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Automatic Pedestrian Counter

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16. Abstract

Emerging sensor technologies accelerated the shift toward automatic pedestrian counting methods to acquire reliable long-term data for transportation design, planning, and safety studies. Although a number of commercial pedestrian sensors are available, their accuracy under different pedestrian traffic flow conditions is still questionable. Moreover, it is difficult to assess the suitability of different sensors for different locations. Some sensors claimed to be more accurate are substantially more expensive. Ease of deployment, power requirements, and long-term deployment issues all play an important role in the selection of sensors. This study attempts to shed light on the understanding of field performance of two commercially available automatic pedestrian sensors by performing rigorous comparisons—namely, a passive infrared counter by EcoCounter and a thermal sensor by TrafSys. A major innovation of this study was to simultaneously deploy the two relatively different sensor technologies—thermal and infrared sensors—under the same experimental conditions to compare their performances. To achieve this in a statistically robust manner, pairwise tests were conducted at trails and intersections with different pedestrian flow levels and characteristics. Statistically significant differences in terms of accuracy were found. The thermal sensor was found to produce less error than EcoCounter, which significantly undercounted pedestrians at intersections. This result was expected since EcoCounter is recommended for trail settings. The results also demonstrated the variability of both sensors given different deployment conditions. A calibration procedure for the EcoCounter data was also presented.

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EXECUTIVE SUMMARY

Emerging sensor technologies have accelerated the shift toward automatic pedestrian counting methods to acquire reliable long-term data for transportation design, planning, and safety studies. Although a number of commercial pedestrian sensors are available, their accuracy under different pedestrian traffic flow conditions is still questionable. Further, it is difficult to assess the suitability of different sensors for different locations. Some sensors that are claimed to be more accurate are substantially more expensive. Ease of deployment, power requirements, and long-term deployment issues all play an important role in the selection of sensors.

This study attempts to shed light on understanding the field performance of two commercially available automatic pedestrian sensors - a passive infrared counter by EcoCounter and a thermal sensor (passive infrared counter with imaging) by TrafSys.

The need to understand pedestrian behavior and to accommodate pedestrians in the transportation system is an issue that has been growing in prominence at the federal, state and local levels. Literature reviewed during the course of this research has identified pedestrian data as a needed input for decision makers in a variety of contexts. The studies that address the importance of pedestrian data are presented in the literature review section. In that section, the available automated pedestrian counting technologies are also reviewed in detail.

As a part of this project, interviews were conducted with a list of key informants, including the New Jersey Department of Transportation (NJDOT) staff who conduct pedestrian counts, section chiefs of other units at NJDOT that requested pedestrian counts in the past, consultants who have conducted pedestrian counts for NJDOT, and personnel from other state departments of transportation who have experience with pedestrian counting. The results of these interviews and the list of interviewees are presented in Appendix A. These interviews give insight into the state of the practice of collecting pedestrian data in New Jersey and a few other states and reveal the officials' opinions about various pedestrian data collection methods. A review of select automated pedestrian count case studies in other states is presented in Appendix C.

The two automated pedestrian counters were deployed and tested at five sites in New Jersey. Three sites were high-volume locations and two were low-volume trails. The details of the sites and the data collection schedule are shown in Figure 8 and Table 9, respectively.

The evaluation methodology section presents in detail the counter deployment, baseline data collection, and measure of effectiveness in determining counter accuracy.

Two relatively different sensor technologies—thermal and infrared sensors—were deployed under the same experimental conditions to compare their performances. To perform the comparison this in a statistically robust manner, pairwise tests were conducted at both trails and intersections with different pedestrian flow levels and characteristics.

The evaluation results section presents a statistical analysis of sensor accuracy based on the field tests. The thermal sensor was found to produce less error than the passive infrared counter, which significantly undercounted pedestrians in most scenarios. The results also demonstrated the variability of both sensors given different deployment conditions.

To quantitatively investigate the performance of each counter, the mean absolute percent error (MAPE) and overall error rates of the entire field tests were calculated and are presented in Table 11. EcoCounter significantly undercounts pedestrians at high-volume sites, with an overall error rate ranging between -5.26 percent and -27.9 percent. The result is greater than the -2 percent errors obtained in Vermont by Bell[26] and the -9 percent to -19 percent errors obtained in California by Greene-Roesel et al.[16]. MAPEs change by dates and locations for both counters. The results at the lower-volume sites show that EcoCounter performs much better, with the MAPEs being below 14 percent.

In contrast, the thermal sensor has an overall error rate ranging between -14.61 percent and 1.3 percent. The largest overall error rate of -14.61 percent occurred at a crosswalk in New Brunswick where pedestrians stop at the detection area waiting for the traffic light. The error rate at the crosswalk in Trenton is -2.2 percent. At the trails or the intersections, the error of the thermal sensor appears to be lower than that of EcoCounter. The results show that the MAPEs of EcoCounter are 1.5 to 2.0 times larger than those of the thermal sensor if they were both deployed at high-volume sites and the data were aggregated into larger time intervals.

The infrared sensor calibration section attempts to identify a statistical conversion so that the overall quality of an infrared counter (i.e., EcoCounter in this study) can be enhanced. The pedestrian arrival pattern was observed to be a major factor for the failure of EcoCounter to count accurately. A strong correlation must exist between the sensor counts and the actual pedestrian counts when other factors are controllable. Therefore, the infrared sensor calibration section focuses on doing an in-depth investigation of the relationship associated with counter error and actual pedestrian traffic. The calibration results showed that the overall error was reduced to -0.7 percent from -20.5 percent at a trail at the Rutgers University campus. The overall error was reduced to -9.7 percent from -27.6 percent at the traffic intersection in Trenton, New Jersey.

General recommendations about how to select an automatic pedestrian counter, deployment, installation, data collection, and calibration are presented in Appendix D. Also, deployment guidelines for the EcoCounter and the thermal sensor are presented in Appendixes E and F, respectively.

The accuracy of each counter was analyzed by in-depth statistical analysis presented in the evaluation results section. As for the performance of each counter as candidates to be used by NJDOT for long-term and short-term pedestrian data collection, our summary of results is presented in the conclusions and future work section.

INTRODUCTION

Pedestrian counts are essential for decision making in pedestrian facility planning, signal timing, and pedestrian safety modeling. However, it remains difficult to obtain high-quality pedestrian counts [1]. Pedestrian and bicycle traffic are still not as extensively monitored as motor vehicle traffic. Data related to pedestrians are lacking in most areas. Even where data exist, they are not always useful [2]. Many pedestrian data sources still rely on conventional methods such as manual counting and video recording [3, 4]. These methods are labor intensive and expensive, and they do not always guarantee economic, sufficient, and accurate pedestrian data.

Automatic pedestrian counting technology is expected to be a viable alternative to manual counting. To explore cost-effective and reliable methods of pedestrian counting, researchers and practitioners have been investigating automatic pedestrian detecting or counting technologies. In a recent study, Bu et al.[5] described the pros and cons of the available pedestrian counting technologies, including infrared beam counters, passive infrared counters, piezoelectric pads, laser scanners, and computer vision.

The advance in new technologies now makes it possible to automatically count pedestrians for long periods of time. However, the feasibility of using these automated pedestrian technologies on a larger scale still needs to be investigated. It is difficult to assess the suitability of different sensor types for different count locations. Some sensors that are claimed to be more accurate are substantially more expensive than comparable products. Ease of deployment, power needs, and other long-term and short-term deployment issues all play an important role in the selection of a suitable pedestrian counter.

In this project, the available automated pedestrian-counting technologies that are usable in outdoor urban environments were reviewed. Two candidate automatic pedestrian counters—EcoCounter and the thermal sensor—were then selected based on various criteria that include, but are not limited to, availability, capability, ease of deployment, reliability, and cost-effectiveness. Accuracy and reliability of the selected counters were evaluated by field tests. Based on the field tests, this report suggests guidelines to deploy an automated pedestrian counter that is best suited for the New Jersey Department of Transportation (NJDOT).

Project Goal and Objectives

The primary goal of this project is to identify the functionalities and evaluate the effectiveness and accuracy of commercially available pedestrian counters for pedestrian data collection. This project goal is supported by the following objectives:

- Identify potential automatic counters for pedestrian data collection.
- Develop an evaluation plan to test the automatic counters.
- Conduct field tests/comparisons to assess the performance of the selected counters.
- Develop guidelines for NJDOT for deploying automatic pedestrian counters.

As part of this project, interviews were conducted with a list of key informants, including NJDOT staff who conduct pedestrian counts, section chiefs of other units at NJDOT that requested pedestrian counts in the past, consultants who have conducted pedestrian counts for NJDOT, and personnel from other state departments of transportation who have experience with pedestrian counting. The results of these interviews and the list of interviewees are presented in Appendix A. These interviews give insight into the state of the practice of collecting pedestrian data in New Jersey and a few other states and reveal officials' opinions about various pedestrian data collection methods.

LITERATURE REVIEW

A wide range of literature was reviewed focusing on pedestrian detection, manual pedestrian counting, and automated pedestrian counting and associated technologies. This literature review first describes the need for pedestrian data, then reviews the state of the practice regarding manual and automated counts, and concludes with a summary of findings. A review of select automated pedestrian count case studies is presented in Appendix C.

Programmatic Need for the Research

In 2003, the Federal Highway Administration (FHWA) established the National Pedestrian Safety Campaign, with the goal of improving pedestrian safety and reducing pedestrian injuries and fatalities on the nation's highways. This program stems from significant financial investments FHWA has made in transportation planning, beginning with the Intermodal Surface Transportation Equity Act in 1991 and continuing with the Transportation Equity Act of the 21st Century in 1998. Pedestrian and bicycle activities in these bills have received increased funding each year, from $17.1 million the first year the law was passed to $564 million in 2007. With the enactment of the Safe, Accountable, Flexible, Efficient, Transportation Equity Act: A Legacy for Users (SAFETY-LU) in 2005, funding is expected to continue through 2010[(6)]. In 2007, as a part of SAFETY-LU, $45.7 million was set aside specifically for the Safe Routes to School Program and Non-Motorized Transportation Programs.

The increased concern for pedestrian safety is not only a federal priority but is an important issue at the state level. In 2006, the governor of New Jersey launched a Statewide Pedestrian Safety Initiative, which states that "The New Jersey Department of Transportation (NJDOT), the Attorney General and the Motor Vehicle Commission (MVC) are investing in a variety of programs to improve pedestrian conditions, including facility improvements, education and enforcement efforts, planning and technical guidance. While the State has made progress, the risk to pedestrians in New Jersey remains too great. We must have a comprehensive statewide pedestrian safety initiative with a goal towards significantly reducing pedestrian accidents" [(7)]. Through this initiative, millions of dollars are being invested in a three-pronged approach of "Safety Through Engineering," "Safety Through Education," and "Safety Through Enforcement."

For both national and state programs, pedestrian data are vital input in how funding should be used and in helping determine areas where safety problems exist, in focusing where interventions should occur, and in making programmatic and policy decisions to improve pedestrian safety. Pedestrian counts are one key data element that can help make these decisions.

Need for Pedestrian Data

The need to understand pedestrian behavior and to accommodate pedestrians in the transportation system is an issue that has been growing in prominence at the federal, state and local levels. Literature reviewed over the course of this research has identified pedestrian data as a needed input for decision makers in a variety of contexts.

In 2000, the U.S. Department of Transportation issued a report addressing the need for pedestrian and bicycle user data. The report characterized the quality of existing count data as poor and considers improving the data a high priority[(1)]. In addition, the report recommended that new bicycle and pedestrian-counting technologies be evaluated and promoted. Another important finding identified in the report was the need for more qualitative data, including user and trip characteristics, classifying the quality of existing data as fair, and the need for improvement as medium to high. Through emerging technologies and models, pedestrian count data can be used to help meet these needs.

