929	79	122
	Sycamore	7.91%	8.18%	7.70%	0.9729	18	81
	Loyola	7.85%	10.84%	9.82%	0.9736	12	51
	Clarendon	-27.35%	27.35%	29.73%	1.0000	3	25
	Key	7.95%	8.13%	6.03%	0.9957	31	92
	University	-4.99%	5.26%	5.00%	0.9878	17	211
	Fell	-9.52%	9.52%	9.51%	0.9981	27	194
	All data*	-14.08%	17.62%	23.63%	0.9648	165	200
	Surface loops*	-20.09%	21.55%	29.34%	0.9420	59	222

Technology	Subset	APD	AAPD	WAPD	*r*	N	Average Hourly Volume
	Embedded loops*	-10.74%	15.44%	19.86%	0.9904	106	187
	Sycamore*	7.91%	8.18%	7.70%	0.9729	18	81
	Loyola*	-1.56%	8.20%	8.35%	0.9766	12	56
	Clarendon*	-27.25%	27.25%	29.73%	1.0000	3	25
	Key*	7.95%	8.13%	6.03%	0.9957	31	92
	Midtown (surface)*	-37.51%	37.51%	41.31%	0.9937	30	298
	Midtown (embedded)*	-20.60%	20.60%	23.01%	0.9977	27	330
	University*	-2.44%	2.80%	2.80%	0.9919	17	206
	Fell*	-25.50%	25.50%	26.05%	0.9904	27	237
Piezoelectric	All data	-11.36%	26.60%	25.24%	0.6910	58	128
Radio Beam	All data	-18.18%	48.15%	27.41%	0.9503	95	129
	Product A (bike)	-31.16%	72.55%	70.18%	0.1041	28	26
	Product A (ped)	-26.27%	52.50%	46.67%	0.7368	27	87
	Product B	-3.63%	28.13%	19.17%	0.9328	40	230
	Berkeley (bike)	42.48%	62.88%	41.38%	0.7817	11	13
	Berkeley (ped)	-26.48%	33.09%	33.50%	0.3383	11	142
	Eastbank (bike)	-78.81%	78.81%	77.43%	0.3763	17	34
	Eastbank (ped)	-26.13%	65.84%	73.29%	-0.1118	16	48
	5th Ave	-15.61%	15.61%	13.79%	0.9779	17	331
	Four Mile Run	5.23%	37.39%	27.59%	0.7394	23	156
Combination (ped)	All data	18.65%	43.78%	21.37%	0.9916	47	176
	Sycamore	90.19%	93.19%	59.93%	0.7886	16	17
	Key Bridge	-18.27%	18.27%	20.08%	0.9822	31	259

Notes: *Denotes values calculated using facility counts (i.e., including bypass errors).
†Denotes value not included in overall accuracy calculations due to identified sensor problems.
(A), (B), (1), and (2) represent different products implementing a given sensor technology.
APD = average percentage deviation, AAPD = average of the absolute percent difference, WAPD = weighted average percentage deviation, *r* = Pearson's Correlation Coefficient, N = number of detectors, Average volume = hourly average pedestrian and bicycle counts based on video observation.

Table 4-16 provides correction factors for each tested sensor technology. The factors are simple multiplicative factors—that is, a multiplier that is applied to the raw count to estimate the true count. For example, if the raw count was 100 bicycles in an hour and the counting technology in use has a correction factor of 1.20, the estimate of the true count would be 120. Although a number of different types of models for correcting counts were tested by NCHRP 07-19, multiplicative factors provided the best combination of prediction accuracy and simplicity of application. The implication is that count errors increased at a linear rate for the technologies tested. Where multiple products representing a given technology were tested, Table 4-15 also provides product-specific, anonymized results.

Table 4-16. Counter Correction Factors Developed by NCHRP Project 07-19

Sensor Technology	Adjustment Factor	Hours of Data
Active infrared*	1.139	30
Combination counter (pedestrian volume)	1.256	47
Inductive loops	1.050	108
Surface loops	1.041	29
Embedded loops	1.054	79
Passive infrared	1.137	298
Product A	1.037	176
Product B	1.412	122
Piezoelectric strips*	1.059	58
Bicycle-specific pneumatic tubes	1.135	160
Product A	1.127	132
Product B	1.520	28
Radio beam	1.130	95
Product A (bike)	1.470	28
Product A (ped)	1.323	27
Product B	1.117	40

Note: *Factor is based on a single sensor at one site; use caution when applying.

Chapter 5: Conclusions and Suggested Research

CONCLUSIONS

Research findings from Project 07-19 indicate the automated count technologies that were tested performed with the accuracy summarized below.

- **Passive Infrared.** Found to have an undercounting rate of 8.75% (average over two different products) and a total deviation from actual counts of 20.11% (average over two different products).
- **Active Infrared.** Found to have an undercounting rate of 9.11% and a total deviation from actual counts of 11.61%.
- **Pneumatic Tubes.** Found to have an undercounting rate of 17.89% (average over two different products) and a total deviation from actual counts of 18.50% (average over two different products).
- **Radio Beam.** Found to have an undercounting rate of 18.18% and a total deviation from actual counts of 48.15%.
- **Inductive Loops.** Found to have an overcounting rate of 0.55% and a total deviation from actual counts of 8.87%.
- **Piezoelectric Strips.** Found to have undercounting rate of 11.36% and a total deviation from actual counts of 26.60%.

The following subsections discuss the factors found to influence the accuracy and recommendations for practitioners interested in using automated count technologies.

Factors Influencing Accuracy

The research team found the accuracy measurements to vary notably depending on site-specific characteristics. Significant site-specific factors influencing the accuracy of the counts included proper calibration and installation of the technologies. For example, passive infrared sensors are susceptible to false positives when windows, mirrors, or other reflective surfaces are positioned behind the pathway being counted. This is because the surfaces collect heat on sunny days that trigger false positives for the counter. Similarly, some technologies have a limited detection zone (e.g., a width no greater than 10 feet for some radio beam products, field of detection defined by inductive loop placement) and the installation design becomes particularly important.

For screenline sensor-based technologies (e.g., radio beam, passive infrared), occlusion is one of the most significant factors in undercounting. The degree to which occlusion may contribute to undercounting is a factor of pedestrian and bicycle platoons or groups of users travel side-by-side. For a specific site and time of day, it may be feasible to develop factors that are able to consistently adjust for such an effect. In this study, it was found that non-linear correction functions improved the fit when adjusting automated counts to reflect ground-truth volumes for passive infrared, active infrared, and radio beam sensors, confirming the occlusion effects.

Facility width appears to have some effect on accuracy, in particular for passive infrared sensors and inductive loops, after facility volumes are considered. Facility width is likely also a predictor of occlusion effects: the wider that a facility is, the more likely that multiple people will walk or ride past a counter simultaneously.

In some cases, two different products implementing the same sensor technology had significantly different accuracies. This result suggests that a specific vendor's implementation of a technology (e.g., the algorithm used to decide whether a detection should be registered) can be as important as the technology itself in determining accuracy. This result also indicates that "one-size-fits-all" correction factors for particular sensor technologies may not be particularly useful, and that product-specific factors should be used instead. Given that site-specific conditions that can also influence accuracy, it is recommended that users develop their own local correction factors for their devices whenever possible.

