Bicycle and Pedestrian Counts at Signalized Intersections Using Existing Infrastructure

Opportunities and Challenges

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Bicycling and walking have gained increased attention recently; however, systematic bicycle and pedestrian counts are still scarce. At intersections, transportation agencies are interested in counting bicycles and pedestrians and leveraging for counting purposes, if possible, existing signal detection equipment. This study evaluated four counting technologies: inductive loops and a thermal camera to count bicycles and passive infrared counters and pedestrian signal actuation data to count pedestrians. The four technologies were tested in a parking lot (controlled environment) and in an intersection (real-world environment). The findings revealed that while the inductive loops and thermal camera counted bicycles accurately in a controlled environment, the loops and cameras failed to do so at an intersection. Passive infrared counters were found to count pedestrians accurately at the intersection sidewalk, and pedestrian signal actuation data could be a cost-effective surrogate for pedestrian demand at signalized intersections.

While motorized traffic counts are systematic and comprehensive, bicycle and pedestrian counts are often unknown. During the past decade, there has been increased interest in counting pedestrians and bicycles and establishing nonmotorized counting programs. However, transportation agencies still struggle with how to integrate bicycle and pedestrian counting into standard practices.

Recognizing the importance of nonmotorized counts, an entire chapter of the 2013 edition of the FHWA *Traffic Monitoring Guide* was devoted to bicycle and pedestrian counting methods and technologies (*1*). Continuous advancement in bicycle detection has led to the development of a variety of technologies capable of counting bicycles; these technologies were tested in a recently released NCHRP study. Equipment tested included inductive loops, piezoelectric strips, passive and active infrared counters, radar, and video image processing for counting bicycles as well as passive and active infrared counters, video image processing, and pressure pads and laser scanners for counting pedestrians (*2*). However, not all technologies listed here are suitable for counting bicyclists and pedestrians at intersections.

Previous studies have investigated the suitability of using existing signal detection equipment to count cyclists and pedestrians (*3, 4*). The findings revealed that while using pedestrian signal actuations was a cost-effective way to measure pedestrian activity, counting bicycles with existing loops proved challenging. Recently, thermal cameras have emerged as a noninvasive detection technology for intersections. Unlike traditional video cameras, they are not influenced by ambient light conditions. In addition, as they are noninvasive, they are less likely to suffer from wear and tear than are inductive loops.

The goal of this study was to build on previous work by further investigating under what conditions existing bicycling and pedestrian detection infrastructure can be cost-effectively integrated into the current signal operation systems of the Oregon Department of Transportation (DOT). While both short-duration and continuous count technologies were evaluated as part of the Oregon DOT study, the focus of this paper is on continuous count technologies for bicycles and pedestrians at signalized intersections.

Inductive loop detectors and thermal cameras were evaluated for bicycle counting abilities at two locations: in a bicycle-only controlled environment and at a suburban intersection in mixed traffic. These two conditions represent the simplest and most challenging environments in which to count bicycles. In the controlled environment, the authors evaluated the accuracy of inductive loops (parallelogram configuration) and a thermal camera under a variety of conditions. Conditions included varying the distance between bicycles (one behind the other and side by side), special bicycle configurations (carbon fiber composition, tandem bicycles, cargo bicycle, and bicycles with trailers), and the direction of travel. The evaluation under mixed traffic conditions was conducted at a suburban signalized intersection on two approaches with an annual average daily traffic greater than 10,000 vehicles by using both parallelogram and diamond loop configurations.

Pedestrian count technologies—pedestrian signal actuations and passive infrared counters—were evaluated at the suburban intersection only. This paper presents the findings of the evaluation. The rest of this paper is laid out in the following manner. The next section covers the background and presents the relevant literature. The methods adopted to evaluate the technologies are then presented, followed by results and conclusions.

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BACKGROUND

This section reviews only the four technologies tested in this study: inductive loops and thermal cameras for counting bicycles and pedestrian signal actuations and passive infrared detectors for counting pedestrians.

Inductive Loops

Inductive loops are commonly used to detect and count motor vehicles. The prevalence of inductive loops and the jurisdictions' familiarity with them make this technology an appealing choice for bicycle counting. Inductive loops are capable of detecting bicycles (usually the wheels) as a result of a change in electromagnetic inductance as a metallic object passes over the loop. The parallelogram, quadrupole, and diamond shapes shown in Figure 1 are known to be able to detect and count bicycles (*2–5*) and generally report less error in situations in which motor vehicles and bicycles are separated (*5*).

The Eco-Counter ZELT is the most widely tested inductive loop product for differentiating bicycles from motorists and has been found to have had success at this task using diamond-shaped loops in mixed traffic (*5*). The parallelogram- and quadrupole-shaped loops have been found to be capable of producing accurate counts when motorists do not drive over the loops (*5–7*). A previous research study by Portland State University researchers revealed difficulties in counting bicycles with diamond-shaped inductive loops that are not able to differentiate bicycles from motor vehicles (*3*).