The need for pedestrian count data identified in the U.S. Department of Transportation report has found support in a variety of research papers either contextually or directly. In 2003, Cottrell and Pal[(3)] evaluated pedestrian data needs and collection efforts. In their findings, they cited a need for a pedestrian data monitoring program similar to the one motor vehicle traffic data collection programs use to monitor traffic. Cottrel and Pal[(3)] also noted that, while automated pedestrian counters might not be a necessity for gathering pedestrian data, they have the potential to improve the data collection process a great deal, as manual and video counts are labor intensive and costly and thus make it difficult to collect data over a prolonged period of time. The report also points out that it would be much more convenient to use automated pedestrian counters to collect data at odd times, particularly at night.

Planning and Policy Development

Much of the literature included discussion of the politics of budgeting and why the data-gathering process is so important for project approval. Pedestrian counts, whether they are one-time studies or ongoing programs, can provide the evidence required for planning various types of projects. Early on in the planning process, pedestrian data can be used to identify locations where pedestrian improvements are needed. For projects already planned around a specific area, the data can be used to justify the construction or improvement of pedestrian facilities. Pedestrian count data are also used to document current pedestrian volume and allow for changes in volume to be tracked over time. This is useful in identifying areas in need of intervention and in measuring the effect of various engineering solutions. Pedestrian count data are also an important input in multimodal transportation models and analyses, which are used to inform transportation policy and resource allocation[(8)].

Health and Safety

The issue of safety is the most significant reason why most pedestrian counts are conducted and more are needed. Pedestrian counts are an important data input for pedestrian safety analysis. Abundant research has been published in recent years addressing the issue of safety in transportation. It is a problem that has been studied globally as well as locally. In 2004, the World Health Organization (WHO) published a report stating that the safety of road traffic systems is a public health concern that “is seriously harming global public health and development.”. WHO estimates that 1.2 million people worldwide are killed and 50 million are injured on the road each year. Those numbers are expected to increase by 65 percent over the next two decades[9]. A large number of these casualties are pedestrians because they are far more exposed and thus are more likely to be injured as a result of a crash than are vehicle occupants. In 2006, 61,000 pedestrians were injured in traffic crashes in the United States and 4,784 were killed[10]. In a typical year, 150 pedestrians lose their lives statewide in New Jersey. For each pedestrian fatality, two more are severely injured[7].

Manual Counting

Manual counting accounts for most of the pedestrian data being collected, mainly because automated counters still represent an unknown factor in terms of reliability and accuracy. The method generally employed for manual pedestrian counts includes the use of a counting tool, or clicker, to keep a running tab of pedestrians. In some cases, the clicker can keep track of several different items at once, making it possible to separate pedestrians according to gender, age group, direction of travel, and various other characteristics depending on the capacity of the counting tool and the user. The equipment allows a trained counter to count 2,000 to 4,000 people per hour; without the equipment, the amount is roughly half [11].

Accuracy and Reliability

A recent study evaluated the reliability of manual counts by hand and with a clicker compared with those done with a video that were counted manually afterward. In this case, the videotaped count was used as the baseline for accuracy because it allowed observers to slow and rewind to ensure the most accurate count. The researcher observed that the reliability of the person doing the counting was essential to the accuracy and reliability of the count. During the study, the counter, “did not follow all of the instructions that he was given, would sometimes arrive late to the area being observed, failed to take note of his breaks and counted bicycles as pedestrians” [12]. The results of the study showed that the counter consistently undercounted pedestrians relative to the video count. The calculated error averaged 15 percent and varied from 9 percent to 25 percent. When the counter used a clicker, the error averaged 11 percent and varied from 8 percent to 15 percent.

Equipment and Staffing Costs

Literature on the cost of conducting manual counts is very limited, largely due to the number of variables involved. A Pedestrian and Bicycle Information Center report, published in 2005, was the only source found that provides dollar amounts(8). The findings of the report illustrated the issues that arise when communities undertake these types of efforts. For one, communities often did not have a clear understanding of the costs of data collection. Some communities assumed that automated technologies would cost more than they actually did and some did not realize how expensive and time-consuming manual counts could become. Different methods were used in an effort to bring down the cost of counts, such as using volunteer labor, employing automated technologies strategically, and adding pedestrian collection to an existing vehicle data collection program. However, no discussion was included as to whether these efforts were ultimately successful or whether they sacrificed accuracy and reliability(8).

Generally, manual counts require two people per intersection, one to count and the other to record; intersections with higher volumes may require more staff. Counters do not have to be very experienced, but they should be reliable and well-organized. The duration of the count varies according to need, although to produce worthwhile data the counts generally need to be done for several hours at a time(11). Additional time is also required for data entry. Because of the number of variables that go into conducting a manual count—including the number of intersections, the length and number of counting intervals, local wage levels, etc.—total costs vary a great deal from region to region. A survey of 29 municipalities that underwent a data collection program found that the costs ranged from a negligible amount to $300,000 for manual counts. In the first case, the community was able to incorporate pedestrian counts into their ongoing traffic counts with little increase in cost. The latter case is the pedestrian-counting program in New York City, which included developing a counting methodology and conducting counts at 100 locations. At a Washington, D.C., study site teams of two and three people collected pedestrian and motor vehicle data for 10-hour periods during the week at more than 100 intersections. Here, the total cost ranged from $400 to $500 per intersection, including data entry once the counting was finished(8).

Automated Counting

Currently, there are five candidate automated pedestrian-counting technologies:

- Infrared beam counters.
- Passive infrared counters.
- Piezoelectric pads.
- Laser scanners, and
- Computer vision.

Infrared Beam Counters

An infrared beam counter is composed of an infrared beam transmitter, a receiver, and a data logger. The transmitter emits a constant infrared beam that is captured by the receiver. When an object passes through, the beam is interrupted and the data logger registers a count[5]. Figure 1 shows the infrared pedestrian counter. Other types of infrared beam counters can detect the direction of passing objects.

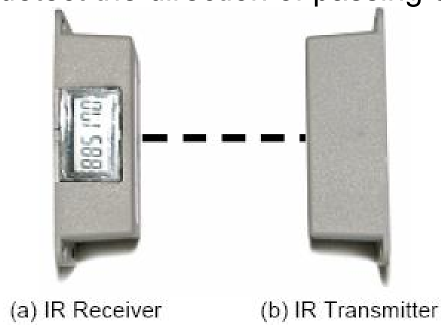


Figure 1. Infrared pedestrian counter[5]

This technology is mostly used indoors. The accuracy of the device is highly affected by outdoor environments, such as wind and rain. Also, this technology cannot differentiate between pedestrians, bicycles, and animals.

Passive Infrared Counters

Passive infrared counters detect the heat emitted by moving objects. EcoCounter, a company based in France, produces double pyroelectric sensors that use the passive infrared technology.

Figure 2 shows an example of a double pyroelectric sensor. This device can provide directional counts. The device registers a count when it detects an object with a temperature exceeding a certain threshold[5].

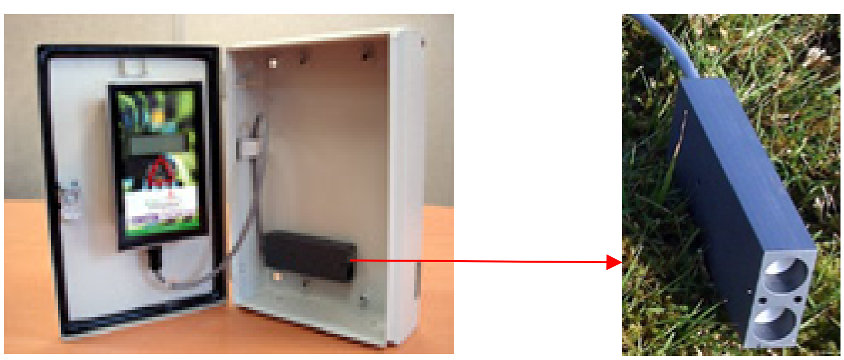


Figure 2. Double pyroelectric sensor by EcoCounter[13]

The device cannot distinguish whether the heat is emitted by a pedestrian or a bicyclist. The sensor shown in Figure 2 must be deployed horizontally. Therefore, it could undercount pedestrians walking in groups.

Another available passive infrared counter is the thermal people-counting device produced by TrafSys. The thermal device generates infrared images by monitoring body heat, processes the counts, and transmits the data wirelessly to a data controller device. The device must be mounted above and directed vertically to the ground. Figure 3 shows the thermal counter produced by TrafSys. Figure 4 shows the infrared image generated by a top-mounted thermal people counter by TrafSys.

Figure 3. Thermal counter by TrafSys

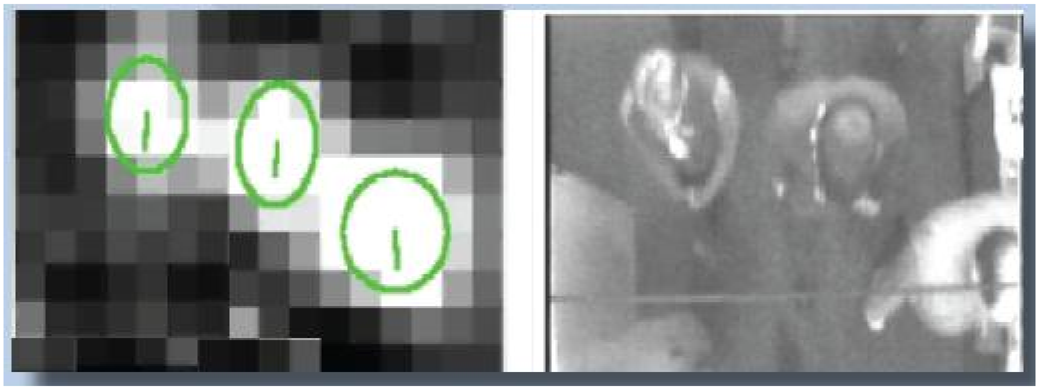


Figure 4. Thermal sensor view (left) and a video image (right)[14]

TrafSys produces thermal counters that are usable in outdoor urban environments. The device requires 12–24 volts of direct current power and must be mounted at 11.5 feet. It can generate directional pedestrian counts.

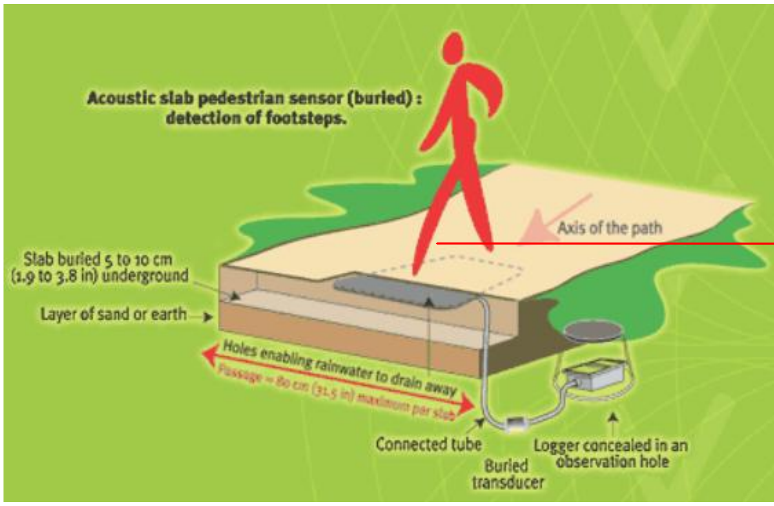
Piezoelectric Pads

Piezoelectric pads produce a change in electrical properties when applied with mechanical pressure. In pedestrian counting, piezocables with piezoelectric material are fabricated in a mat[5]. One or more underground mats sensitive to microvariations in pressure are used to detect footsteps. A timer system prevents overcounting if a person steps on the mat twice.

Figure 5 shows a typical setup for pedestrian counting with piezoelectric pads.

Piezoelectric pads are unable to differentiate between single pedestrians and people walking in groups. To distinguish people walking in groups, separate mats may be placed side by side. The installation of this device requires digging a hole that is 2 to 4 inches deep.

The piezoelectric pad appears to be best suited for rural environments. The subsurface installation would make it costly for temporary installation under a cement or asphalt surface.