Factors Not Found to Influence Accuracy

Several factors anticipated to affect the accuracy of counting technologies were not evident in the NCHRP 07-19 testing. For example, concern has been expressed that the age of inductive loops influences their accuracy. However, the inductive loops tested by this project included loops that were 2 and 3½ years old, and the team did not detect poor quality in those loops' counting accuracy. Similar concerns have been expressed related to the age of pneumatic tubes. However, over the six-month duration of the testing, count quality was not observed to decline over time.

The research team did not find a clear impact or effect of temperature on the accuracy of any of the technologies. The temperatures captured within the duration of this research did not reach the extremes of colds and heat included in other studies; however, for the temperature ranges captured in the research, no impact on the accuracy of the tested devices was observed. Similarly, there was no indicative or quantitative effect found on count accuracy due to snow or rain events. There were limited snow and rain events within the data set, but those that did occur did not appear to influence the quality of the data. Anecdotally, the research team is aware of situations that have occurred with active infrared technologies having a higher rate of false positives during heavy rain events; however, this phenomenon was not observed in this project's testing.

Recommendations for Practitioners

The research team recommends that practitioners calibrate and conduct their own ground-truth count tests for the automated technologies they deploy at a given site or set of sites. This project's research results are intended to provide information to practitioners on the types of technologies that may be most promising for a specific circumstance, use, or location where automated count technology is being considered. The project's accuracy findings should not be blindly applied to other sites than those at which these technologies were tested at, and it should not be assumed that the same degree of accuracy will occur at other site locations or with other products. Practitioners can use the research approach described in this report and accompanying guidebook to, on a smaller scale, test and evaluate the performance of their automated count technologies at their installation sites.

It should be noted that when automated counting technologies are used, finding an ideal counting site is just the first step in implementing a count program. As experienced by the research team, getting the roadway or path owner to approve the site can be a significant endeavor. In some cases, the approval of private adjacent developments may also be required. The research team recommends that practitioners consider the time required for obtaining necessary approvals when developing a count program.

SUGGESTED RESEARCH

The research team identified several areas for suggested additional research. These areas include additional testing for automated technologies not included or underrepresented in the NCHRP 07-19 testing, a more robust method for extrapolating short duration counts to longer time periods, and adjustment factors to account for changes in pedestrian and bicycle demand (or the potential for demand) based on environmental contexts (e.g., weather, land use characteristics, urban design characteristics). Each of the following is discussed in more detail below.

Additional Testing of Automated Technologies

The research team suggests additional investment in testing of automated count technologies. This future research would focus on technologies that were not included in the NCHRP 07-19 testing, notably automated video, thermal, and potentially fiber-optic pressure sensors, as well as those technologies that were underrepresented in Project 07-19 (i.e., active infrared, radio beam, and piezoelectric strips). The future research would test additional sites to further understand the degree of accuracy and performance of the technologies under high-volume conditions, mixed road user conditions, and to the extent possible, extreme weather conditions.

Correction Factors for Bypass Errors

Counters subject to bypass errors (e.g., inductive loops in bicycle lanes) can likely have their raw data adjusted based on site factors to estimate facility-level volumes. NCHRP 07-19 simply recommends that practitioners develop these factors on a site-specific basis, as insufficient data were available to arrive at general conclusions. However, future projects could likely arrive at general findings on the factors that influence bicyclists to bypass counters. Potential topics to look at include facility design, microscopic traffic patterns (e.g., how many bicyclists approach from each direction), and volumes.

Extrapolating Short-Duration Counts to Longer-Duration Counts

It is recommended that a robust method be investigated for identifying and extrapolating longer-duration counts from shorter-duration counts at sites where continuous data have not been collected. A potential approach would be to create groups of sites that are considered similar in their pedestrian or bicycle volume peaking characteristics (i.e., factor groups). Current standard guidance is to match short-term count sites with continuous count sites in the same factor group to determine the appropriate expansion factors. However, this approach is mostly performed on an ad hoc basis (e.g., central business district vs. multiuse path in suburban context, count program manager's local knowledge). Potential directions for this research include land use–based assignments, data fusion with GPS tracking data, or point sampling of very short (e.g. 5–10 minute) counts.

Adjustment Factors for Environmental Factors

Developing adjustment factors for different environmental factors would enable practitioners to better estimate and predict potential demand on facilities based on changes in land use, design characteristics of the roadway, and how the roadway interfaces with the surrounding land uses (e.g., density of destinations, building set-backs, parking availability and design). This information would also be useful as input into a methodology for extrapolating short duration counts to longer duration time periods. Advances in travel demand modeling and discrete choice models to activity-based modeling techniques are beginning to make progress in the understanding of the potential demand, movement, and mode of person trips. In addition to the continued development of activity-based model methods, a sketch-planning tool is also needed for practitioners to use to understand reasonable expected changes in bicycle and pedestrian traffic volumes due to changes in road, multiuse path, and land use characteristics.

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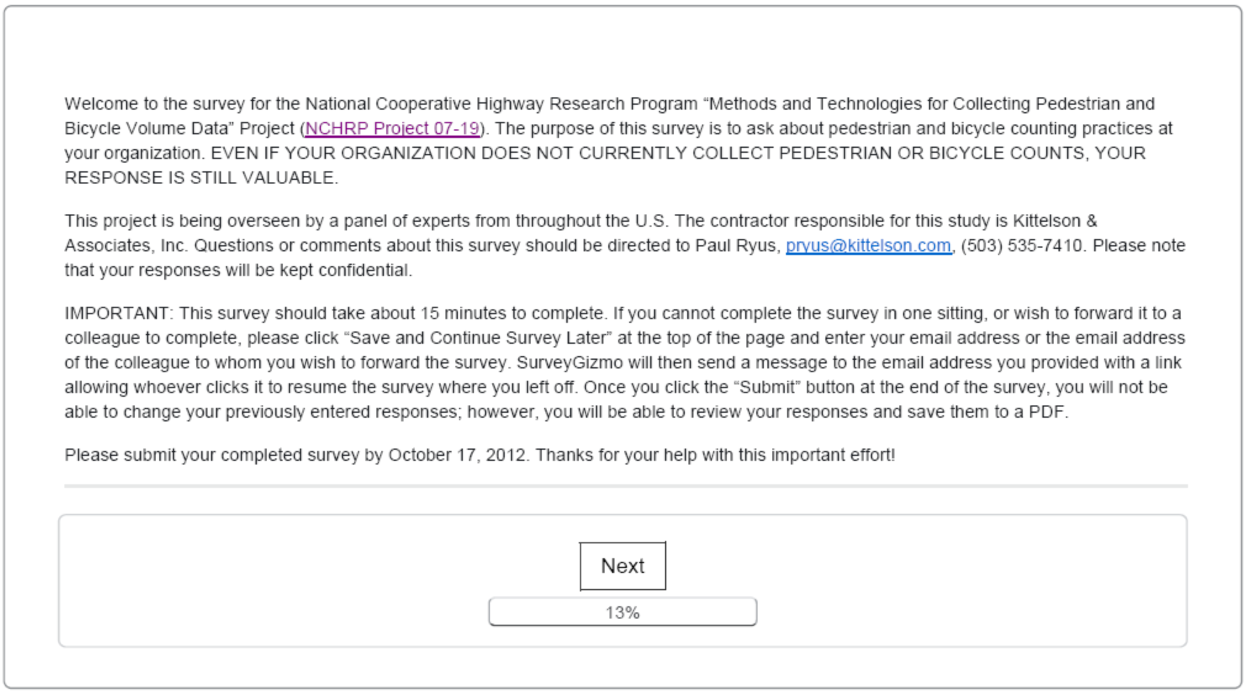
Appendix A: Practitioner Survey Form

This section provides screen captures of the online survey instrument used for the practitioner survey. The survey was designed to hide certain questions unless required. Therefore, these screen captures sometimes show answers to questions filled in. This has been done to unhide certain questions; the actual survey did not provide "default answers" for questions.