Thermal Cameras

Thermal cameras detect the presence of vehicles by observing heat images and looking for changes from image to image. A bicyclist can be detected because cyclists generate heat and can be differentiated from other heat-emitting objects, such as motor vehicles, by their shapes. This ability is similar to video image recognition but has the potential to function during poor light or weather conditions that would affect video images. FLIR's TrafiSense thermal traffic camera was chosen for this study because of the manufacturer's claim that the technology is capable of differentiating between the thermal image emitted by vehicles and bicycles and the Oregon DOT's interest in its use for traffic signal detection purposes. At the time of the study, there was no published peer-reviewed research on the effectiveness of using thermal camera signal-detection equipment for bicycle counting.

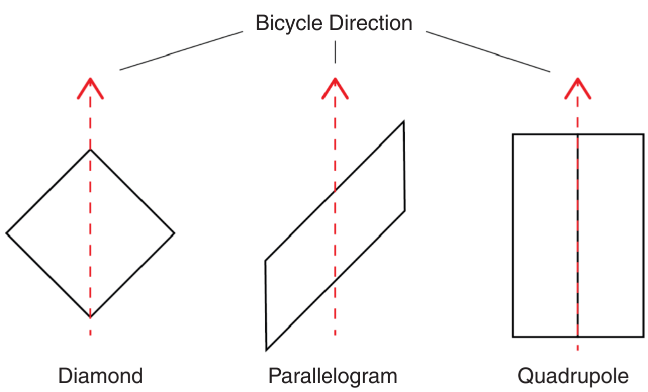


FIGURE 1 Inductive loop geometry.

Passive Infrared Counters

Passive infrared devices detect pedestrians and bicyclists by comparing the ambient temperature with the infrared radiation emitted by people passing in front of the sensor (*2*). These devices cannot distinguish between pedestrians and bicyclists; however, they are often used in conjunction with other bicycle counting technologies, such as inductive loops or pneumatic tubes, to allow for separate counts of bicyclists and pedestrians. In such a case, the pedestrian count is obtained by subtracting the bicycle count from the combined count. While positioning the device appropriately is critical for accuracy, occlusion and extreme ambient temperatures can affect device performance (*2*). Most studies have shown that these devices undercount pedestrians, with an increase in the rate of undercounting as the pedestrian volumes increase (*2, 8–10*).

Pedestrian Signal Actuations

The purpose of push buttons at intersections is to allow pedestrians to request the pedestrian phase to cross an intersection. A few studies have investigated the possibility of using pedestrian push-button actuations as a proxy for pedestrian demand at an intersection (*3, 4, 11*). These actuations can be used as proxies for pedestrian counts at the intersections. An intersection-specific factor can be calibrated to translate actuations into counts (*3*). However, more research is needed to understand the accuracy and transferability of this approach.

METHOD

The method for evaluating these technologies consisted primarily of two sets of tests for bicycle counting technologies and one set for pedestrian counting technologies. For bicycles, to understand whether these technologies could count bicycles under ideal conditions and what types of bicycle-specific conditions might prevent accuracy, tests were performed first in a controlled environment. Technologies that were successful in counting bicycles in the controlled test were then tested in the mixed traffic conditions at the test intersection. The parallelogram was tested in a bicycle-only controlled environment, and the diamond and the parallelogram were tested in the suburban intersection with mixed traffic. The thermal camera was tested in the controlled environment and at the suburban intersection with mixed traffic. Pedestrian signal actuations and passive infrared counters were tested as part of the mixed traffic test at the suburban intersection.

Controlled Environment Test

Testing under a controlled environment was performed in the parking lot of the Oregon DOT's traffic systems service unit in Salem, Oregon, on February 23, 2015, with mild weather and a high of 60°F. This location has been described previously (*12*). The testing consisted of morning and afternoon sessions. Both sessions consisted of a standard bicycle test and a test of special bicycle configurations. For both sessions and in both standard and special bicycle tests, cyclists were asked to ride over the detection zones in first one direction and then in the opposite. The special bicycle test included distance between bicycles, special bicycle configurations (e.g., carbon fiber frame, tandem bicycle, cargo bicycle, and bicycle with trailer), and direction of travel.

Detection occurs when the inductance change is measured by a signal detection card. During the controlled environment test, two detection cards were evaluated for the parallelogram loops: Reno A&E Model C-1101 B and EDI, Inc., Model LM222. The Reno A&E Model C-1101 B was designed for the Type 2070 signal controller and is designed to differentiate between bicycles and motor vehicles in addition to extending the minimum green times for detected bicycles. The EDI, Inc., Model LM222 was not designed to distinguish between bicycles and motor vehicles and is therefore restricted to bicycle lanes with a low probability of motor vehicle traffic. The Reno A&E Model C-1101 B and the EDI, Inc., Model LM222 detection cards were tested with the parallelogram loop configuration delineated with zones depicted in Figure 2 with the use of standard and special bicycle configurations.