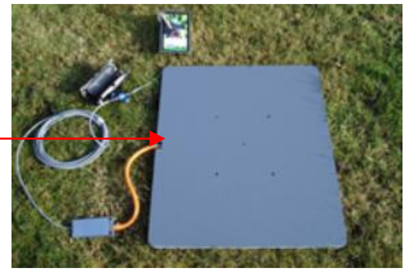


Figure 5. Pedestrian counting using a piezoelectric pad by EcoCounter(13)

Laser Scanner

The laser scanner emits infrared laser pulses and detects the reflected pulses. The measurement beam is scanned by a rotating prism and covers a viewing angle of up to 360 degrees. It then produces an image that is processed further to derive pedestrian counts. There are two types of laser scanners: horizontal scanning and vertical scanning[5]. Figure 6 shows both types of laser scanners.

(a) Horizontal (b) Vertical

Figure 6. Examples of laser scanners

This technology is generally suited for both urban and rural settings, although installation requirements should be taken into account during site selection. The horizontal laser scanner needs an open detection area and should not be obstructed by plants and trees or furniture. The vertical laser scanner needs to be mounted over the detection area, which may not be feasible for most trail settings or some urban areas.

Because they are optical sensors, weather conditions such as rain, snow, and fog will reduce the accuracy of data[5].

Computer Vision

The term computer vision refers to any artificial system that obtains information from images. In the case of pedestrian counting, computer vision technology utilizes intelligent processing of digital images of pedestrians captured with a video camera, as shown in Figure 7. Computer vision can make use of existing closed-circuit television (CCTV) cameras in many locations; in much of the literature, it is referred to as a CCTV system. Although a video camera can obtain much richer information about the surrounding environment than other types of sensors, the image sequences cannot be used for anything directly without further interpretation. In a typical video image processing procedure for pedestrian counts, the processor must undergo several steps to be able to discern useable information from video footage of pedestrians[5].

Figure 7. Computer vision detection[15]

Computer vision technology is unsuitable for urban environments for several reasons. The need for light, an external power source, and overhead installation all make the device difficult to use effectively in a trail setting. In addition, the device's advanced processing allows for pedestrian counting in complicated urban environments.

Findings of Literature Review

- Pedestrian count data have been identified as an important input for transportation policy decision making.
- Pedestrian count data are not systematically gathered and are typically gathered on a project need basis.
- Typically, pedestrian count data are gathered through manual counts.
- Automated pedestrian counters have been identified as an emerging technology that could be critical for establishing robust pedestrian count data sets.
- Manual counts are useful for getting a "snapshot" of a site but a better understanding requires prolonged counts, which can be very expensive to conduct manually.
- Automated pedestrian counters are an emerging technology.

- A variety of automated counter technologies are available that vary in price and function.
- Automated pedestrian counters have various levels of accuracy depending on the conditions under which they are deployed and the technology type utilized.
- Further evaluation of automated pedestrian counters is needed.

SELECTION OF PEDESTRIAN COUNTERS

The following selection criteria were considered as guidance for selecting the pedestrian counters in this project.

- Availability: The counter should be commercially available and supplied by the vendor in time for the field tests.

- Capability: The counter should satisfy the minimum counting requirements for the needed traffic parameters, such as directional counting and the ability to distinguish the same targets without repeat counting.

- Vendor Support: Once bought from the vendor, necessary technical support should be provided for the counter installation and deployment. The vendor's product information should include the overall accuracy of the counter under different working conditions.

- Ease of Deployment: Once installed, other than minor calibration for the detection zone, no elaborate effort should be needed to operate the counter.

- Adjustability: The counter can be mounted at different heights or positions without sacrificing its performance.

- Reliability: The counter can work continuously in different weather conditions and traffic conditions.

- Compatibility: The counter should have an interface to connect with a computer to easily retrieve data.

- Economical: The counter must be cost-effective when not only the initial purchase price but also the deployment and maintenance costs are included.

A variety of technologies on the market have the potential to count pedestrians. Each technology has advantages and disadvantages that make it particularly applicable to different applications, budgets, and counting environments. Table 1 presents each pedestrian-counting technology with its pros and cons and a list of vendors who provide the automated pedestrian counters with these technologies.

Various studies conducted a number of field evaluation studies with the goal of assessing the accuracy and ease of use of commercially available automatic pedestrian counters. A detailed review of these studies is presented in Appendix C.

Table 1. Pros and cons of different automated pedestrian-counting technologies[5]

Counter	Pros	Cons	Manufacturer and Cost
Infrared beam counter	Cheap and widely available commercially; Low power consumption; Easy installation; Highly portable.	Infrared beam counter cannot differentiate pedestrian and other objects; Transmitter and receiver need to be aligned carefully to ensure reception of the beam at the receiver end; Both transmitter and receiver should not be installed on a flexible structure; When several pedestrians cross the counting beam simultaneously, they are registered as only one count.	Jamar Technologies Inc. $790
Passive infrared counter	Counter with multiple sensor arrays could achieve performance comparable to computer vision; Low power consumption; Not affected by wet or foggy weather; Cheap and widely available commercially.	Single or double sensor counter cannot distinguish between individuals and groups; Temperature can affect counter performance; Limited coverage area.	Irisys $1,400 for counter with multiple sensor array EcoCounter $3,000 for counter, $600 for software
Piezoelectric pad	Low maintenance cost; Capable of counting pedestrians on sidewalks; Low power consumption.	Need physical contact between pedestrian and pad; Some products cannot differentiate between single pedestrians and groups; Subsurface installation is expensive; Limited coverage area.	EcoCounter cost estimate not available
Laser scanner	Accurate range measurement; Can differentiate pedestrians according to their height; Easy setup; Large coverage area.	Expensive; Performance could be affected by weather conditions.	LASE GmbH Around $9,000 for counter only
Computer vision	Large coverage area; Potential to count accurately in various conditions: crowded pedestrians, different lighting; Can be manually reviewed to collect pedestrian characteristics; Easy installation and setup;	Most commercially available products are intended for indoor setting; The difficulty of counting pedestrians in crowded settings has not been resolved; The performance can be affected by different environmental conditions if not designed properly.	Video Turnstile Start from $1,230

MS Sedco SmartWalk is one of the major representatives of microwave radar counters that have been tested in field. After its capability was reviewed, it was found that SmartWalk 1400 is designed mainly for real-time pedestrian presence of bi-directional motion in the curbside area to active traffic signals, while SmartWalk 1800 is capable of detecting pedestrian presence in the crosswalk area to extend the length of the pedestrian signal phase. If volume information is needed, the real-time count data must be collected manually by counting an external light-emitting diode flasher that is connected to the sensor(16). Because the required functionality of candidate pedestrian counters for this project is the ability to count pedestrians and not to make any real-time decisions based on current pedestrian activity at an intersection, MS Sedco SmartWalk was not selected.

Pulsed laser active infrared counters such as ASIM and Diamond TTC are most effective in a trail setting, where the traffic flow is simple and not very heavy. The accuracy of the devices has been shown to decrease when multiple pedestrians pass through the beam at the same time or when pedestrians stop in front of the beam. Infrared beam counters cannot differentiate between pedestrians and other objects. Vehicles, animals, insects flying close to the transmitter, and even rain drops could block the counting beam and trigger the counter. Therefore, this technology is not suited for counting pedestrians in adverse weather conditions, and it was eliminated from consideration.

The piezoelectric pad was eliminated because of its in-ground installation requirements. The desired automatic pedestrian counter should be portable and should not require extensive installation procedures.

Laser and computer vision technologies were disregarded because of the shortcomings of these technologies when installed outdoors as explained earlier and because of their complex installation and calibration requirements.

Based on the findings of the literature review and follow-ups with various vendors, we selected two passive infrared counters:

- Double pyroelectric sensor from EcoCounter (passive infrared technology without vision).
- Thermal sensor from TrafSys (passive infrared thermal imaging technology).

Table 2 lists the detailed functionalities of the two selected pedestrian counters and how they meet the counter selection criteria listed above.

Table 2. Summary of functionalities of the selected counters

Requirements	Description	EcoCounter	Thermal sensor
Function	Presence detection		
	Count by time and direction	X	X
	Only total counts		
	Record pedestrian speed		
Technology	Passive infrared	X	X
	Laser scanner		
	Computer vision		
	Pad		
System work time	Only during day		
	Only during night		
	All day	X	X
Counting capability	Ideal for higher volume		
	Ideal for lower volume	X	
	Ideal for multilevels of volume		X
Installation position	Overhead		X
	Sidefire	X	
	Underground		
Mounting height	High		X
	Medium		
	Low	X	
Detection area	Adjustable		X
	Fixed range	X	
Data storage	Long term	X	
	Short term		
	Real time		
	Temporary storage or real time		X
Data acquisition	Remote communication		X
	PDA download	X	
	On-site check and record		
Data integration approach	Fixed time interval		
	Selectable time interval	X	
	Customizable time interval		X
Complexity of setup	Easy	X	
	Difficult		X
Complexity of deployment (location dependent)	Easy	X	
	Difficult		X
Weather constraint	Fewer limitations	X	X
	More limitations		
Power source requirement	External power		X
	Internal battery	X	
Software need	Data process only	X	
	Calibration and data process		X
Accessory need	More		X
	Less	X	
Acquisition cost	High		X
	Medium	X	
	Low		X
Deployment cost	High		
	Medium		X
	Low	X	
Maintenance cost	High		
	Medium		
	Low	X	X

EVALUATION METHODOLOGY

The Intelligent Transportation Systems (ITS) Joint Program Office of the U.S. Department of Transportation has presented national ITS evaluation guidelines to evaluate ITS projects(17). General evaluation processes including forming an evaluation team, developing an evaluation strategy, developing a test plan, collecting and analyzing data, and preparing a final report are the components of the national ITS evaluation guidelines. Experience of NJDOT in conducting ITS evaluation projects also found that the key components of any ITS evaluation plan are the identification of functionality requirements of the ITS system, selection and acquisition of the system, integration and installation of the system, and accurate collection and analysis of data(18). The specific evaluation methodology for each project will differ because of the discrepancy in evaluation goals. To make the evaluation more effective, the lessons learned in the course of conducting a large number of ITS evaluation projects that contribute to a successful evaluation are summarized as follows(19):

- The evaluation should be transparent and allow for simple updating of impact parameters.
- The evaluation should provide accurate output and should be objective without any positive or negative bias.
- The evaluation should allow comparison of results of the evaluation of ITS and conventional transport projects.
- The evaluation should include rigorous sensitivity testing and not apply false precision to the estimated impacts.
- The evaluation should consider the combined effect of implementing various combinations of ITS.
- The evaluation must be developed to avoid double counting benefits.
- The base and project cases studied in the evaluation must be based on the same operational conditions.

Because the main purpose of this project is to test the selected pedestrian counters' functionalities and effectiveness, to conduct quantitative and qualitative evaluation based on the criteria listed above, four important aspects of the counters are investigated: functional requirements, system availability, system accuracy, and system reliability. The evaluation framework related to the objectives, measures, and methods of this project are shown in Table 3.

Table 3. Evaluation objectives, measures, and methods

Evaluation Goal	Objectives	Hypothesis	Measures/Surrogate Measures	Data Collection Method/Source
System performance	Functional satisfaction (20)	APC* has the capability to provide necessary information.	• Volume counting • Time recording • Direction identification	Interviews with vendors; Survey of users.
	System availability	APC is ready to be deployed and produce objective data for the whole duration.	• Ready to order • Delivery time • Data storage and acquisition	Interviews with vendors; Test of data available versus needed for the given duration.
	System accuracy (21)	APC can accurately collect the information.	• Volume • Time interval • Direction	Manual counting versus APC counting in field.
	System reliability (22)	APC produces the same output from the given input.	• Accurate response • Missed response • False response • Failure time	Controlled experiments and comparisons

* Automatic pedestrian counter.