Welcome to the survey for the National Cooperative Highway Research Program "Methods and Technologies for Collecting Pedestrian and Bicycle Volume Data" Project (NCHRP Project 07-19). The purpose of this survey is to ask about pedestrian and bicycle counting practices at your organization. EVEN IF YOUR ORGANIZATION DOES NOT CURRENTLY COLLECT PEDESTRIAN OR BICYCLE COUNTS, YOUR RESPONSE IS STILL VALUABLE.

This project is being overseen by a panel of experts from throughout the U.S. The contractor responsible for this study is Kittelson & Associates, Inc. Questions or comments about this survey should be directed to Paul Ryus, pryus@kittelson.com, (503) 535-7410. Please note that your responses will be kept confidential.

IMPORTANT: This survey should take about 15 minutes to complete. If you cannot complete the survey in one sitting, or wish to forward it to a colleague to complete, please click "Save and Continue Survey Later" at the top of the page and enter your email address or the email address of the colleague to whom you wish to forward the survey. SurveyGizmo will then send a message to the email address you provided with a link allowing whoever clicks it to resume the survey where you left off. Once you click the "Submit" button at the end of the survey, you will not be able to change your previously entered responses; however, you will be able to review your responses and save them to a PDF.

Please submit your completed survey by October 17, 2012. Thanks for your help with this important effort!

Next

13%

1. What is the name of your organization?

[ ]

Where is your organization located?

Country

[▼]

City

[ ]

2. What type of organization are you?

- ○ U.S. city
- ● U.S. county
- ○ U.S. state department of transportation
- ○ U.S. federal agency
- ○ Metropolitan Planning Organization (MPO)/Regional Planning Commission (RPC)
- ○ Transit agency
- ○ Non-U.S. public agency
- ○ University
- ○ Non-profit/advocacy
- ○ Consulting firm
- ○ Other [ ]

What size population does your organization serve?

- ○ 1-4,999
- ○ 5,000-10,000
- ○ 10,000-50,000
- ○ 50,000-100,000
- ○ 100,000-500,000
- ○ 500,000-1,000,000
- ○ 1,000,000+

3. Does your organization routinely collect non-motorized (pedestrian or bicycle) count data?

- (selected) Yes, on a periodic basis
- Yes, project by project
- Yes, both periodically and project by project
- No

4. How does your organization select sites to be counted?

4. Does your organization maintain a database of non-motorized count data?

- (selected) Yes
- No

5. At approximately how many different locations has your organization collected the following types of counts during the last 2 years?

Select an option for each count type.

Pedestrian only counts	1-4
Bicycle only counts	1-4
Combined pedestrian/bicycle counts	1-4
Motorized vehicle counts	1-4

The following questions address **PEDESTRIAN** counts.

6. On average for a given count location, how frequently does your organization collect pedestrian counts manually, with field data collectors?

- No manual counts performed
- Less than 1 time per year
- 1 time per year
- 2 times per year
- More than 2 times per year

7. What types of locations do your pedestrian counts (manual and automated) cover?

Select all that apply. See image below for an illustration of differences between screenline counts and intersection counts.

- Sidewalk (screenline)
- Multi-use trail (screenline)
- Roadway intersection (turning count)
- Intersection crosswalk
- Mid-block crosswalk
- Other

The following questions address **PEDESTRIAN** counts.

6. On average for a given count location, how frequently does your organization collect pedestrian counts manually, with field data collectors?

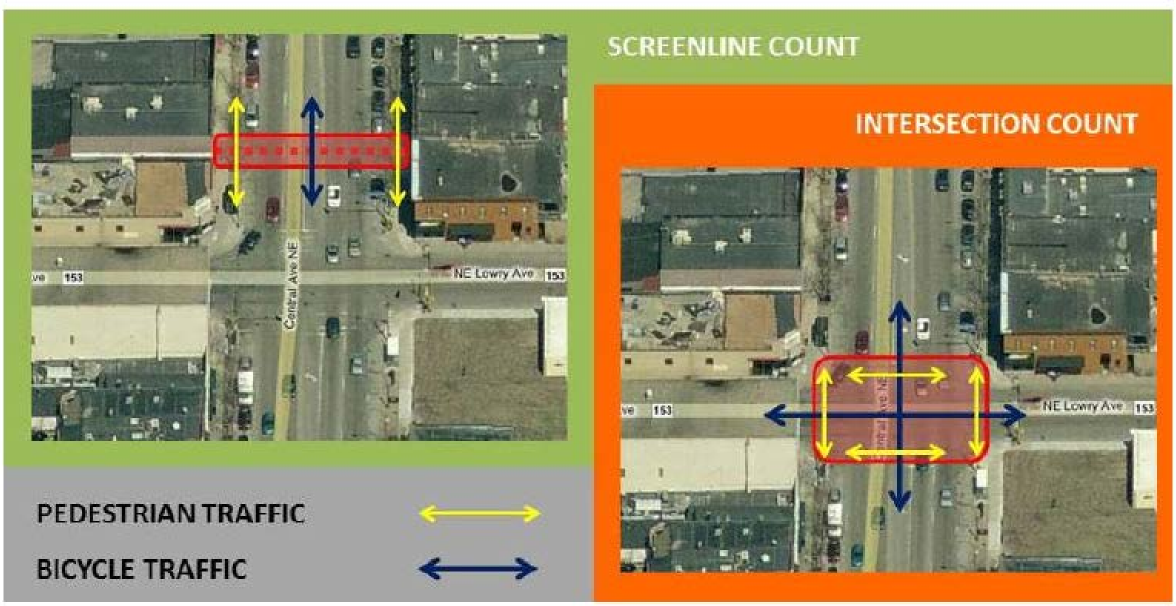
- No manual counts performed
- Less than 1 time per year
- 1 time per year
- 2 times per year
- More than 2 times per year

7. What types of locations do your pedestrian counts (manual and automated) cover?

Select all that apply. See image below for an illustration of differences between screenline counts and intersection counts.

- Sidewalk (screenline)
- Multi-use trail (screenline)
- Roadway intersection (turning count)
- Intersection crosswalk
- Mid-block crosswalk
- Other

Screenline Counts vs. Intersection Counts



8. What is your organization's experience with the following pedestrian count methodologies and technologies?

Manual counts with in-field staff or volunteers	
Manual counts from video	
Automated video counters	
Passive infrared	
Active infrared	
Laser scanners	
Infrared cameras	

9. Has your organization used other pedestrian count methodologies and technologies? If so, what are the names of the technologies and what was your organization's experience with them?