FLIR's TrafiSense thermal camera was also tested during the controlled environment test. A rectangular zone simulating a short bicycle lane was outlined as the detection area in the closed parking lot.

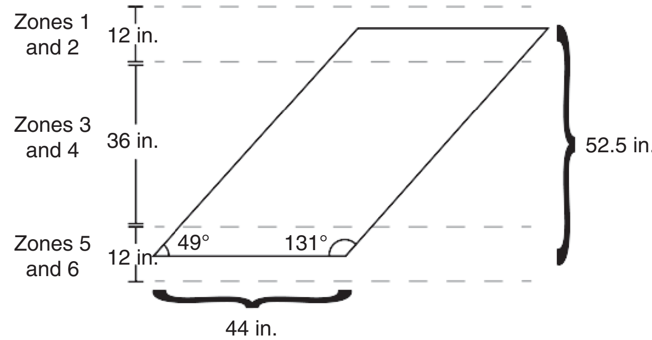


FIGURE 2 Parallelogram loop zones.

Mixed Traffic Test

The mixed traffic test was conducted at the intersection of Hall Boulevard and 99 West in Tigard, Oregon, from September 8, 2015, to September 11, 2015, with high temperatures between 80°F and 95°F with no precipitation. This intersection was chosen because it is a typical suburban intersection with high levels of motorized traffic and sufficient bicycle and pedestrian traffic for testing. In addition, a previous study conducted tests at this intersection and provided a basis for comparison. Figure 3 shows the intersection layout as well as locations of the video (ground truth) and thermal cameras, inductive loops, pedestrian push buttons, and passive infrared counters. Three cameras mounted on poles were used to record video that was later used to obtain ground truth counts.

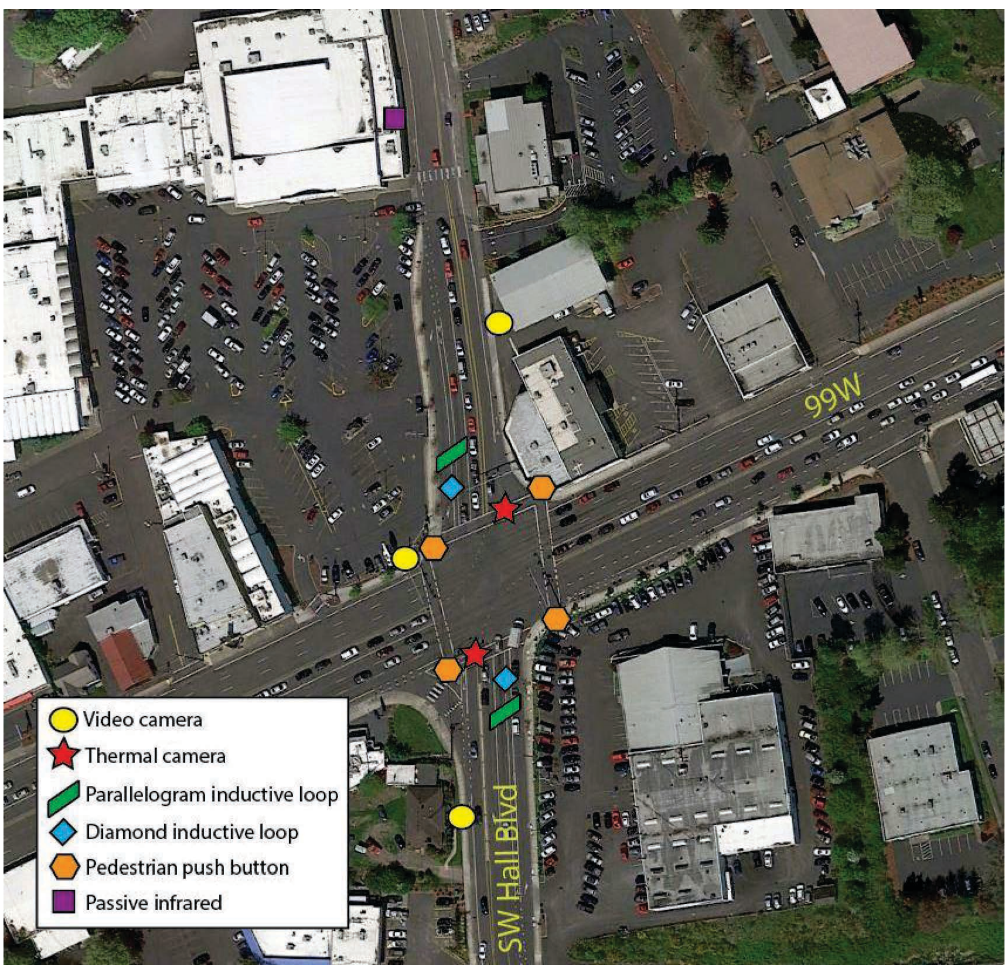


FIGURE 3 Equipment location for mixed traffic test.