Test Site Selection

An important component of the evaluation process of the selected pedestrian counters was to identify the locations to test the counters. The final test sites were selected considering the following criteria proposed in the evaluation plan:

- Facilities and Users: The candidate locations should have pedestrian facilities such as a crosswalk or a pedestrian sidewalk.
- Accident Occurrence: The candidate locations should have pedestrian safety problems.
- Mounting Structure: There should be a mounting structure such as a light pole or an overhead sign to install counters at the elevation recommended by the vendors. This was confirmed by pretest site visits.
- Energy Supply: Power supply should be available for the counters at the selected sites.
- Traffic Pattern: The locations should have simple or basic pedestrian patterns, such as crossing flow and sidewalk flow. Locations with irregular weaving flows should be avoided.
- Visibility: There should not be any physical objects such as trees or signs that block the clear sight of the counters after deployment.
- Safety: There should be a secure location onsite for surveyors to stand and set up equipment such as video cameras, laptops, and microcontrollers without disturbing normal traffic.

Two types of deployment locations were considered for field tests:

- High volume: Three locations were selected for deployment of automated pedestrian counters:
  Site 1: Pedestrian trail in front of Busch campus center at Rutgers University, Piscataway.
  Site 2: Crosswalk of the intersection in front of the New Brunswick train station.
  Site 3: Crosswalk of the intersection in front of the Trenton transit center.
- Low Volume: Two locations were selected:
  Site 4: Pedestrian trail near the Civil and Environmental Engineering (CEE) building on Busch campus at Rutgers University.
  Site 5: Delaware and Raritan Canal Park pedestrian bridge over Route 1.

These sites were selected based on various criteria including ease of access, secure location, and minimum obstruction such as trees, plants, and parked cars or buses. All the locations selected were approved by NJDOT. Figure 8 shows the selected sites. Table 4, Table 5, Table 6, Table 7, and Table 8 list some basic information about each test site.

(a) Site 1

(b) Site 2

(c) Site 3

(d) Site 4

(e) Site 5

Site 1: Trail nearby Busch campus center
Site 2: Crosswalk at New Brunswick train station
Site 3: Crosswalk at Trenton transit center
Site 4: Trail nearby CEE building at Rutgers
Site 5: Delaware and Raritan Canal Park pedestrian bridge

Figure 8. Selected test sites

Table 4. Site 1 trail in front of Busch campus center

Requirements	Features	Yes	Unknown
Facility type	Crosswalk		
	Sidewalk		
	Trail	X	
	Pedestrian bridge		
Environment	Urban		
	Suburban	X	
	Rural		
Pedestrian volume	High level	X	
	Medium level	X	
	Low level		
Vehicle volume	High level		
	Medium level		
	Low level		
Bicycle volume	High level		
	Medium level		
	Low level	X	
Pedestrian involved crash	High level		
	Medium level		
	Low level		
Accessibility	Acceptable travel time	X	
	Safe space for field surveyors	X	
	Safe space for device setup	X	
Geometric design of the site	Typical pattern	X	
	Unusual pattern		
Security concern	Sensitive to homeland security		
	General concern		
Facility for counter mounting	Available on site	X	
	Accessory facility needed		
Power source Availability	Available on site		
Traffic interruption during device setup	Serious		
	Moderate		
	Minimum		

Table 5. Site 2 crosswalk in front of New Brunswick train station

Requirements	Features	Yes	Unknown
Facility type	Crosswalk	X	
	Sidewalk		
	Trail		
	Pedestrian bridge		
Environment	Urban	X	
	Suburban		
	Rural		
Pedestrian volume	High level	X	
	Medium level	X	
	Low level		
Vehicle volume	High level	X	
	Medium level		
	Low level		
Bicycle volume	High level		
	Medium level		
	Low level		
Pedestrian involved crash	High level		
	Medium level		
	Low level		X
Accessibility	Acceptable travel time	X	
	Safe space for field surveyors	X	
	Safe space for device setup		
Geometric design of the site	Typical pattern		
	Unusual pattern	X	
Security concern	Sensitive to homeland security		
	General concern	X	
Facility for counter mounting	Available on site		
	Accessory facility needed	X	
Power source availability	Available on site		
Traffic interruption during device setup	Serious		
	Moderate	X	
	Minimum		

Table 6. Site 3 crosswalk in front of Trenton transit center

Requirements	Features	Yes	Unknown
Facility type	Crosswalk	X	
	Sidewalk		
	Trail		
	Pedestrian bridge		
Environment	Urban	X	
	Suburban		
	Rural		
Pedestrian volume	High level		
	Medium level	X	
	Low level		
Vehicle volume	High level		
	Medium level	X	
	Low level		
Bicycle volume	High level		
	Medium level		
	Low level	X	
Pedestrian involved crash	High level		
	Medium level		
	Low level		X
Accessibility	Acceptable travel time	X	
	Safe space for field surveyors	X	
	Safe space for device setup	X	
Geometric design of the site	Typical pattern	X	
	Unusual pattern		
Security concern	Sensitive to homeland security		
	General concern	X	
Facility for counter mounting	Available on site		
	Accessory facility needed	X	
Power source availability	Available on site		
Traffic interruption during device setup	Serious		
	Moderate		
	Minimum		

Table 7. Site 4 trail near CEE building on Rutgers Busch campus

Requirements	Features	Yes	Unknown
Facility type	Crosswalk		
	Sidewalk		
	Trail	X	
	Pedestrian bridge		
Environment	Urban		
	Suburban	X	
	Rural		
Pedestrian volume	High level		
	Medium level		
	Low level	X	
Vehicle volume	High level		
	Medium level		
	Low level		
Bicycle volume	High level		
	Medium level		
	Low level	X	
Pedestrian involved crash	High level		
	Medium level		
	Low level		
Accessibility	Acceptable travel time	X	
	Safe space for field surveyors	X	
	Safe space for device setup	X	
Geometric design of the site	Typical pattern	X	
	Unusual pattern		
Security concern	Sensitive to homeland security		
	General concern		
Facility for counter mounting	Available on site	X	
	Accessory facility needed		
Power source availability	Available on site		
Traffic interruption during device setup	Serious		
	Moderate		
	Minimum		

Table 8. Site 5 Delaware and Raritan Canal Park pedestrian bridge over Route 1

Requirements	Features	Yes	Unknown
Facility type	Crosswalk		
	Sidewalk		
	Trail		
	Pedestrian bridge	X	
Environment	Urban		
	Suburban	X	
	Rural		
Pedestrian volume	High level		
	Medium level		
	Low level	X	
Vehicle volume	High level	X	
	Medium level		
	Low level		
Bicycle volume	High level		
	Medium level		
	Low level	X	
Pedestrian involved crash	High level		
	Medium level		
	Low level		X
Accessibility	Acceptable travel time	X	
	Safe space for field surveyors	X	
	Safe space for setup device	X	
Geometric design of the site	Typical pattern		
	Untypical pattern	X	
Security concern	Sensitive to homeland security		
	General concern	X	
Facility for counter mounting	Available on site		
	Accessory facility needed	X	
Power source availability	Available on site		
Traffic interruption during device setup	Serious		
	Moderate		
	Minimum		

Counter Deployment

The two pedestrian counters were deployed pairwise at sites 1, 2, 3 and 5. Only EcoCounter was tested at site 4. For the tests at pedestrian trails, the counters were installed on an existing pole near the trail (see Figure 9b and 9e). They were mounted at a height according to the manufacturers' instructions. At the sites where no poles were available for deployment, the Rutgers team deployed a customized mounting pole which can extend up to 20 feet. As shown in Figure 9a, the items include a portable pole, a tripod, a metal base, and two containers with counter connections and electrical power. Figure 9b through 9f demonstrates the final deployment of the counters for field data collection.

Table 9 summarizes information about the test schedule and related activities. Because of easy access to site 1 and site 4, multiple 12-hour tests were conducted. The tests at other sites were limited to 6 to 8 hours. However, all these test durations are far beyond those test periods used in the literature—for instance, 4 hours by Greene-Roesel et al.[23].

Table 9. Summary of data collection schedule

Site	Location	Type	Tested Counter	Test Date	Test Period	Flow
Site 1	Nearby Busch campus center, Piscataway	Trail	EcoCounter Thermal sensor	March 12 March 13 April 10 April 13	10:30am to 10:30pm	High
Site 2	Route 27/Easton Ave., New Brunswick	Crosswalk	EcoCounter Thermal sensor	May 13* August 13	9:00am to 5:00pm 1:00pm to 7:00pm	High
Site 3	South Clinton Ave./Raul Wallenberg Ave., Trenton	Crosswalk	EcoCounter Thermal sensor	May 22	9:00am to 5:00pm	High
Site 4	Nearby CEE building of Rutgers, Piscataway	Trail	EcoCounter	March 4 March 5	9:30am to 9:30pm	Low
Site 5	Delaware and Raritan Canal Park pedestrian bridge over Route 1	Pedestrian bridge	EcoCounter Thermal sensor	August 19 August 23	12:00pm to 6:00pm	Low

* During the test at site 2 on May 13, 2009, it was noted that the EcoCounter had been interrupted by the left-turn vehicles at the intersection. Thus, an additional test was conducted on August 13 to make the data comparable for two counters.

(a) Customized tools for sensor deployment

(b) Sensor deployed at site 1

(c) Sensor deployed at site 2

(d) Sensor deployed at site 3

(e) Sensor deployed at site 4

(f) Sensor deployed at site 5

Figure 9. Deployment of pedestrian counters

Baseline Data Collection

Baseline data were also collected as a benchmark to evaluate the accuracy of selected pedestrian counters. Pedestrian counts extracted from digital video recordings were used as the ground truth data.

Traditionally, manual counts are used as the baseline data. However, because of expensive labor costs, only limited data can be recorded by individual members of the survey team. Also, there is concern about the error rates after several hours of counting due to fatigue or distraction of the surveyors. If the pedestrian volume is high, the error rate increases. Moreover, for the long-term tests such as 6 to 8 hours, it is impractical to conduct manual counting.

Video recordings were carefully reviewed and pedestrian counts were extracted in the Rutgers Intelligent Transportation Systems (RITS) laboratory. Repeated data extractions by different team members were done to ensure valid baseline data. Data were then aggregated into different time intervals of 15 minutes, 30 minutes, and 1 hour.

Though videotaping has many advantages, it was found that baseline data collection is time-consuming. The procedure to extract raw data is illustrated in Figure 10. To extract 1-hour data from video takes approximately 4 hours when pedestrian volume is high (e.g., 400 pedestrians per hour).

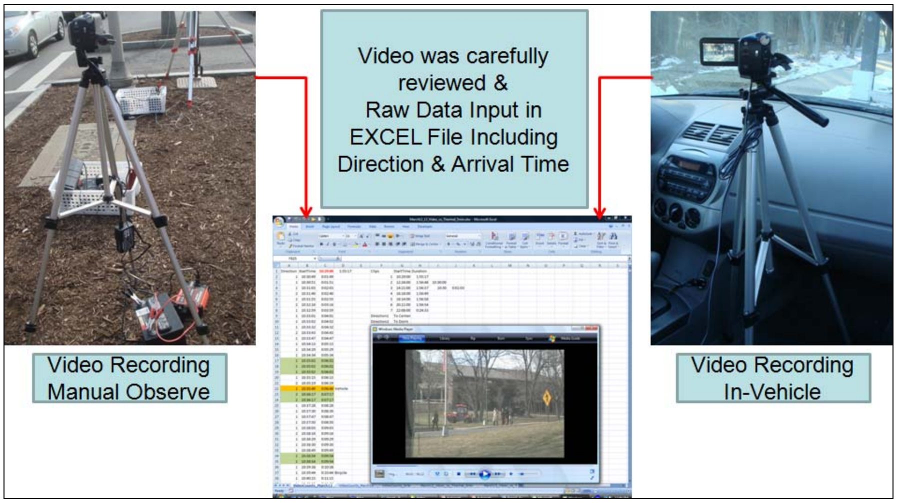


Figure 10. Procedure for baseline data collection

Data Collection Using Automated Pedestrian Counters

Tests conducted in previous studies include reliability of the pedestrian counter, counter deployment, and data calibration. The counter should always be installed and maintained according to the vendors' recommendations. Crew sizes of at least two or three people are necessary to deploy and dismount the equipment. One person is primarily responsible for watching and warning approaching pedestrians while the other person(s) installs the equipment. Table 10 lists the major checklist before any formal data collection activities start.