10. Which of the following data adjustment factor types (if any) have been applied to your pedestrian data?

Select all that apply

- ☐ Error correction factors (to adjust for under/over counting)
- ☐ Temporal adjustment factors (to account for higher/lower counts during certain times/days/seasons)
- ☐ Weather adjustment factors (to account for higher/lower counts in certain weather conditions)
- ☐ Land use adjustment factors (to account for different activity patterns near certain land uses)
- ☐ Other
- ☐ No adjustment

11. What applications does your organization use pedestrian volume data for?

Select all that apply

- ☐ Tracking increases/decreases in activity over time
- ☐ Project prioritization
- ☐ Risk/exposure analysis
- ☐ Before/after studies of new infrastructure
- ☐ Network modeling and/or estimating ADT
- ☐ Other ______

12. Have any of the following factors prevented your organization from collecting more pedestrian volume data?

Select all that apply

- ☐ Lack of staff time or volunteer interest
- ☐ Lack of technological tools to collect data
- ☐ Lack of knowledge of topic
- ☐ Lack of organizational interest or defined need for pedestrian or bicycle data
- ☐ Funding limitations/cutbacks
- ☐ Potential for unexpected results
- ☐ Not confident in the accuracy of current count efforts
- ☐ Other ______
- ☐ No, we currently collect as much volume data as we would like to

13. Are you satisfied with the process of pedestrian data collection and analysis that your organization uses?

- ○ Yes
- ○ No

The following questions address BICYCLE counts.

14. On average for a given count location, how frequently does your organization collect bicycle counts manually, with field data collectors?

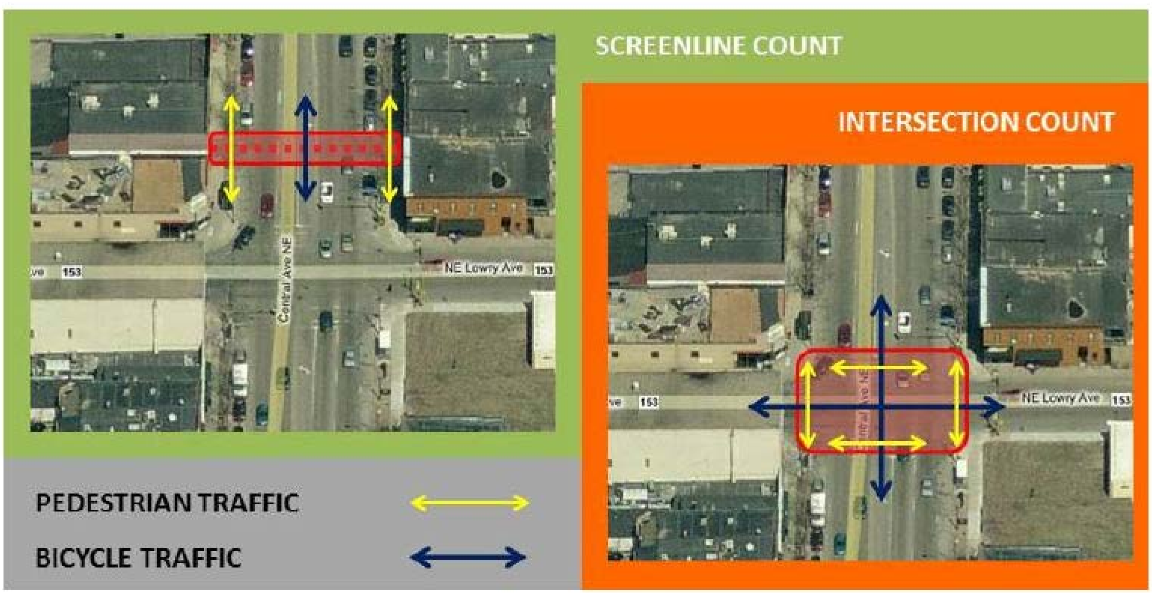
- ○ No manual counts performed
- ○ Less than 1 time per year
- ○ 1 time per year
- ○ 2 times per year
- ○ More than 2 times per year

15. What types of locations do your bicycle counts (manual and automated) cover?

Select all that apply. See the image below for an illustration of differences between screenline counts and intersection counts.

- ☐ On-street/sidewalk (screenline)
- ☐ Multi-use trail (screenline)
- ☐ Roadway intersection (intersection count)
- ☐ Roadway intersection (screenline)
- ☐ Mid-block roadway crossing (intersection count)
- ☐ Mid-block roadway crossing (screenline)
- ☐ Other ________

Screenline Counts vs. Intersection Counts



16. What is your organization's experience with the following bicycle count methodologies and technologies?

Manual counts	▾
Pneumatic tubes	▾
Piezoelectric strips	▾
Inductive loops	▾
Automated video counters	▾
Passive infrared	▾
Active infrared	▾
Laser scanner	▾
Infrared cameras	▾
Fiber optic pressure sensors	▾

17. Has your organization used other bicycle count methodologies and technologies? If so, what are the names of the technologies and what was your organization's experience with them?

18. Which of the following data adjustment factor types (if any) have been applied to your bicycle data?

Select all that apply

- ☐ Error correction factors (to adjust for under/over counting)
- ☐ Temporal adjustment factors (to account for higher/lower counts during certain times/days/seasons)
- ☐ Weather adjustment factors (to account for higher/lower counts in certain weather conditions)
- ☐ Land use adjustment factors (to account for different activity patterns near certain land uses)
- ☐ Other
- ☐ No adjustment

19. What applications does your organization use bicycle volume data for?
Select all that apply

- ☐ Tracking increases/decreases in activity over time
- ☐ Project prioritization
- ☐ Risk/exposure analysis
- ☐ Before/after studies of new infrastructure
- ☐ Network modeling and/or estimating ADT
- ☐ Other [ ]

20. Have any of the following factors prevented your organization from collecting more bicycle volume data?
Select all that apply

- ☐ Lack of staff time or volunteer interest
- ☐ Lack of technological tools to collect data
- ☐ Lack of knowledge of topic
- ☐ Lack of organizational interest or defined need for pedestrian or bicycle data
- ☐ Funding limitations/cutbacks
- ☐ Potential for unexpected results
- ☐ Not confident in the accuracy of current count efforts
- ☐ Other [ ]
- ☐ No, we currently collect as much volume data as we would like to

21. Are you satisfied with the process of bicycle data collection and analysis that your organization uses?

- ○ Yes
- ○ No

Earlier in the survey, you said that your organization maintains a database of non-motorized count data.

23. Which non-motorized modes are included in the database?
Check all that apply

- ☐ Pedestrians
- ☐ Bicycles

24. What types of counts are included in the database?
Check all that apply

- ☐ Manual
- ☐ Automated

25. What counting time periods are represented in the database?
Check all that apply

- ☐ AADT
- ☐ Monthly
- ☐ Daily
- ☐ Hourly
- ☐ 15 minute
- ☐ 5 minute

26. Who maintains your database?

- ○ We do
- ○ A consultant does
- ○ Another public agency does
- ○ Other ______

27. What type of software is used for your database?

- ○ Spreadsheet
- ○ Off-the-shelf desktop database software
- ○ Off-the-shelf server-based software
- ○ Vendor specific product
- ○ In-house customized software
- ○ Other ______

28. What is the name of the software?

29. Is your non-motorized count database linked to a database of motorized count data?

- Yes--it is part of the same database
- Yes--it can be linked easily through a unique ID field or other geographic identifier
- No--it is completely separate
- No--we do not have a database of motorized count data.