Parallelogram and diamond loops were installed in succession in the northbound and southbound bike lanes to ensure that both counters were counting the same bicyclists. The FLIR TrafiSense thermal camera was installed on luminaire arms for the northbound and southbound approaches on Southwest Hall Boulevard to detect bicycles and pedestrians in the left- and right-turn lanes, bicycle lane, and adjacent sidewalk. A passive infrared counter, an Eco-Counter PYRO Box, was installed on a signpost according to the manufacturer's specifications to detect pedestrians and cyclists traveling along a sidewalk near a commercial shopping center. The box was mounted in a position such that the infrared sensor was 27 in. above the sidewalk. The sensor was positioned to point directly toward the brick wall of a commercial building.

Ground Truth

For the purpose of determining the accuracy of the counting technologies for both tests, the authors reviewed video footage to determine whether each bicycle was detected by the counting device. Two types of video cameras were used to gather video footage at this intersection for deriving ground truth counts.

Performance Metrics

The performance metric used for analysis in this study is overall error. To compute this metric, the counts from the automated equipment were compared with ground truth counts. The ground truth for the controlled environment and special cases tests was the count collected by manual counters in the field; that count was later verified by video counts. The ground truth for the mixed traffic test was manually counted video.

Overall error was calculated as the difference between the ground truth and counting equipment count divided by the total ground truth count for the study period as explained in Equation 1.

$$\text{overall error} = \frac{c - m}{m} \qquad (1)$$

where c is the device count and m is the ground truth count from video observation.

BICYCLE RESULTS

Results from the controlled environment and the mixed traffic tests are reported below.

Controlled Environment

Inductive Loop

The Reno A&E Model C-1101 B significantly undercounted standard bicycles traveling along the edge of the parallelogram loop (Zones 1 and 2 and 5 and 6) by 93% and 97%, respectively. However, standard bicycles traveling through the center of the loop (Zones 3 and 4) were detected with a 1% undercount. The undercount along the edges was attributed to the way in which the Reno A&E detector card was designed to function. Conversely, the EDI, Inc., Model LM222 detector card significantly overcounted standard bicycles traveling through the center of the loop (Zones 3 and 4) by 64%. However, standard bicycles along the edges of the parallelogram loop (Zones 1 and 2 and 5 and 6) were detected with a 2% error. The overcounts may have been the result of the sensitivity level being set too high.

With special cases, errors were high with the Reno A&E card for bicyclists riding one behind the other (48%) and those riding side by side (100%). Higher inaccuracies were observed with the EDI card while tandems and bicycles with trailers (22%), bicyclists riding one behind the other (18%), and those riding side by side (43%) were counted. Errors were low (less than 5%) for the carbon fiber and cargo bicycles.

Thermal Camera

For the controlled environment test, a rectangular zone was created and taped off. Only cyclists riding toward the camera were designed to be counted, so only such cyclists were included in the computation of error. The thermal camera had less than a 1% overall error when standard bicycles were being counted and was very accurate in counting tandems, bikes with trailers, carbon fiber, and cargo bicycles. Higher inaccuracies were observed when bicyclists riding one behind the other and side by side (errors of about 20%) were counted.

Mixed Traffic Test

Diamond and Parallelogram Loops

The bicycle counts recorded by the diamond and parallelogram loops were compared with those obtained from video for the northbound and southbound approaches of Hall Boulevard in the bike lane only. Bicyclists riding on the sidewalk, therefore, were not counted. In locations where bicycles often ride on the sidewalk, such as at this site, additional loops could be installed in the sidewalks to capture that volume. That situation was not tested in this study, because counting bicycles in nonmotorized facilities has already been tested and found to be accurate when equipment is properly installed (*2, 5*). Instead, this study focused on the more challenging task of counting bicycles with loops in mixed traffic. The comparisons of ground truth with inductive loop counts were made for data starting at 11 a.m. on September 8, 2015, and ending at 7:30 a.m. on September 11, 2015. Also, because the video data were available only from 6:30 a.m. to 7:30 p.m. each day, the comparisons on September 9 and 10 were limited to those time periods. For both approaches, the diamond loops were equipped with the EDI detector cards, which were not designed to distinguish between motor vehicles and bicycles. The parallelogram loops were equipped with Reno A&E cards that were designed to distinguish between bicycles and motor vehicles. Table 1 shows the comparison between bicycles detected by the parallelogram and diamond loops and ground truth counts. A significant overcount was observed for the diamond and parallelogram inductive loops on northbound and southbound approaches. The overcount was slightly less for the parallelogram inductive loop on the southbound approach. This finding may be the result of its location at the intersection, which may have fewer motor vehicles passing over the loop.