Table 10. Automatic counting checklists

Project: _______Count Location: ____ Date: _____ Time of Count:
1. Check all equipment for proper operation and calibration. 2. Bring necessary accessories such as batteries, locks, nails, etc. 3. Identify required data collection before leaving. 4. Specify the counter-placing location and adjust as necessary in the field. 5. Install and fasten counting sensors securely. 6. Synchronize the beginning time of the counting operation. 7. Periodically check the counter especially during poor weather conditions. 8. Record the checking results and recover the counter if it fails.

A real-time stamp of pedestrians' time crossing the intersection or trail is not possible to record by either counter. Instead, each sensor aggregates data in a preset time interval. The minimum intervals for EcoCounter and the thermal sensor are 15 minutes and 5 minutes, respectively. Both counters have the capability to store data. Once the tests were completed, the data-processing software was used to download and initially process the raw counts in the laboratory. Figure 11 and Figure 12 illustrate the procedure of automatic data extraction. Detailed information on how to extract data from EcoCounter and the thermal sensor is presented in Appendix E and Appendix F, respectively.

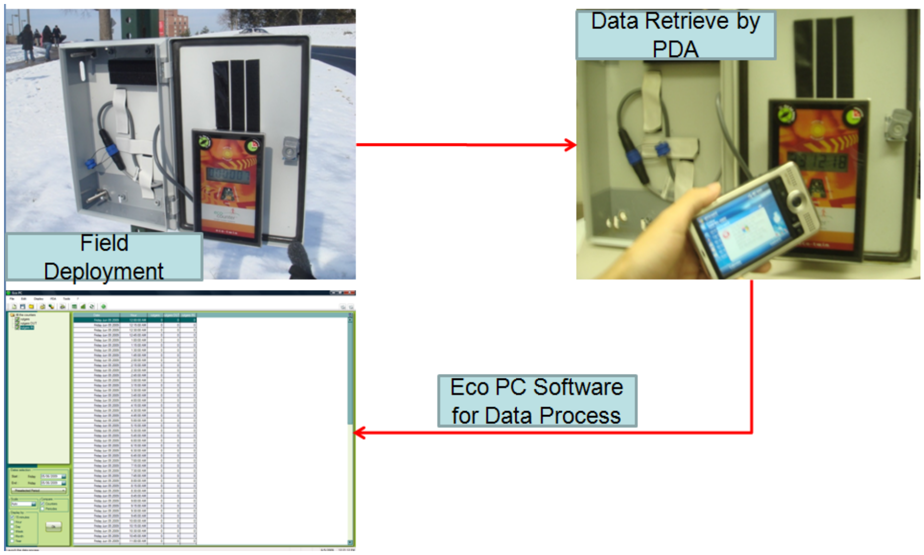


Figure 11. EcoCounter data extraction

Figure 12. Thermal sensor data extraction

Data Analysis

According to definitions of the quality of traffic data by FHWA(24), accuracy is defined as **"**the measure or degree of agreement between a data value or set of values and a source assumed to be correct." The output accuracy of a pedestrian counter is evaluated by the relationship between the ground truth counts of pedestrians crossing and the output of the automated counter. Typical examples of possible relationships between the sensor counts and the ground truth counts are illustrated in Figure 13. The straight line A shows the actual counts. Curves B and C show possible variations in pedestrian counts, which tend to consistently overcount and undercount the actual number of pedestrians. Curve D illustrates an even more complex case that periodically overcounts or undercounts. For a single test period, the diagram also illustrates two constraints if a counter works correctly: (1) If there are no pedestrians at the site, the system must yield zero count for that period and (2) the cumulative number of counts should be consistent with the actual counts at any time instead of occasionally matching at certain points of the cumulative arrival curve as shown by curve D (due to canceling out of the errors by under- and overcounting).

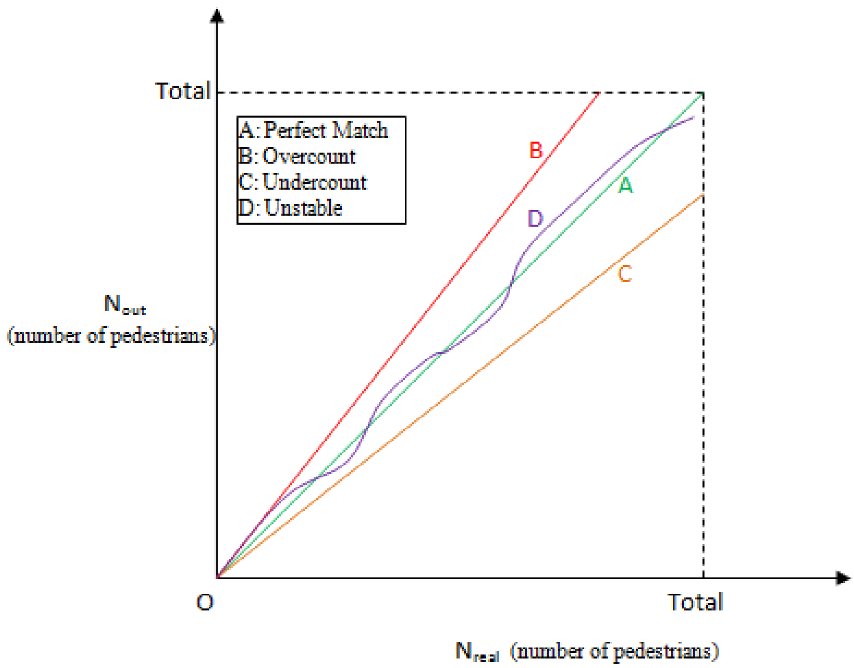


Figure 13. Hypothetical relationships between actual counts and APC outputs

Since the automatic and baseline counts deployed at the same location can be regarded as a paired measurement, it is possible to use a paired *t*-test to investigate the statistical significance of their differences. However, when the normality of collected data is not guaranteed, it is safe to apply the Wilcoxon matched-pairs signed-ranks test. This is a nonparametric test used to determine the directional differences between groups of paired data without the assumption of normality needed for a *t*-test to be valid. The test first computes the difference between the paired measurements of each group and analyzes only the list of differences. If the *p*-value is small, one can reject the idea that the difference between the paired measurements is coincidence and conclude instead that the two groups have different medians with regard to their observed values. It can further test the sign of the difference: one group is either larger or smaller than the other. Details of this test can be found in the handbook by Sheskin[25].

To better quantify the accuracy of pedestrian counters, the following error indicators are also defined. In each of these error formulations, the error is the difference between the observed values and the reference (i.e., ground truth) value, and the percent error is the difference divided by the reference value.

$$Relative\ Error\ per\ Period\ (REP)(\%) = \frac{Y_t - X_t}{X_t} \tag{1}$$

$$Mean\ Absolute\ Percent\ Error\ (MAPE)(\%) = \frac{1}{n}\sum_{t=1}^{n} \left| \frac{Y_t - X_t}{X_t} \right| \tag{2}$$

$$Overall\ Error\ (OE)(\%) = \frac{\sum_{t=1}^{n} Y_t - \sum_{t=1}^{n} X_t}{\sum_{t=1}^{n} X_t} \tag{3}$$

where X_t is the ground truth count at period *t*, Y_t is the automatic pedestrian count at period *t*, and *n* is the total number of all observed periods.

These different error formulations are all valid measures of accuracy but may yield slightly different results. The errors are expressed as percentages. The relative error per period provides an in-depth investigation of different counter performances for the test duration. For each test, the errors are calculated for different data integration intervals—for instance, 5 minutes, 15 minutes, 30 minutes, and 1 hour. The average value of relative errors for all periods was not used as an indicator because the positive and negative errors cancel out in this indicator. Instead, the mean absolute percent error (MAPE) statistic is used. MAPE is a commonly used measure that corrects the “canceling out” effects and also takes into account the different scales at which this measure can be computed. The overall error can be used to compare the aggregate accuracy of the measurements over the test duration. It shows the performance in a larger scope.

EVALUATION RESULTS

The original sensor counts and the baseline data collected are shown in Appendix G.

Sensor Errors

To quantitatively investigate the performance of each counter, the MAPEs and overall error rates of the entire field tests are calculated and presented in Table 11. EcoCounter significantly undercounts pedestrians at high-volume sites, with an overall error rate ranging between -5.26 percent and -27.9 percent. The result is greater than the -2 percent errors obtained in Vermont by Bell[(26)] and the -9 percent to -19 percent errors obtained in California by Greene-Roesel et al.[(23)]. MAPEs change by dates and locations for both counters. The results at the lower-volume sites show that EcoCounter performs much better, with the MAPEs being below 14 percent. On August 13, the corresponding overall error is only -5.26 percent.

In contrast, the thermal sensor has an overall error rate ranging between -14.61 percent and 1.3 percent. The largest overall error rate of -14.61 percent occurred at the crosswalk in New Brunswick where pedestrians linger around the detection area waiting for the pedestrian signal. The error rate at the crosswalk in Trenton is -2.2 percent. Except for the test on August 13, at the trails or the intersections the error of the thermal sensor appears to be lower than that of EcoCounter. The results show that the MAPEs of EcoCounter are 1.5 to 2.0 times larger than those of the thermal sensor if both were deployed at high-volume sites and the data were aggregated into larger time intervals.

Table 11. Error rates for sensors deployed simultaneously at the same sites

Sensor Type	Date	Duration	Ground Truth	Sensor Counts	Overall Error (%)	MAPE Under Different Time Interval (%)		
						15-min	30-min	1-hour
EcoCounter	4 Mar	12 hours	78	73	-6.40	2.30	4.00	6.00
	5 Mar	12 hours	110	110	0.00	3.30	5.80	4.30
	12 Mar	12 hours	3,688	3,129	-15.20	15.50	14.90	14.80
	13 Mar	12 hours	2,147	1,549	-27.90	22.50	23.10	22.80
	10 Apr	12 hours	3,103	2,468	-20.50	19.70	18.10	18.20
	13 Apr	12 hours	3,995	3,310	-17.10	15.90	15.60	15.60
	22 May	8 hours	1,359	1,050	-22.70	39.30	31.90	32.00
	13 Aug	6 hours	1,273	1,206	-5.26	7.57	6.68	5.66
	19 Aug	6 hours	21	17	-19.05	3.75	6.67	13.33
	23 Aug	6 hours	31	27	-12.90	6.60	6.94	10.56
Thermal sensor	12 Mar	12 hours	3,688	3,737	1.30	10.60	6.70	5.60
	13 Mar	9 hours	2,099	2,012	-4.10	10.30	8.00	6.10
	10 Apr	12 hours	3,103	2,947	-5.00	13.10	7.90	7.40
	13 Apr	12 hours	3,995	4,002	0.20	10.10	7.10	6.80
	13 May	8 hours	2,238	2,061	-7.90	11.70	9.30	7.90
	22 May	8 hours	1,359	1,329	-2.20	12.70	4.80	3.20
	13 Aug	6 hours	1,273	1,087	-14.61	16.98	14.82	14.91
	19 Aug	6 hours	21	19	-9.52	1.88	3.75	6.11
	23 Aug	6 hours	31	31	0.00	0.00	0.00	0.00

Characteristics of Errors

The above results illustrate the overall performance of the sensors and show that the overall errors are not necessarily higher under high-volume conditions. For instance, the overall error is -17.10 percent on April 13 and -27.90 percent on March 13 even though the former date had the higher volume. ANOVA test was conducted to compare the hourly error rates of these two dates. The test resulted in *p*-value of 0.1315, which indicated that high pedestrian volume do not necessarily cause larger error in the pedestrian counter output.

Table 12 summarizes the number of periods of undercounting, correct counting, and overcounting. This information gives an idea about the possible bias of the sensor data. Regardless of which time interval is used, the number of undercounting periods for EcoCounter is higher than those for the thermal sensor. Second, the ranges of errors are shown in Figure 14. The red dashed lines indicate a range of ±15 percent error. Most observations of error for the thermal sensor are located within this range. However, EcoCounter errors are more skewed, and most of them are more than 15 percent less than the actual counts.