30. Do you have any additional responses related to these responses?

31. Would you or another representative of your organization be interested in taking part in a follow-up interview based on your survey responses?

- Yes
- No

32. If information about your counting program and/or your non-motorized count data is available online or summarized in a document online, please provide the website or location here.

If information about your counting program and/or counts is not available online, but is available as a PDF or Word document, please e-mail it to Paul Ryus at pryus@kittelson.com. (Total file size should not exceed 10 MB per e-mail. If an individual file is greater than 10 MB in size, please contact Jessica for an alternate way of sending it.)

The survey is complete. Thank you for taking the time to contribute to this important research.

100%

Appendix B: Practitioner Survey Results

The following tables supplement the tables and information presented in Chapter 3.

RESPONDENT LOCATIONS

State	Number of Respondents	State	Number of Respondents
Alabama	5	Missouri	6
Alaska	4	Montana	3
Arizona	8	Nebraska	2
Arkansas	1	Nevada	2
California	37	New Jersey	6
Colorado	13	New Mexico	4
Connecticut	2	New York	8
Delaware	1	North Carolina	24
District of Columbia	2	Ohio	9
Florida	8	Oklahoma	1
Georgia	4	Oregon	11
Idaho	2	Pennsylvania	8
Illinois	5	Rhode Island	2
Indiana	3	South Carolina	3
Iowa	2	South Dakota	1
Kansas	1	Tennessee	4
Kentucky	2	Texas	8
Louisiana	2	Utah	1
Maryland	3	Vermont	4
Massachusetts	9	Virginia	8
Michigan	5	Washington	8
Minnesota	6	West Virginia	1
Mississippi	1	Wisconsin	6

COUNT SITE SELECTION RESPONSES

bike traffic and bicycle facilities
"Expert judgement" selected points on important bicycle routes, aiming to limit overlap.
(1) project-by-project (2) cma congestion management locations (3) other
1. Based on a request for a share the road sign. 2. Collect data on a large event ride. 3. Site location for testing collection data equipment.
1. Regular bike counts at selected representative intersections throughout the city 2. As part of a specific infrastructure project 3. As required for development projects
According to criteria espoused by National Documentation Project: where there are gaps, crash history, improvements expected in the future, areas where there are various types of facilities and land uses, areas where bicyclists and pedestrians can be expected.
All schools are asked to collect data, so selection is based on time frame rather than on a site by site basis.
Annual counts are collected at 36 intersections as described here: http://www2.oaklandnet.com/Government/o/PWA/o/EC/s/BicycleandPedestrianProgram/OAK033011. Project by project counts are collected for traffic impact studies and for grant reporting.
annual counts are held based on past screen counts. project counts are used pre and post.
As part of our normal traffic safety investigations, if we see a pattern for pedestrian or bicycle collisions we may collect count data.
As part of research projects
As related to specific engineering requests for services within a specific location.
At locations where bike facilities are planned in order to collect before and after data; at locations that have high bike/ped volumes, but no facilities are planned, in order to demonstrate support and demand; and at locations that have facilities in order to track changes in use.
Based on a particular project's boundaries, we will count peds/bikes within that area.
based on committee recommendation
Based on environment of development
Based on local knowledge of potential intersections/routes, and geographic distribution
Based on project needs or perceived high demand/ use locations
Based on projects and citizen request
Based on the project needs.
Based on the relevance of the intersection to the project. For example, we'll count ped & bike data for development projects to gather a snapshot of what is going on for the current year.
Bicycle counts are done in locations that are part of the existing bikeway network (Class I, II, or III), or at proposed project locations. Less formal Pedestrian counts have been done at the same time on the Class I facilities (which are really Multi Use Paths). Counts are also done on a project by project basis, usually related to grant funding applications.
Bike-ped project or high interest areas
Bikes - 8 standing locations along established routes Project by project
busy intersections and bike paths

By geospatial selection, volume and type of user.
By project objective.
CDOT conducts monthly bike counts at 6 locations (starting in Jan 2012) during the AM/PM peak hours. The locations were selected based upon existing bike network, planned projects and geographic equity. CDOT also conducts quarterly counts at approx. 20 locations during a weekday AM/PM peak hours and Saturday midday. These locations surround the Central Business District (CBD) and are intended to capture the number of people entering and exiting the CBD by bike.
Certain sites were selected to fill knowledge gaps encountered in developing Chapter 16, Pedestrian and Bicycle Facilities, of TCRP Report 95, Traveler Response to Transportation System Changes handbook.
City of Omaha helps collect data for MPO to run travel forecasts. In general, our organization maintains current (not more than 5 years old) counts on major arterial streets. Then priority given on a project by project basis. Ped volumes are counted routinely as part of regular manual intersection counts (working to integrate bikes into mix).
Combination of legacy locations, major destinations, and major bike/ped project locations.
Combination of strategic locations where we want more infrastructure mixed with availability of volunteers
Count bikes at all bike parking in all 17 district school sites at least one or two times/year. Conduct annual transportation tally survey at all 12 elementary school sites 1X/year. Periodic on-street counts related to support for specific projects. Types of projects vary.
Count locations are chosen based on a number of factors, including if a location is along an existing or future major bike route, shared-use path, or bike boulevard, or if it is near a major traffic generator (such as the university or downtown). We also make sure to get counts in each of our member jurisdictions and to get a good geographical spread of locations throughout the region.
Data needs are defined as part of project scoping.
Depending on project requirements, existing infrastructure and available budget
Depends on specific project need.
Depends on the project, mostly manual, some automated sites for motor vehicles, and some cameras
Depends on the project. Sometimes based on needs associated with grant applications. More general counts look toward capturing commuting bikes.
Depends on the project... typically with research in mind
Discussion among staff
Each new large scale development must conduct a Transportation Impact Analysis (TIA) Report, among which includes bike and pedestrian counts at intersections near the development. Then our roadways are divided into tiers (1, 2 &3), based on importance, which are collected every 1, 2, and 4 years by a regional organization.
Ease of data collection and non-motorized volume.
east, west, north and south gateways into downtown and major gateways to the University of TN. Have tried other locations occasionally, near a school and along a corridor with new bike lanes.
Eco-Counter
Either on request or between logical termini.