TABLE 1 Parallelogram and Diamond Loop Errors

	Northbound			Southbound		
Loop Shape	Ground Truth	Loop Count	Error (%)	Ground Truth	Loop Count	Error (%)
Diamond	108	706	553	105	668	536
Parallelogram	108	566	424	105	276	162

TABLE 2 Comparison of FLIR and Ground Truth Counts

		Northbound			Southbound		
Zone	Facility	Ground Truth	Thermal Camera Count	Error (%)	Ground Truth	Thermal Camera Count	Error (%)
1	Sidewalk[a]	65	20	−69	122	34	−72
2	Right turn[b]	5	207	4,040	9	57	533
3	Bike lane[b]	104	63	−39	113	59	−48
4	Left turn[b]	3	14	367	1	22	2,100

[a]Ground truth for the sidewalk includes the number of bicyclists and pedestrians coming toward the camera.
[b]Ground truth is bicycles only.

Thermal Camera

The FLIR thermal camera was set up to count bicycles (and pedestrians in one zone) in four zones on the northbound and southbound approaches of Hall Boulevard. The zones were designated as follows: Zone 1, sidewalk; Zone 2, right-turn lane; Zone 3, bike lane; and Zone 4, left-turn lane. The bicycle counts obtained from the thermal camera for each of these zones were compared with the ground truth counts obtained from the video data as seen in Table 2. For Zone 1, the manufacturer indicated that the thermal camera was designed to count all bicycles and pedestrians coming toward the camera. For that reason, the ground truth included all bicyclists and pedestrians coming toward the camera in Zone 1, but only bicyclists in the other zones. However, cyclists represented 13% of sidewalk use in all directions during the period observed. For Zones 2 and 4, thermal camera counts were higher than the ground truth for both approaches, indicating that the thermal camera was classifying motor vehicles as bicycles in these zones. The overcounting was especially pronounced for the right-turn lane in the northbound approach and for the left-turn lane in the southbound approach. However, for Zone 3 (i.e., the bike lane), the thermal camera undercounted bicycles compared with the ground truth counts.

Further analysis explored the differences between thermal camera counts and ground truth counts in the bike lane (Zone 3). The time stamp of each bicycle count recorded by the thermal camera was used to identify whether a corresponding count was recorded in the ground truth data. False positives are defined as counts that were recorded by the thermal camera but were not present in the ground truth data. False negatives are defined as counts that were not recorded by the thermal camera but were present in the ground truth data.

Table 3 shows the results of this analysis. The northbound and southbound approaches both showed a higher incidence of undercounts (49%) than overcounts. The false negatives explain the undercounting phenomenon for bike lane counts (Zone 3) as seen in Table 2. In addition, a number of false negatives occurred during the late afternoon and early evening hours and indicated a potential effect of temperature on count accuracy. However, more research is needed to understand the effects fully.

Because the video captured by the thermal camera during the actual testing was unavailable, 4 h of supplemental thermal camera video for the southbound approach were analyzed from the same intersection on September 3, 2015, from 1:00 to 5:00 p.m. Figure 4 shows common sources of false positives counted by the FLIR thermal camera. Many vehicles with irregular shapes and sizes, such as trucks with protruding equipment and cars with roof attachments, appear to be common sources of false positives.