Table 12. Number of periods for different types of errors

Date	Interval	Thermal Sensor				EcoCounter			
		Total Periods	Underco unt Periods	Correct Count Periods	Overcou nt Periods	Total Periods	Underco unt Periods	Correct Count Periods	Overcou nt Periods
4 Mar	15 min	NA*	NA	NA	NA	48	5	43	0
5 Mar	15 min	NA	NA	NA	NA	48	3	42	3
12 Mar	15 min	48	20	0	28	48	44	2	2
13 Mar	15 min	36	24	3	9	48	39	5	4
10 Apr	15 min	48	23	9	16	48	42	2	4
13 Apr	15 min	48	17	3	28	48	43	1	4
13 May	15 min	32	26	0	6	NA	NA	NA	NA
22 May	15 min	32	19	1	12	32	30	0	2
13 Aug	15 min	24	22	0	2	24	17	2	5
19 Aug	15 min	24	2	22	0	24	2	22	0
23 Aug	15 min	24	0	24	0	24	4	18	0
4 Mar	30 min	NA	NA	NA	NA	24	5	19	0
5 Mar	30 min	NA	NA	NA	NA	24	3	18	3
12 Mar	30 min	24	8	1	15	24	22	0	2
13 Mar	30 min	18	12	0	6	24	21	2	1
10 Apr	30 min	24	11	5	8	24	23	0	1
13 Apr	30 min	24	11	2	11	24	23	0	1
13 May	30 min	16	13	0	3	NA	NA	NA	NA
22 May	30 min	16	10	1	5	16	15	0	1
13 Aug	30 min	12	12	0	0	12	10	0	2
19 Aug	30 min	12	2	10	0	12	2	10	0
23 Aug	30 min	12	0	12	0	12	3	9	0
4 Mar	1 hour	NA	NA	NA	NA	12	5	7	0
5 Mar	1 hour	NA	NA	NA	NA	12	2	8	2
12 Mar	1 hour	12	4	0	8	12	12	0	0
13 Mar	1 hour	9	7	0	2	12	11	0	1
10 Apr	1 hour	12	8	0	4	12	12	0	0
13 Apr	1 hour	12	6	0	6	12	12	0	0
13 May	1 hour	8	8	0	0	8	0	0	8
22 May	1 hour	8	6	1	1	8	7	0	1
13 Aug	1 hour	6	6	0	0	6	6	0	0
19 Aug	1 hour	6	2	4	0	6	2	4	0
23 Aug	1 hour	6	0	6	0	6	3	3	0

* Not applicable.

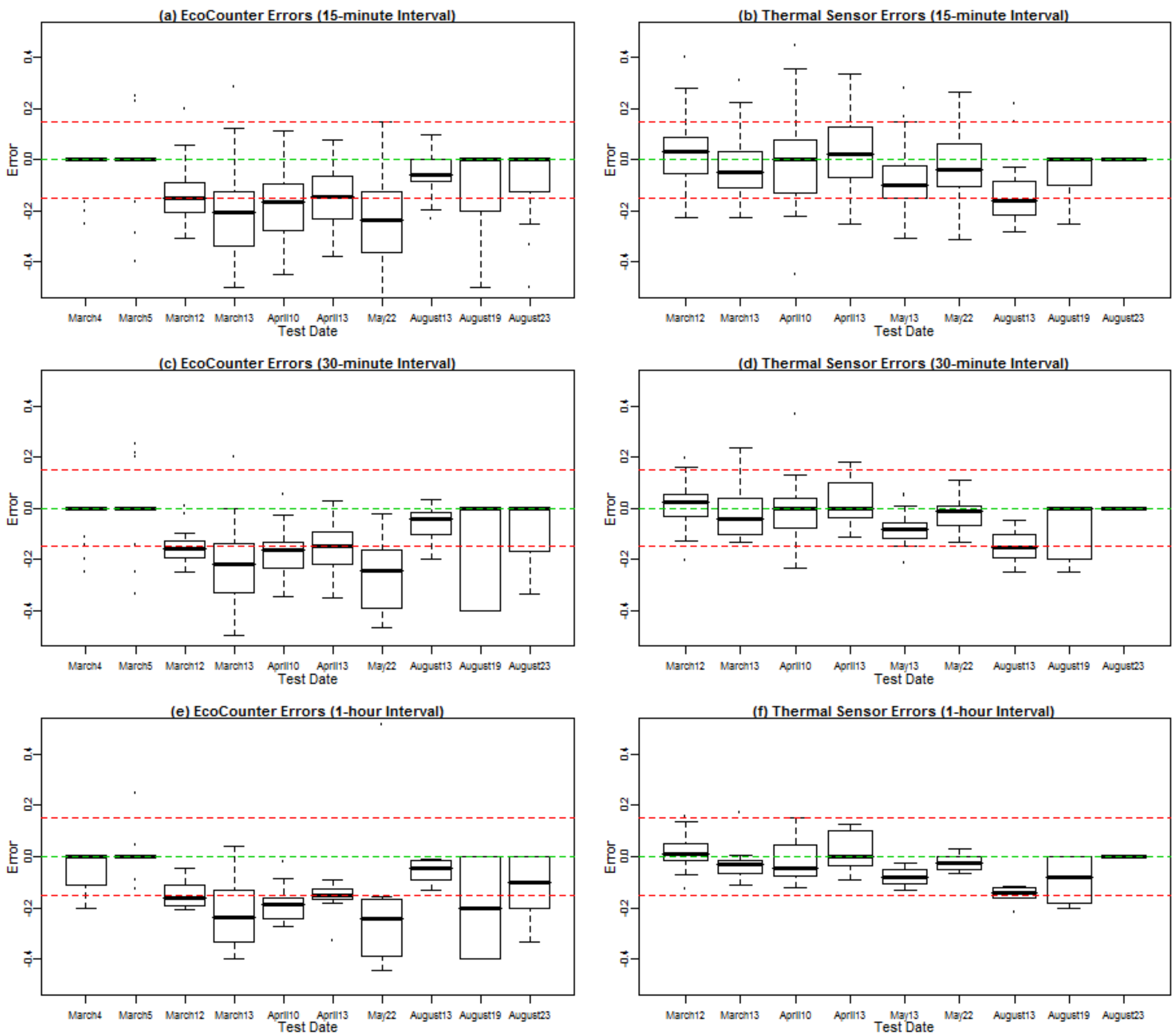


Figure 14. Box plot of periodical sensor errors

The frequency distributions of counting errors are shown in Figure 15. A Kolmogorov-Smirnov test showed that none of these data is normally distributed at a significance level of alpha = 0.05. To investigate the bias of sensor errors, a Wilcoxon matched-pairs signed-ranks test is a better choice than a traditional paired *t*-test as the normality of the errors of our data is not guaranteed. Statistical test results are summarized in Table 13 and Table 14. There is a statistically significant difference between the observed counts by EcoCounter and the ground truth data. This result suggests that EcoCounter did undercount the number of pedestrians at all high-volume sites. However, there are no such consistent results for the thermal sensor. The differences between the outputs of the thermal sensor and the ground truth were tested. The results of April 10, May 13, and August 13 were found to be undercounted as the overall errors were more than -5.0 percent. Even though the thermal sensor overcounts in some cases,the overall error rate was less than +5 percent.

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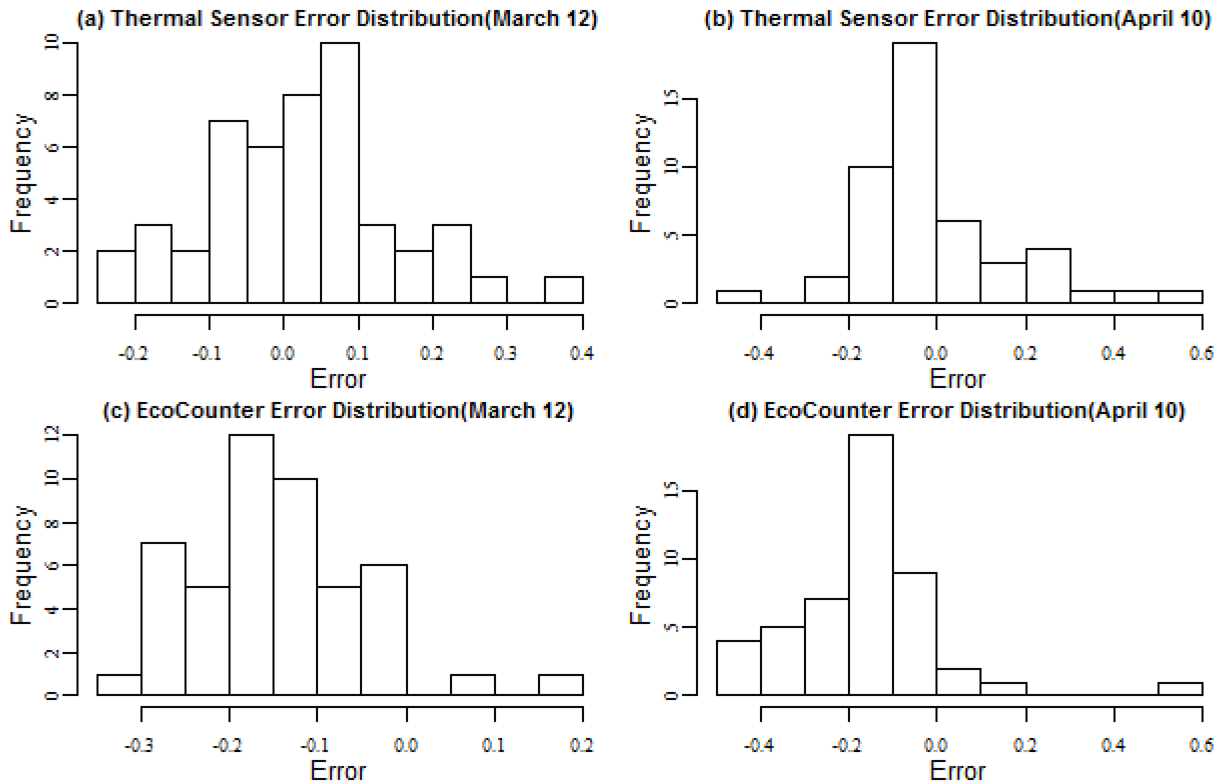

Figure 15. Examples of error distribution (15-minute intervals)

Error rates shown in Figure 14 suggest that there is no consistent error rate within the multiple tests at the same site. For instance, EcoCounter's overall error rates were -15.20 percent, -27.90 percent, -20.50 percent, and -17.10 percent for four field tests at the high-volume trail (site 1). The difference between the largest error rate and the minimum is more than 10 percent. Similarly, thermal sensor error rates also changed: the overall error rate ranges from -5.00 percent to +1.30 percent for the four field tests at the high-volume trail.

As expected, both sensors had a different performance even when they were deployed at the same types of locations (trail or intersection) with different levels of pedestrian volumes. When the thermal sensor was deployed at the two intersections—namely, sites 2 and 3—the overall error rate was -14.61 percent at site 2 and -2.20 percent at site 3, although the pedestrian volume at site 2 was higher than that at site 3. These results indicate no definitive relationship between pedestrian flow and the error rates of the thermal sensor. The correlation coefficients in Table 14 between periodic error rates of the thermal sensor and the corresponding volume further confirm that the error rates need not necessarily be high given that the volume is high. With the 30-minute interval observations used as an example, the correlation coefficients vary between -0.65 and +0.16. Therefore, it is difficult to conclude that there is any positive or negative relationship between pedestrian flow and thermal sensor error rates. Similarly, for EcoCounter with 30-minute interval observations, the coefficients in Table 13 vary between -0.66 and +0.43. There is still no guarantee of a definitive relationship between pedestrian flow and error rates.