existing identified need or based on professional judgment (i.e. location close to project site, on route to school, etc.)
Expert panel interactively selects on Google Maps application relative to population density, existing facilities, and other considerations.
Federal-aid designated roadways and by select corridor analyses. Primarily at intersections where manually counted. Approx. 150 sites / year.
First focus is on entry points/streets for the University since most people who come to the University live outside of the University. Second focus is on high-traffic crossing points/road intersections that people use to get across the campus.
First, locations that will capture bike commuting from all directions. Multi use paths. We asked our town engineers and planners which locations they would like to see counted. we also got input from some of our volunteer counters
For bicycle counts we choose locations that are on our major corridors or pre/post project implementation. For pedestrian counts we choose locations that have large attractors.
for capital project development
For our planning department, we select sites as part of the existing conditions report process. We have just started participating in the annual bike/ped counts in September. The locations were chosen by an engineer hired by a local government agency. The locations were based on: 1. existing infrastructure 2. roads with planned infrastructure (to establish baseline data) 3. areas we believed to be heavily used by pedestrians and bicyclists 4. areas where we had specific questions about usage
For specific projects, we may count pedestrians/bicyclists at key intersections near the project area. For our upcoming Pedestrian-Bicycle Plan Update, we selected key downtown streets and intersections, as well as some rail trail locations and areas of concern based on crash data and volunteer input.
Generally based on project by project and often determined by Client. In some cases sites will be visited and identified based on project requirements and evaluated.
high traffic urban intersections
Highest bike /ped crash locations
Identified locations in the City's Pedestrian Master Plan + with Traffic Impact Assessments (TIA) on large scale private developments
In 2008, sites representing a statistically valid sampling of the state was established and each year since more cities/sites have been added (voluntarily joined) the statewide count effort, but the original sites have been counted each year (5 years total) in order to observe any trends.
In conjunction with all other counts at intersections. Counts are done every 2-3 years or as needed for upcoming project assessment.
Initially by advice of a transportation engineer; we add intersections by consensus of the committee depending on our perceived needs for bicycle improvements.
Inuition, availability of volunteers affected ability to cover a site, coordination with counts by MPO
It's been more of project by project. Knowing that a roadway project is being designed for in the future. Some regions have included bike/ped counts in manual traffic counts done at signalized intersections. Other times staff has picked locations (trail crossings) to conduct at count at (this may be a manual or using a tube or pyro-electric counter).

Jointly determined with local downtown advocacy organization
Just bicycle counts who use the bike and ride system. Have not developed a ped or bike count outside of the bike and bus program
Key corridors, population densities, greenway facilities, university.
location that has a metric we wish to measure.
Locations are defined by both special requests and specific project instructions.
Locations selected for likely bicycle use.
Locations were non-motorized activity is evident, and/or where there are signs of such activity (such as goat paths for pedestrians or trail heads for bicyclists).
Look at areas that have increased Bicycle traffic
Major transportation corridors and school routes; also locations of major projects
Manual Counts Screenline and Intersection
Members of our group discuss and select
Most locations where intersection turning movement counts are performed, we collect pedestrian crossing and bike turning movement counts, too.
Mostly to be consistent with past collection sites, in order to facilitate before/after comparisons. Sometimes we add new sites when we find out about new projects (e.g. road diets).
National Bicycle and Pedestrian Documentation Project (spring/fall biannual surveys)
Needs.
Observed data; user recommendations
on a request/complaint basis
Once per year on Bike to Work Day
Our focus has been on collecting data on existing trails to find usage.
patron habits, parking areas,
Pedestrian counts are typically at a known crossing location near a school.
Pedestrian data is routinely collected with intersection turning movement counts.
Pedestrians and cyclists are counted anytime we conduct a peak hour turning movement count. We also conduct annual trail counts a
Places in downtown Wilkes-Barre likely to have pedestrian and bicycle traffic, and on trailheads of local trails.
Pre and post new facilities
Project areas which will be receiving new facilities or intend to receive them. Areas which have received new facilities. Areas and corridors where many users are.
Project location and need.
Project sites based on the projects selected for study. Continuous counts as budget allows for installation of devices
Prominent access points to campus, or in many cases they're dedicated facilities for bike parking.
Proximity to regional bicycle network
Public Request
Randomly by GIS

Relevant to the particular issue being investigated OR students select sites for fieldwork assignments
Requests by project managers and member governments
schools voluntarily submit tally data to the National Center for Safe Routes to School, housed at HSRC
Selection of count sites is based on a number of criteria - both high and low volume sites are counted, although an emphasis is placed on locations where we expect there to be a least some non-motorized traffic. Most of our count sites are along planned or existing projects in the City's Bike and Pedestrian Plans. This is allows us to track changes in traffic before and after a project is installed. We also have a number of sites that are simply counted out of curiosity.
Signal Warrant Study Locations Multi-Way Stop Warrant Study Locations School Zone Studies Special Ped Studies
Signalized intersections are counted on an on-going, rolling basis. Project locations are counted to capture "before" conditions. We have 11 permanent bike and/or ped counters in the field, all of which are on our principal off-road trail corridors. We have an additional three portable passive infrared detectors (Eco-Counter pyrobox) which are moved from place to place for shorter-term counts. We do an annual volunteer count (timed to contribute to the NBPD project). We just completed our 5th September count. Locations are typically chosen based on known safety issues, and known high bike/ped volumes.
Site/location specific data is collected as needed and/or required for project.
Sites are chosen based on project criteria and at natural cordon locations (bridges, bike lane intersections etc.)
Sites are selected based on proximity to current highway improvement project. The traffic analyst may specify that all or only selected modes be counted. The counts are typically used for basic capacity analysis, but occasionally for bike or ped needs.
Sites are selected based on three criteria: 1) site of new or planned bicycle or pedestrian infrastructure improvements; 2)representative of a particular neighborhood; or 3)area with high concentration of bike or ped crashes
Sites must be counted for environmental review on some projects, and we take counts on our bridges once each year
Sites selected for project-by-project counts are based on project location. Periodic counts are dispersed geographically to cover a range of facilities, neighborhoods, and traffic patterns.
Sometimes counts are done in conjunction with an vehicular traffic count at intersections. This past September 2012, the City and Rockingham County used the National Bicycle & Pedestrian Documentation Project methods to conduct a count. We selected counts by asking the City's Bicycle & Pedestrian Subcommittee and the County's Bicycle Advisory Committee for input on where they thought counts should be completed . For #5 we don't have a database per se, but we have an excel spreadsheet.
Staff selected sites
Surface type, paved only.
Surrounding destinations and/or population density, the presence of a bikeway or planned bikeway, stakeholder input, and previous count locations.
The client selects sites to collect data from and our TRADAS product stores all the count data.
The school board and FDOT do the counts. The TAC CAC and BPAC make Recommendations to the TPO Board based on the counts.
the sites were selected to aid in the preparation of the RTP, TIP, and UPWP.

Through an evaluation of the project area - homes, services, schools, employment - and the desire lines between these. We also look at accident data and will try to include disproportionately dangerous intersections.
Travel diary survey data is collected from specified geographic areas where marketing interventions are conducted. Random representative population respondents are surveyed before and after interventions to measure mode share change. The data is only collected when funding has been secured (2004, 2007, and 2009 only). WCOG participated in the annual nationwide pedestrian and bicycle count week in 2010 for two small cities. The number or people walking and cycling was too small to justify continuing the counts annually.
type of cycling users (commuter vs recreational); critical links to collect "screenline" type data, highest ped volumes, highest cycling volumes, before & after data (i.e. where we will be improving the network or we just have improved...)
Typically based project specific requirements
Typically on dedicated bike/ped facilities or infrequently, at on-street facilities
Typically overlaying various GIS land use layers to identify areas with large numbers of destinations and then sampling in this vicinity to get a sense of where people are coming from and going to.
Typically sites with and without high pedestrian- and bicycle-vehicle crash densities.
Usage on newly constructed trails and existing trails as needed.
Usually a local government agency will collaborate with the University to research an area of concern.
Visual Surveys and counters
We are currently conducting a study to determine he accuracy and feasibility of using pneumatic tubes to count bicycles.
We are developing a software application in HTML5 and later as an iOS and Android app. We have piloted our system on paper in one city and one town. The plan is to crowd source the data, hence locations are selected by the user and/or they have the option to "add" to a count that someone else has started. So far, locations are usually concentrated around schools, due to the types of people we have engaged - but not necessarily. We are developing the option of counting a line, point and area. The point being the one that dovetails best with current DVT collection strategies at the municipal level. The area is to enable us to capture parking lots, intersections, etc.. The points are to enable us to collect mode share at an institution or fixed place (O-D). Note that most counts include both Active and Morotizes modes, broken into sub-categories based on user needs types. That's why I answer "don't know" for all four count types in the fields for #6 - there is no option for a count of all traffic at the same time - which is what we intend to do.
We began collecting data this year at 4 locations throughout Rosmeount. These locations were selected based on perceived ped/bike activity and geographic balance. We also count participation at various pedestrian and bicycle events.
We collect along known trail systems of interest to planning and collect periodically along other trails within the MOA.
We collect data at funded SRTS program sites.
We collect data at locations on our bikeway network distributed geographically throughout the City.
We count at intersections surrounding our commuter rail station
We count each multiuse trail in the regional trail network as well as a few on street bikeways.