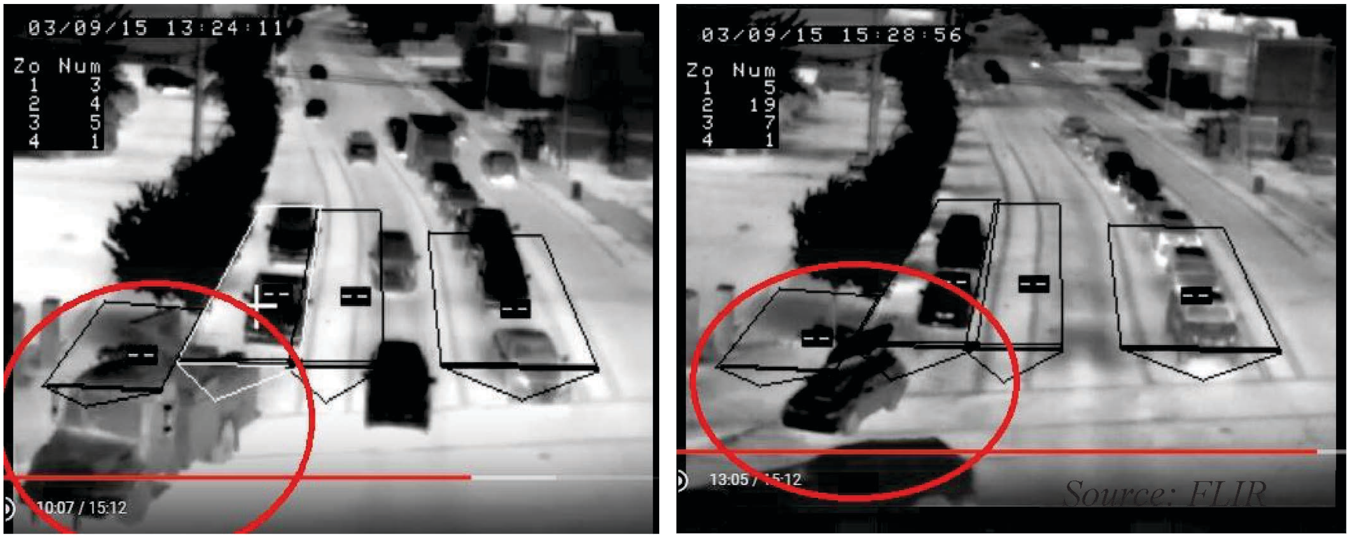
PEDESTRIAN RESULTS

Sidewalks: Passive Infrared

The Eco-Counter PYRO Box was mounted on a pole and recorded pedestrians on the sidewalk beginning September 9, 2015, through to September 11, 2015. Only morning hours could be included because shadows obscured the sidewalk at other times, such that researchers could not identify pedestrians in the video. Counts from the PYRO Box were compared with the ground truth counts obtained from the video. In the 12-h period, 78 pedestrians and 12 bicyclists were observed on the sidewalk. The overall error for the time period was a 4% overcount. Figure 5 shows the relationship between PYRO

TABLE 3 FLIR False Positives and Negatives in Bike Lane

	Northbound		Southbound	
Counting Error	Count	Percentage	Count	Percentage
False positive	6	6	4	4
False negative	50	49	55	49



(a) (b)

FIGURE 4 FLIR sources of false positives in right-turn lane: (*a*) trucks with protruding equipment and (*b*) cars with roof attachments.

Box counts and the video counts (ground truth). The solid diagonal line indicates a perfect match between PYRO Box counts and the video counts. More points in the plot are above the solid line than below it, indicating that the PYRO Box is overcounting in more cases than it is undercounting compared with video counts.

Greater error (false negatives and false positives) was observed in the southbound direction of travel. Although the exact cause of the false negatives is unknown, as many as four detections, or 80% of false positives in the southbound direction, may have been cyclists. The reason is that cyclists were assumed to be traveling in the adjacent bicycle lane but were indistinguishable in the video from cyclists on the sidewalk.

Intersection Crossings: Pedestrian Push Buttons

The pedestrian crossings classified as ground truth were observed from the video recording beginning September 8, 2015, at 3:00 p.m.

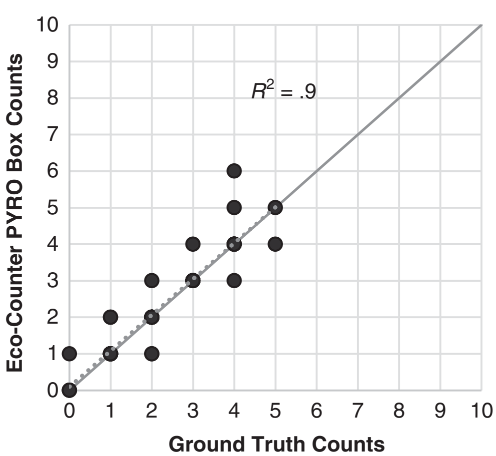


FIGURE 5 Comparison of Eco-Counter PYRO Box and ground truth counts.

through to September 11, 2015, at 9:00 a.m., from 7:00 a.m. to 6:00 p.m. daily. These counts were compared with the pedestrian phases logged by the signal controller. The phase data were obtained from the measures of effectiveness logs from the signal controller. Table 4 presents the pedestrian counts and pedestrian phases from the signal controller logs by location of crosswalk with respect to the intersection. A ratio of pedestrian volume to pedestrian phases is also estimated and presented in Table 4. These ratios can be used as adjustment factors to estimate pedestrian volume if pedestrian phase information is known. The north, south, and west crosswalks had ratios greater than one, indicating higher numbers of crossing pedestrians than pedestrian phases. This finding, in turn, implied that more than one pedestrian was crossing per phase at these crosswalks. Conversely, the east crosswalk had a ratio of less than 1. Scatterplots showing the relationship between pedestrian phases and pedestrian volumes by each crosswalk per hour are shown in Figure 6. At all four crosswalks, there is evidence of a linear relationship between pedestrian volumes and pedestrian phases as indicated by the R^2-values.