Table 13. EcoCounter Wilcoxon matched-pairs signed-ranks test results

Test	Date	Valid Periods	Volume and Error Correlation	Wilcoxon Matched-Pairs Signed-Ranks Test		
				H0	H1	*p*-Value<0.05
EcoCounter	4 Mar	48	-0.67	Difference=0	Difference<0	Yes
	5 Mar	48	0.02	Difference=0	Difference≠0	No
(15-min interval)	12 Mar	48	-0.2	Difference=0	Difference<0	Yes
	13 Mar	48	-0.52	Difference=0	Difference<0	Yes
	10 Apr	48	-0.35	Difference=0	Difference<0	Yes
	13 Apr	48	-0.36	Difference=0	Difference<0	Yes
	22 May	32	-0.31	Difference=0	Difference<0	Yes
	13 Aug	24	0.14	Difference=0	Difference<0	Yes
	19 Aug	24	-0.68	Difference=0	Difference≠0	No
	23 Aug	24	-0.44	Difference=0	Difference<0	Yes
EcoCounter	4 Mar	24	-0.48	Difference=0	Difference<0	Yes
	5 Mar	24	0.03	Difference=0	Difference≠0	No
(30-min interval)	12 Mar	24	-0.19	Difference=0	Difference<0	Yes
	13 Mar	24	-0.52	Difference=0	Difference<0	Yes
	10 Apr	24	-0.49	Difference=0	Difference<0	Yes
	13 Apr	24	-0.51	Difference=0	Difference<0	Yes
	22 May	16	-0.38	Difference=0	Difference<0	Yes
	13 Aug	12	0.43	Difference=0	Difference<0	Yes
	19 Aug	12	-0.66	Difference=0	Difference≠0	No
	23 Aug	12	-0.57	Difference=0	Difference≠0	No
EcoCounter	4 Mar	12	-0.13	Difference=0	Difference<0	Yes
	5 Mar	12	-0.13	Difference=0	Difference≠0	No
(1-hour interval)	12 Mar	12	-0.28	Difference=0	Difference<0	Yes
	13 Mar	12	-0.59	Difference=0	Difference<0	Yes
	10 Apr	12	-0.54	Difference=0	Difference<0	Yes
	13 Apr	12	-0.79	Difference=0	Difference<0	Yes
	22 May	8	-0.52	Difference=0	Difference<0	Yes
	13 Aug	6	0.55	Difference=0	Difference<0	Yes
	19 Aug	6	-0.42	Difference=0	Difference≠0	No
	23 Aug	6	-0.33	Difference=0	Difference≠0	No

Table 14. Thermal sensor Wilcoxon matched-pairs signed-ranks test results

Test	Date	Valid Periods	Volume and Error	Wilcoxon Matched-Pairs Signed-Ranks Test		
			Correlation	H0	H1	*p*-Value<0.05
Thermal sensor	12 Mar	48	-0.27	Difference=0	Difference≠0	No
	13 Mar	36	-0.25	Difference=0	Difference≠0	No
(15-min interval)	10 Apr	48	-0.42	Difference=0	Difference<0	Yes
	13 Apr	48	-0.5	Difference=0	Difference≠0	No
	13 May	32	-0.22	Difference=0	Difference<0	Yes
	22 May	32	-0.18	Difference=0	Difference≠0	No
	13 Aug	24	-0.24	Difference=0	Difference<0	Yes
	19 Aug	24	-0.68	Difference=0	Difference≠0	No
	23 Aug	24	NA*	Difference=0	Difference≠0	No
Thermal Sensor	12 Mar	24	-0.17	Difference=0	Difference≠0	No
	13 Mar	18	-0.42	Difference=0	Difference≠0	No
(30-min interval)	10 Apr	24	-0.65	Difference=0	Difference<0	Yes
	13 Apr	24	-0.64	Difference=0	Difference≠0	No
	13 May	16	0.04	Difference=0	Difference<0	Yes
	22 May	16	0.06	Difference=0	Difference≠0	No
	13 Aug	12	0.16	Difference=0	Difference<0	Yes
	19 Aug	12	-0.54	Difference=0	Difference≠0	No
	23 Aug	12	NA	Difference=0	Difference≠0	No
Thermal sensor	12 Mar	12	-0.3	Difference=0	Difference≠0	No
	13 Mar	9	-0.51	Difference=0	Difference≠0	No
(1-hour interval)	10 Apr	12	-0.68	Difference=0	Difference<0	Yes
	13 Apr	12	-0.84	Difference=0	Difference≠0	No
	13 May	8	-0.11	Difference=0	Difference<0	Yes
	22 May	8	0.31	Difference=0	Difference≠0	No
	13 Aug	6	0.56	Difference=0	Difference<0	Yes
	19 Aug	6	-0.54	Difference=0	Difference≠0	No
	23 Aug	6	NA	Difference=0	Difference≠0	No

* Not applicable.

Summary of Findings

The main goal of the field tests conducted with the selected automated pedestrian counters was to assess the accuracy of sensors at various locations under various conditions. We also decided to collect side-by-side data to have a better comparison of the performance of these sensors. Our experimental setup allows us to eliminate the bias due to testing at different locations, times, and pedestrian traffic conditions and enables us to focus solely on the individual performance of each sensor. Furthermore, data were collected for longer periods than is usually reported in the literature—for instance, 4 hours[23, 27]—to ensure that we have sufficient data to conduct our comparisons in a statistically significant manner.

These two sensors were also tested under different weather conditions, including rain, snow and clear weather. Both sensors worked properly under these conditions; they did not fail to detect pedestrians' presence during adverse weather conditions such as rain and snow. To directly compare the accuracy of counting performance, sensors were installed at the same locations for most tests. Long-term field tests were conducted and the baseline data were extracted from the corresponding videotape recordings. It should be emphasized that baseline data collection is a time-intensive task. To extract 1-hour data from video, approximately 4 hours of manual counting effort is needed. This further illustrates the importance of exploring the feasibility of automatic pedestrian-counting technologies that will reduce the need for manual counts.

The field test results indicate that there are statistically significant differences between thermal and EcoCounter sensors in comparison with the baseline data. For both sensors, it was found that the periodic error range changed under different time intervals—namely, the larger the interval the smaller the error range.

EcoCounter was found to clearly undercount pedestrians, especially at high-volume sites. The errors were larger than findings reported in previous studies[23, 26]. However, it was known before the field tests that EcoCounter would not perform well at intersections. EcoCounter was not recommended for intersections by the manufacturer. Our purpose was to observe the extent of under- or overcounting by EcoCounter and to determine ways to improve its accuracy by using postprocessing (calibration) techniques, as shown in the next section.

The thermal sensor had relatively lower overall error rates as well as MAPEs in most cases compared with EcoCounter. Both undercounting and overcounting cases were also observed for the thermal sensor.

Table 15 summarizes the variability of the sensors' accuracy as reported in previous studies as well as our study. Similarly, even though multiple long-term tests were conducted in this study, there is still no definitive conclusion for the error rates of each automatic counter.

The accuracy of pedestrian counts is a function of many factors. Results can be influenced by the deployment location of the counter, the type of technology (thermal versus infrared), and the time interval used to aggregate the data. Although pedestrian volume does not directly appear to have a strong influence on a counter's performance, more complex pedestrian patterns such as group arrivals, side-by-side walking, and pedestrians lingering around the detection area are observed to affect the performance of sensors. To obtain reliable results, all these factors need to be considered when selecting and implementing an appropriate automatic pedestrian counter at a given location.

Table 15. Summary of other related field test results

Field Test	State	Sensor	Technology	Location	Test Duration	Time Interval	Volume	Measurement	Results
SRF, Inc. (2003) (16)	MN	ASIM DT272	Passive infrared	Crosswalk	Oct-8-2002	Real time	100	Difference (%)	0%
		Diamond TTC4420	Pulsed infrared	Crosswalk			100		7%
		MS Sedco SmartWalk1400	Microwave	Crosswalk			100		0%
		Autoscope Solo	Video	Crosswalk			100		0%
Bell (2006) (26)	VT	EcoCounter	Passive infrared	Sidewalk	5 busiest days, 5 slowest days, 5 busiest hours	Hourly, weekly, monthly	Low and high	Difference (%)	2%
Noyce et al. (2002, 2006) (28,29)	MA	AutoSense II	Active-infrared imaging	Trail		Unknown	357	Correct detections (%)	97%
Turner et al. (2007) (27)	TX	MS Sedco SmartWalk1400	Microwave	Curbside	4 hours	Unknown	Low and high	Overall error (%)	ASIM: 9% to 32%, SEDCO:11% to 39% Diamond: -7% to -24%, TrafX: -52% to 0% Jamar: -100% to 0%
		MS Sedco SmartWalk1800	Microwave	Crosswalk					
		ASIM IR201	Passive infrared	Curbside				Missed detection Error (%)	ASIM: 7%~22%, SEDCO:10%~31% Jamar:-100%~0%, TrafX: -52%~0%
		ASIM IR207	Passive infrared	Crosswalk					
		Jamar Scanner	Passive infrared	Trail					
		TrafX Infrared Trail Counter	Passive infrared	Trail				False detection error (%)	ASIM: 2% to 16%, SEDCO: 0% to 13% Jamar: 0% TrafX: 0% to 1%
		Diamond TTC4420	Pulsed infrared	Trail					
Greene-Roesel et al. (2008) (23)	CA	EcoCounter	Passive infrared	Sidewalk	4 hours	15 minutes	654 ped/hr	Difference/period (%) overall error(%)	Period: -46% to 8%, Overall: -14%
							56 ped/hr		Period: -25% to 43%, Overall : -9%
							367 ped/hr		Period: -26% to -11%, Overall:-19%
Current Study	NJ	EcoCounter	Passive infrared	Trail crosswalk bridge	6 to 12hours	15 minutes 30 minutes 1 hour	Low and high	MAPE overall error (%)	15-minute MAPE: 2.3% to 39.3% 30-minute MAPE: 4.0% to 31.9% 1-hour MAPE: 4.3% to 32.0% Overall: -27.9% to 0.0%
		Thermal sensor	Thermal						15-minute MAPE: 0.0% to 16.98% 30-minute MAPE: 0.0% to 14.82% 1-hour MAPE: 0% to 14.91% Overall: -14.61% to 1.3%

INFRARED SENSOR CALIBRATION

Introduction

Different technologies are used to perform automated pedestrian counts, such as video detection, microwave and infrared counters. Among them, infrared counters are one of the frequently used counting devices. It is now easy to find examples of its application in shopping malls, stores, libraries and visitor centers. These devices work relatively well for indoor settings. Application of these automatic pedestrian counters outdoors such as on sidewalks and at intersections is less widespread, partly because of the complexity of adapting the technology to work correctly outdoors where many factors will affect the results(30). The characteristics of infrared data collection raise some accuracy concerns. Infrared counters require pedestrians to pass the sensing area in single file for maximum accuracy(4). It is particularly inaccurate at distinguishing group arrivals and pedestrians simultaneously walking side by side. Other factors such as falling leaves, animals, strollers and large suitcases may also contaminate the real counts. Nevertheless, with sufficient samples, it is possible to establish a statistical conversion that can improve the accuracy in the long run.

Since no automatic counter will be 100 percent accurate, the outputs of these counters should be used with caution. Thus, the main objective of this section is to identify a statistical conversion so that the overall quality of an infrared counter can be enhanced. As mentioned before, the pedestrian arrival pattern is a major factor for the counter failing to count accurately. A strong correlation must exist between the sensor counts and the actual pedestrian counts when other factors are controllable. Therefore, this section focuses on making an in-depth investigation of the relationship associated with counter error and actual pedestrian traffic.

Case Studies of Sensor Calibration

Though not as common as indoor application, infrared counters have been installed by several agencies to collect automated counts of pedestrians as well as bicyclists in urban environments. The city government of Cheyenne, Wyoming, installed an infrared laser counter to record path counts to justify the usage of the greenway system in the 1990s(8). In 2002, the Licking County Ohio Area Transportation Study began installing passive infrared counters along a shared-use path system to provide data for a comprehensive bicycle and pedestrian plan(31). An active infrared counter was also placed above the Norwottuck trail in Amherst, Massachusetts, to measure pedestrians and bicycle use in 2001(28). These applications show that none of these counters performed perfectly at a level acceptable for use in transportation studies.