We count every off-street trail.
We count only our site
We count users of new infrastructure pieces (roundabout, cycletrack, etc.). We also respond to requests for improvements (crosswalks, stop signs, bike lanes, etc.) by counting users.
We established the locations with input from city engineers; keep consistent year to year so we can compare the data trends; occasionally add a location per city request
We have identified regionally significant locations that also adhere to some of our transportation demand model districts. We also used route choice data collected by smart phone and information from a travel survey to guide the placement of locations
We have selected 2 sites along our more heavily used on-street bikeway. We have counted a site along our busiest off street trail.
We have two counters on bicycle paths, one along the beach, and one entering town.
We have two permanent Eco Compteur Zelt inductive loop bike counters at strategic locations.
We identified the 14 intersections that we felt the data would be valuable for and would represent a cross-section of town.
We look at high volume locations or areas where planned improvements are pending to access success of new infrastructure.
We look for high-traffic sites, sites that have been counted previously, sites being considered for infrastructure changes, sites of interest to the organizations and agencies we partner with, and sites that have recently received improvements to bike facilities.
We partner with local community groups to perform bikeability assessments, which may include counts, and the local groups pick the sites.
We select our own sites and many are selected from meeting with our local RPC regional offices.
We select sites that have particular conditions of note that can help us answer specific research questions.
We selected areas that have consistent bike and pedestrian traffic on both our Class I Trails and on-street bike lanes.
We use popular multi-use trailheads
We work in national parks and outdoor recreation areas on cooperative research projects Sites are selected in conjunction with land managers based on project demands. They are frequently high traffic attraction sites, key intersections or trailheads.
We work with City and County staff to determine key count locations and corridors. We also vet these locations with local cyclists.
We work with local organizations and other agencies to determine where to count based on what type of information is desired. I.e. traffic volume, safety, before and after information, changes after public health strategies are done, Safe Routes to School studies and more.
We've been counting at several locations since 2005. I believe those locations were selected by MORPC staff working with the relevant advocacy groups and staff from public agencies in the region. We recently expanded the list of locations and eliminated a few. The new locations were added in an attempt to better represent the entire region, while the locations removed were due to low volumes or difficulty finding volunteers.
We've identified key route and corridors where we expect to improve sidewalks and bicycles lanes

when we analyse new projects with security issues when we work on transportation plans
Where there are problems
Wherever possible
With every 6-hour intersection count, bicycles and pedestrians are counted. Pre and post evaluation of pedestrian and bicycle projects (e.g. bike lanes) Establishing a baseline for pedestrian overpass usage- counting about 10 different ones per year until all (approx. 150) have been counted at least once. Annual Central Business District cordon count includes pedestrians and bicycles
www.saferoutesdata.org K-8 school travel mode and parent attitude data (about school travel) are collected voluntarily by local programs throughout the country and are entered into the National Center's online data system.
Yes (or dictated by client)
Yes, but it depends upon the scope of work.

NAMES OF DATABASE SOFTWARE

What is the name of the software?	Count of Response ID
Access	1
ArcGIS	1
ArcMap ultimate source.	1
ATR Data Processing	1
CountDracula	1
Depends on the equipment	1
Eco PC	1
Eco-Visio	1
Eco-Visio	1
Excel	33
Excel + SPSS	1
Excel for SS and datanet for vendor	1
Excel, Access	1
Excel, Midwestern Software Solution	1
file Maker Pro	1
file maker to access or excell for analysis - ports to GIS as well	1
I don't know. It will have a public-facing web display.	1
Microsoft	1
Microsoft Excel	1
Microsoft Excel and Access	1
Microsoft Excel	1

MioVision	1
MS Access	1
MS Excel	1
N/A	2
NA	1
not sure	1
not sure--need to ask SRTS folks	1
oracle database	1
Petra	2
Petra Pro and Eco-Counter	1
Postgres SQL	1
SPSS, MS Excel	1
to be determined, we have some ideas	1
TRADAS	2
Traffic Counts GIS	1
TrafficCountManagement by PTV	1
TrafX	3
TRAFx Datanet	1
Volunteers are trained to use Excel spreadsheets; master data is stored in Access	1
(blank)	20
Grand Total	**97**

Appendix C: Non-Motorized Count Programs Described in the Literature

Tables C-1 and C-2 provide examples of pedestrian and bicycle count programs in use by specific agencies or organizations within the U.S. that had been documented in the literature as of 2012. Chapter 3 provides additional examples identified through this project's surveys and interviews. Table C-3 summarizes the user interface elements of counting products identified in the literature.

Table C-1. Examples of Pedestrian Count Programs

Agency	Number of Sites	Count Frequency	Count Duration	Time Period	Count Method	Location Type	NBPD[1] Method	Site Selection Criteria
Minneapolis Public Works Department (2012a, 2012b)	23 annual sites 300 three-year sites	Annual and 3-year	2, 12, and 24-hour	Midweek Sept.	Manual	Mid-block screenlines	X	High traffic locations Range of facility types Near planned projects
Delaware Valley Regional Planning Commission (2012)	Numerous locations	2010-11	Weeklong		Automated	Mid-block screenlines		
BikeArlington (2012)	11 locations	Continuous	Continuous	Continuous	Automated	Trails	X	Trail locations
Portland Bureau of Transportation (2012, Portland State University 2012)	14 automated demonstration sites 156 manual sites	Automated: Continuous Manual: annual	Automated: Continuous Manual: 2-hour PM	Automated: Continuous Manual: Midweek July-Sept	Pushbutton actuations Manual	Bridges, paths, intersections	X	Bridges Trails Geographic diversity
Boston Region Metropolitan Planning Organization (2012)	500+ counts	Varies (1974 to present)	Varies		Manual	Varies		
Metropolitan Transportation Commission (San Francisco) (2012, Wilbur Smith Associates 2003)	100-150 sites	Periodic	2-hour	Midweek Sept./Oct. midday & PM	Manual	Intersections/ crossings	X	Bicycle count locations
Puget Sound Regional Council (2012)	384 sites	One-time (2010)	3-hour	Midweek Oct. AM and PM	Manual	Trails, intersections		