The ratios of pedestrian volumes to pedestrian phases as well as scatterplots were compared with previous research findings for which similar analysis was conducted (*3*). The ratios and R^2-values were fairly similar across both studies.

CONCLUSIONS

Test results revealed that inductive loops and a thermal camera could accurately count bicycles under controlled conditions but not at an intersection in mixed traffic conditions. It is not recommended to use loops and a thermal camera in mixed traffic at intersections for combined counting and detection purposes at this time (*13*). However, if the loop or thermal camera can be placed in a bicycle-only environment, such as a separated bike lane, loops could be a viable option for counting and detecting bicycles. Loop and thermal camera configurations and algorithms to separate bicycles from motor vehicles are continuously being refined by vendors. Therefore, as these new configurations and algorithms become commercially available, further testing is warranted.

TABLE 4 Video Counts Versus Pedestrian Counts

	Count by Crosswalk				
Parameter	North	South	East	West	Total
Pedestrian volume (video counts)	217	173	150	278	818
Pedestrian phases (2,070 data)	190	145	158	230	723
Ratio (pedestrians/phase)	1.14	1.19	0.95	1.21	1.13

Pedestrian counting technologies performed well at the intersection. Collecting and archiving pedestrian phase calls from the Oregon DOT traffic signals is a low-cost approach to measure pedestrian activity at signalized intersections around the state. Further research can study how these phase calls relate to actual counts depending on time of day, weather, and surrounding land use. Passive infrared can work well to count pedestrians in a pedestrian-only environment with low pedestrian traffic and few people walking side by side. Site selection is key for the success of this technology. Appropriate considerations for device placement include a narrow pedestrian facility, the availability of a pole to mount the device, and having the infrared beam pointed toward a nonreflective, nonmoving surface.

Bicycle and pedestrian counting is a more challenging task than counting motor vehicles and should be approached with attention to detail. Regardless of which equipment is used, verification testing should be conducted and care should be taken in setting up the equipment and processing the data.

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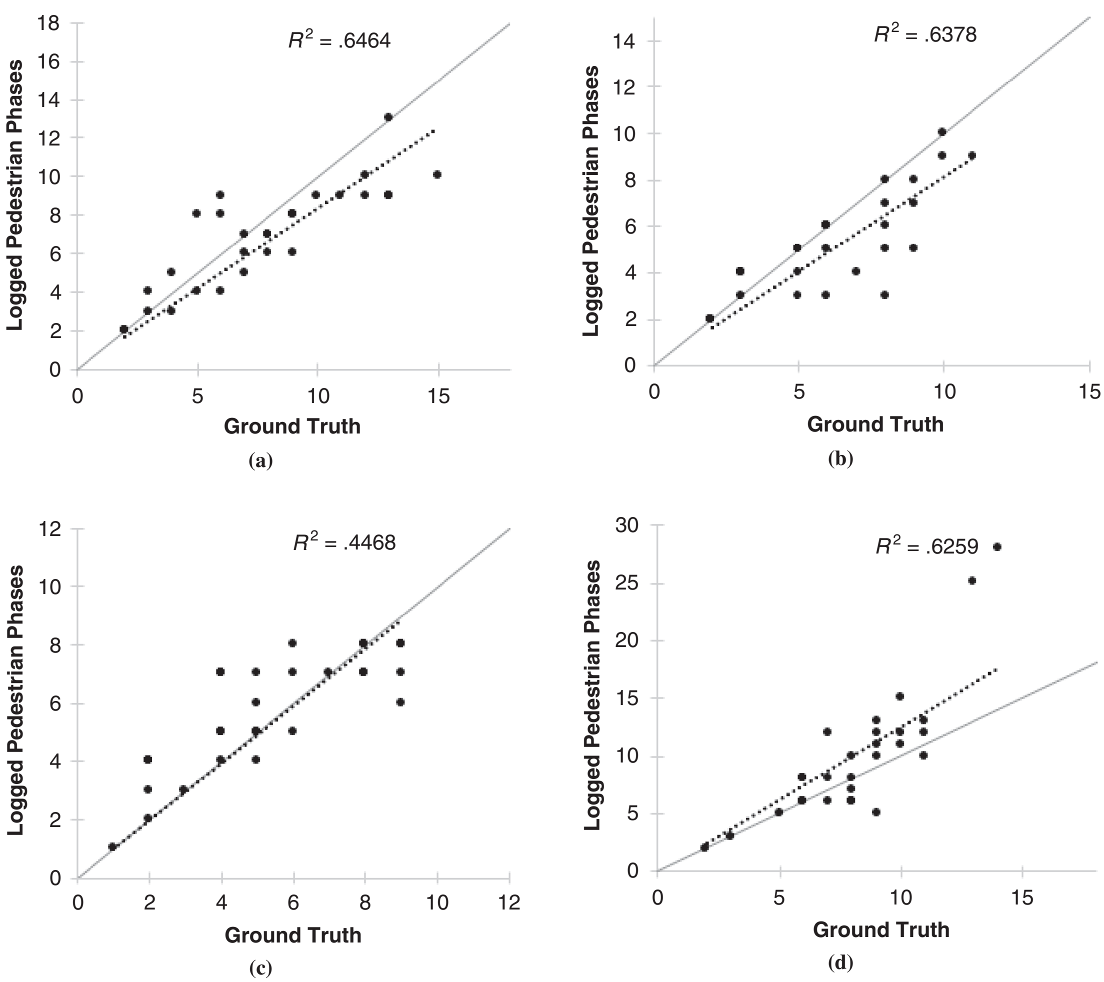