Agency	Number of Sites	Count Frequency	Count Duration	Time Period	Count Method	Location Type	NBPD[1] Method	Site Selection Criteria
San Francisco Municipal Transportation Agency (2011a)	25 manual sites per year Rotating automated counter sites	Annual	Manual: 2-hour Automated: 2-week	Manual: Midweek AM and PM Automated: continuous	Manual and automated	Intersections/ crossings		Geographic distribution Land use characteristics Demographic characteristics Proximity to transit
Mid-Ohio Regional Planning Commission (2010)	22 sites	Biannual	2-hour	AM and midday	Manual	Midblock screenlines	X	Activity areas or corridors Representative locations Key corridors Previous count locations Potential improvement areas High-collision areas
City of Glendale, California (Alta Planning + Design 2009)	24 sites	One-time (2009)	2-hour peaks	Weekday AM and PM Weekend midday	Manual	Intersections	X	Activity areas or corridors Representative locations Key corridors Previous count locations Potential improvement areas High-collision areas
Washington State Department of Transportation (2012)	229 sites	Annual	3-hour	Midweek Sept. AM and PM	Manual	Paths and midblock screenlines	X	Activity areas or corridors Representative locations Key corridors Previous count locations Potential improvement areas High-collision areas

Agency	Number of Sites	Count Frequency	Count Duration	Time Period	Count Method	Location Type	NBPD[1] Method	Site Selection Criteria
Colorado Department of Transportation (Jacobsen and Hudson 2012)	6 permanent sites 5 rotating temporary sites	Continuous	Continuous	Continuous	Automated	Trails/paths	X	

[1] National Bicycle and Pedestrian Documentation Project (2014).

Table C-2. Examples of Bicycle Count Programs

Agency	Number of Sites	Count Frequency	Count Duration	Time Period	Count Method	Location Type	NBPD[1] Method	Additional Data Recorded	Site Selection Criteria
Minneapolis Public Works Department (2012a, 2012b)	30 annual sites 300 three-year sites	Annual and 3-year	2, 12, and 24- Hour	Midweek Sept.	Manual and automated	Trails and midblock screenlines	X	• Sidewalk riding	• High traffic locations • Range of facility types • Near planned projects
Delaware Valley Regional Planning Commission (2012)	Numerous locations	2010-11	Weeklong		Automated	Mid-block screenlines			
BikeArlington (2012)	11 locations	Continuous	Continuous	Continuous	Automated	Trails	X		• Trail locations
Portland Bureau of Transportation (2012, Portland State University 2012)	14 automated sites 4 automated bridge sites 156 manual sites	Automated: Continuous Manual: annual	Automated: Continuous Manual: 2-hour PM	Automated: Continuous Manual: Midweek July-Sept.	Loop detectors Manual and automated	Bridges, paths, and intersections		• Bicycle delay • Helmet use • Gender • Turning movement	• Bridges • Trails • Bike routes Geographic diversity
Boston Region Metropolitan Planning Organization (2012)	500+ counts	1974 to present		Varies	Manual	Varies		• Varies	

Agency	Number of Sites	Count Frequency	Count Duration	Time Period	Count Method	Location Type	NBPD[1] Method	Additional Data Recorded	Site Selection Criteria
Metropolitan Transportation Commission (San Francisco) (2012, Wilbur Smith Associates 2003)	100-150 sites	Periodic (2002-04, 2010-11)	2- Hour	Midweek Sept/Oct Midday or AM and PM	Manual	Intersections/ crossings	X		• High bicycle collision rates • On the local or regional bicycle network • Proximity to major transit facilities • Proximity to schools and colleges/universities • Proximity to attractions/destinations
Puget Sound Regional Council (2012)	384 sites	One-time count (2010)	3-hour	Midweek Oct. AM and PM	Manual	Trails, intersections		• Turning movement • Helmet use • Bicycles on buses • Weather	
San Francisco Municipal Transportation Agency (2011b)	41 manual sites 16 automated sites		Manual: 2-hour Automated: Continuous	Manual: Midweek Sept. PM Automated: Continuous	Manual and automated	Intersections	X	• Wrong-way and sidewalk riding • Turning movement • Helmet use	• New bicycle facilities • Heavy transit/pedestrian sites • High bicycle traffic
Mid-Ohio Regional Planning Commission (2010)	22 sites	Biannual	2-hour	AM and midday	Manual	Midblock screenlines	X	• Sidewalk riding • Gender • Weather	• Activity areas or corridors • Representative locations • Key corridors • Previous count locations • Potential improvement areas • High-collision areas

Agency	Number of Sites	Count Frequency	Count Duration	Time Period	Count Method	Location Type	NBPD[1] Method	Additional Data Recorded	Site Selection Criteria
City of Glendale, California (Alta Planning + Design 2009)	24 sites	One-time count (2009)	2-hour	Weekday AM and PM Weekend midday	Manual	Intersections	X	• Helmet use • Wrong-way riding • Sidewalk riding	• Activity areas or corridors • Representative locations • Key corridors • Previous count locations • Potential improvement areas • High-collision areas
Washington State Department of Transportation (2012)	229 sites	Annual	3-hour	AM and PM Midweek September	Manual	Paths and midblock screenlines	X		• Activity areas or corridors • Representative locations • Key corridors • Previous count locations • Potential improvement areas • High-collision areas
Colorado Department of Transportation (Jacobsen and Hudson 2012)	6 permanent sites 5 rotating temporary sites	Continuous	Continuous	Continuous	Automated	Trails/paths			

[1] National Bicycle and Pedestrian Documentation Project (2014).

Table C-3. Literature Review Summary of Pedestrian and Bicycle Data Collection Methods and Technologies: User Interface

Technology	User Types	Count Type	Mobility	Ease of Installation	Count Storage Capacity	Battery Life
Manual counts	Both	Any	High	None-requires training	Human limitations	N/A
Manual counts with smartphone apps	Both	Any	High	None	Limited by device (iPhone/ iPad)	Limited by device
Manual counts with counting devices	Both	Any	High	None	180k-4 million records	90–270 days
Pneumatic tubes	Bikes	Screenline	Moderate-High	Easy	2 yrs.	290 days (MC5600) to 10 years (Eco TUBES)
Piezoelectric strips	Bikes	Screenline	No	Difficult (~2 hour installation time)		2 yrs.
Pressure or Acoustic Pads	Peds and Bikes separately (some able to distinguish bikes and peds)	Screenline	No	Difficult		10 yrs.
Loop Detectors – Temporary	Bikes	Screenline	Moderate-High	Easy	2 yrs.	2 yrs.
Loop Detectors – Embedded	Bikes	Screenline	No	Difficult	2 yrs.	1-2 yrs.
Active Infrared	Both	Screenline	Moderate-High	Moderate	1k-16k events, depending on model	8-12 months
Passive Infrared	Both	Screenline	High	Easy	1 year @ 15 minute count intervals	10 years (EcoCounter)
Laser Scanning	Both	Any	High	Easy		
Radio Waves	Both	Screenline	Moderate-High	Easy	1338 days at 1 hr count intervals	100 days
Video – Manual Analysis	Both	Any	Moderate	Moderate	Limited by camera	Limited by camera
Video – Automated Analysis	Both	Any	Moderate	Moderate	Up to 360 hours	72 hrs/7 days w/extra battery (Miovision Scout)