FIGURE 6 Scatterplots of hourly video counts versus hourly logged pedestrian phases: (*a*) north crosswalk, (*b*) south crosswalk, (*c*) east crosswalk, and (*d*) west crosswalk.

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REFERENCES

1. *Traffic Monitoring Guide.* FHWA, Department of Transportation, Washington, D.C., 2013.
2. Ryus, P., E. Ferguson, K.M. Laustsen, R.J. Schneider, F.R. Proulx, T. Hull, and L. Miranda-Moreno. *NCHRP Report 797: Guidebook on Pedestrian and Bicycle Volume Data Collection.* Transportation Research Board of the National Academies, Washington, D.C., 2015.
3. Blanc, B., P. Johnson, M. Figliozzi, C. Monsere, and K. Nordback. Leveraging Signal Infrastructure for Nonmotorized Counts in a Statewide Program: Pilot Study. *Transportation Research Record: Journal of the Transportation Research Board,* No. 2527, 2015, pp. 69–79. http://dx.doi.org/10.3141/2527-08.
4. Kothuri, S.M., T. Reynolds, C.M. Monsere, and P. Koonce. Preliminary Development of Methods to Automatically Gather Bicycle Counts and Pedestrian Delay at Signalized Intersections. Presented at 91st Annual Meeting of the Transportation Research Board, Washington, D.C., 2012.
5. Nordback, K., D. Piatkowski, B.N. Janson, W.E. Marshall, K.J. Krizek, and D.S. Main. Using Inductive Loops to Count Bicycles in Mixed Traffic. *Journal of Transportation,* Vol. 2, No. 1, 2011, pp. 39–56.
6. Nordback, K., and B.N. Janson. Automated Bicycle Counts: Lessons from Boulder, Colorado. *Transportation Research Record: Journal of the Transportation Research Board,* No. 2190, 2010, pp. 11–18. http://dx.doi.org/10.3141/2190-02.
7. Veenstra, S.A., T. Thomas, and K.T. Guers. Monitoring Urban Bicycle Volumes Using Inductive Loops at Signalized Intersections. Presented at 92nd Annual Meeting of the Transportation Research Board, Washington, D.C., 2013.
8. Greene-Roesel, R., M. Diogenes, D. Ragland, and L. Lindau. *Effectiveness of a Commercially Available Automated Pedestrian Counting Device in Urban Environments: Comparison with Manual Counts.* Paper UCB-ITS-TSC-RR-2008-5. University of California, Berkeley, Traffic Safety Center, Berkeley, 2008.
9. Schneider, R.J., L.S. Arnold, and D.R. Ragland. Methodology for Counting Pedestrians at Intersections: Use of Automated Counters to Extrapolate Weekly Volumes from Short Manual Counts. *Transportation Research Record: Journal of the Transportation Research Board,* No. 2140, 2009, pp. 1–12. http://dx.doi.org/10.3141/2140-01.
10. Turner, S. *Technical Memorandum: Task 5—Summary of Preliminary Trial Counter Evaluations,* Feb. 22, 2012.
11. Day, C.M., H. Premachandra, and D.M. Bullock. Rate of Pedestrian Signal Phase Actuation as a Proxy Measurement of Pedestrian Demand. Presented at 90th Annual Meeting of the Transportation Research Board, Washington, D.C., 2011.
12. Nordback, K., S. Kothuri, T. Phillips, C. Gorecki, and M. Figliozzi. Accuracy of Bicycle Counting with Pneumatic Tubes in Oregon. *Transportation Research Record: Journal of the Transportation Research Board,* No. 2593, 2016, pp. 8–17. http://dx.doi.org/10.3141/2593-02.
13. Nordback, K., S. Kothuri, M. Figliozzi, T. Phillips, C. Gorecki, and A. Schrope. *Investigation of Bicycle and Pedestrian Continuous and Short Duration Counts in Oregon.* Project SPR 772. Final report. Oregon Department of Transportation, Salem, 2016.

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