There are several cases as mentioned in previous sections that directly tested and reported the performance of a type of commercially available infrared counter. However, all these studies focused mainly on testing the accuracy of the infrared counters and not on ways to improve the quality of the automatic counts. As count errors were found to be significantly related to pedestrian flow characteristics, it is concluded that a robust calibration procedure is needed to obtain reliable results from the raw counts.

Kuah[32] enhanced an infrared pedestrian-counting system for shopping malls. Simultaneous pedestrian crossings contributed to the high error rates. A nonlinear relationship between sensor data and simultaneous pedestrian crossings by multiple shoppers was constructed. Three regression models—linear, multiplicative, and exponential—were proposed. Data aggregated by 15-minute intervals were used to develop and test the regression models. A nonlinear model was recommended as a way to correct for the errors in raw counts. The model was presented as follows:

$$Y = e^{[1.432 + 1.111 \times \ln(X)]} \quad (4)$$

where X is the infrared counter counts for each 15 minutes, and Y is the estimated counts of 15 minutes after correction.

This was one of the first pilot studies on the topic of calibration of an infrared counter. However, since Kuah[32], this issue of calibrating infrared sensors used for counting pedestrians was rarely addressed.

Only in recent years did researchers start to reinvestigate the calibration issue. Lindsey and Nguyen[33] analyzed the use of pedestrian data by infrared counters—namely, Trailmaster along the greenway trails in Indiana. The researchers made three adjustments to counter readings to account for errors and missing observations. An important adjustment was the development of a linear correction model to adjust for systematic errors associated with users passing simultaneously. The model parameters were estimated by using actual hourly traffic and the associated automatic hourly pedestrian counter as follows:

$$Y = 4.315 + 1.153 \times X \quad (5)$$

where X is the hourly infrared counter count for each 15 minutes, and Y is the estimated hourly count after correction.

However, when the same infrared counters were employed in a similar study by Lindsey and Lindsey[34], a different adjustment equation was obtained.

$$Y = 5.22 + 1.55 \times X \quad (6)$$

where X is the hourly infrared counter count for each 15 minutes, and Y is the estimated hourly count after correction.

The infrared counter was used by Lindsey et al.[35] to model daily pedestrian traffic. To reduce the error caused by pedestrians passing simultaneously, and to recalibrate the counter for better performance, hourly correction models from 442 hours of trail traffic at 28 locations were developed. This time the model specification was completely different from the previous ones.

$$Y = (-0.0205 + X_1 + 1.04563 \times \sqrt{X_2})^2 \qquad (7)$$

where X_2 is the hourly infrared counter count, and Y is the estimated hourly count after correction. X_1 is a parameter specified as follows:
$X_1 = 0$, if 0 < monitor count ≤ 60;
$X_1 = 0.2287$, if 60 < monitor count ≤ 110;
$X_1 = 0.3938$, if 110 < monitor count ≤ 200;
$X_1 - 0.4551$, if monitor count > 200.

The coefficients are obtained by comparing manual counts and infrared counts. Surveyors had to manually record total traffic, mode of trail use (walking, running, skating, cycling, or other activity), gender, number of groups, and people per group. Such a complex task may result in difficulties in collecting all the correct information. The same adjustment procedure was also used in a later study by Lindsey et al.[36].

The above calibration models directly correlated manual counts and sensor counts to derive a regression model for correcting raw counts. It has been shown that there is no unique model. Different counters may require different calibration models. Different calibration equations are needed even if the same type of counter was used at different sites. This is due to the unique pedestrian traffic flow characteristics at each site but so far none of the models has addressed the impact of the pedestrian flow.

Thus, we propose a research methodology that is specifically designed to address this issue of errors due to pedestrian traffic flow characteristics. Our calibration methodology can be summarized as follows:

1. Conduct pilot lab tests to characterize sensor errors due to pedestrian dynamics in a carefully controlled environment.
2. Conduct field tests to acquire real-world sensor data that can be used for the estimation of models used for final calibration. Collect video data to be used as the basis for ground truth data.
3. Process video data in the laboratory to obtain ground truth data.
4. Estimate calibration equations using the sensor data.
5. Test calibration equations with new field data, which are not used for estimation of the calibration equations.
6. Provide general findings and suggestions for calibration of future pedestrian data collection based on the results of this study.

Pilot Lab Tests

A pilot lab test was conducted to investigate the effect of pedestrian arrival patterns on EcoCounter's performance. In EcoCounter, two lenses sensitive to the infrared radiation emitted by the human body detect each time a person passes. The counter uses a four-threshold algorithm to avoid false counts generated by vegetation movement, rain or the sun. Its double-direction vertical technology allows dual-direction counts in any temperature[(37)]. Its metal box keeps it working properly in all weather conditions. Internal battery life is up to 10 years and the data logger can store data in 15-minute intervals for up to 1 year. It can be easily deployed for long-term counting.

The lab-controlled test was scheduled on 9 January 2009, in the RITS lab. Five scenarios were designed as shown in Figure 16. The counter was mounted at a height recommended by the manufacturer. The participants were instructed to walk accordingly: (a) single pedestrian walks at normal pace; (b) single pedestrian stands for 5 seconds in front of the counter; (c) two pedestrians walk side by side; (d) two pedestrians occasionally arrive from different directions; and (e) one pedestrian closely follows the other. Scenarios tested the reliability of counters in an ideal environment. Scenarios (b) to (e) try to show the disturbance of typical cases in reality. Each scenario was run 25 times. The sensor counts were recorded.

Results, presented in Table 16, illustrate that the counter works accurately if pedestrians walk in single file. The counter also performs relatively well even when pedestrians follow each other very closely. However, if a pedestrian stops in front of the sensor for a couple of seconds, overcounts occur. The number of overcounts depends on the magnitude of standstill time. The counter will undercount if two pedestrians walk side by side or arrive at exactly the same time. It is confirmed that if more people walk side by side or arrive at the same time, they are counted as one. Given a real context where a stop scenario is expected to be negligible, the error will be associated mainly with simultaneous arrivals. If the likelihood of simultaneous arrivals is high at a location, more undercounting cases are expected to occur.

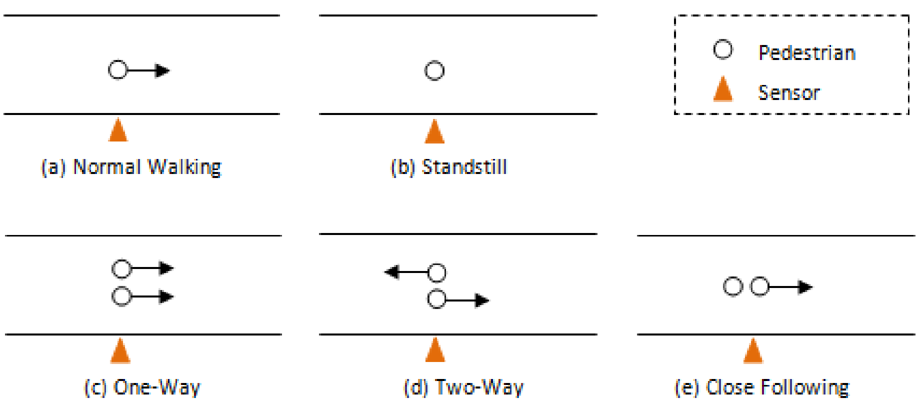

Figure 16. Controlled pedestrian arrival pattern

Table 16. Pilot test results

Sequence	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
(a)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
(b)	2	1	2	1	1	1	2	1	1	2	1	2	1	1	1	2	1	1	3	3	3	3	2	1	2
(c)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1
(d)	2	2	2	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	2	1	1	2	2	2	2
(e)	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	2	2	2	2	2

Note: The shaded areas represent miscounts

Proposed Calibration Method

Previous studies used regression analysis to directly establish a functional relationship between ground truth and sensor counts. This is a feasible way to calibrate the EcoCounter infrared counter. However, previous calibration approaches did not attempt to capture the real impact of pedestrian arrival patterns. The pilot laboratory study presented above has already demonstrated that simultaneous arrivals of pedestrians have a significant impact on the accuracy of sensor counts. Therefore, this study takes advantage of this information about pedestrian arrival patterns to seek an enhanced calibration procedure.

Since pedestrians arrive randomly, it is impossible to assume that everyone arrives as individuals or groups of a certain size. During the data collection stage, pedestrian arrival patterns can be determined through video recordings of field data. Depending on how many people arrive at the same time, the arrival patterns can be classified into several types:

- Group 1 — Arrival of one person.
- Group 2 — Arrival of two people simultaneously.
- Group 3 — Arrival of three people simultaneously.
- Group 4 — Arrival of four people simultaneously.
- Group 5 — Arrival of five people simultaneously.
- Group 6 — Arrival of six people simultaneously.

Based on the results of the pilot tests, field data collected at site 1 (Busch student center trail) are applied for further analysis. Six days of data were used for sensor calibration: March 12, March 13, April 10, April 13, April 14, and April 15, 2009. The data covered all the weekdays.

The group patterns observed at site 1 are summarized in Table 17. More than half of the arrivals consist of individual pedestrians. About 30 percent of the arrivals fall into group 2. Approximately 10 percent of pedestrians arrive in groups of three people. Few people arrive in larger groups. As the number of arrivals falling into groups 1 and 2 is quite large, they have a significant impact on counter errors. By further analyzing the data in 15-minute intervals, a high correlation was found between the actual total flow and the number of people in each group, especially groups 1, 2, and 3. The information is shown in Table 18. The correlation coefficients in each cell of the table are calculated as follows: Suppose the observed flows for the eight periods (each period is 15 minutes) are listed as F = (10, 20, 30, 40, 50, 60, 70, 80). Assume there are only three types of groups: group 1, group 2, and group 3. The number of pedestrians in group 1 for each 15-minute interval is calculated as G1 = (5, 10, 15, 20, 25, 30, 35, 40), the number of pedestrians in group 2 for each 15-minute interval is G2 = (2, 4, 6, 8, 10, 12, 14, 16), and the number of pedestrians in group 3 for each 15-minute interval is calculated as G3 = (3, 6, 9, 12, 15, 18, 21, 24). Note that F = G1 + G2 + G3. Then correlation coefficients are calculated between F and G1, F and G2, and F and G3.

The positive correlation coefficients indicate that, when the total flow increases, the number of people in each group also increases.

Table 17. Pedestrian arrival patterns

Test Date	Weekday	Group 1 (1 person)	Group 2 (2 people)	Group 3 (3 people)	Group 4 (4 people)	Group 5 (5 people)	Group 6 (6 people)
12 Mar	Thursday	54.70%	30.60%	11.30%	2.90%	0.30%	0.20%
13 Mar	Friday	57.40%	32.80%	8.10%	1.70%	0.00%	0.00%
10 Apr	Friday	54.10%	29.40%	12.50%	3.70%	0.30%	0.00%
13 Apr	Monday	67.10%	24.70%	6.60%	1.60%	0.00%	0.00%
14 Apr	Tuesday	53.70%	37.00%	8.10%	1.20%	0.00%	0.00%
15 Apr	Wednesday	62.10%	32.00%	5.20%	0.70%	0.00%	0.00%

Table 18. Correlation of pedestrian flow and counts in group (15-minute interval)

Date	Duration	Total Flow	Correlation		
			Flow vs. Group 1	Flow vs. Group 2	Flow vs. Group 3
12 Mar	10:30 am-10:30 pm	3,688	0.852	0.790	0.692
13 Mar	10:30 am-10:30 pm	2,147	0.973	0.968	0.709
10 Apr	10:30 am-10:30 pm	3,103	0.893	0.955	0.803
13 Apr	10:30 am-10:30 pm	3,995	0.908	0.867	0.635
14 Apr	10:30 am-10:30 pm	3,781	0.876	0.890	0.661
15 Apr	10:30 am-08:30 pm	3,299	0.900	0.874	0.429

Pilot tests showed that the EcoCounter works perfectly if pedestrians arrive individually. On the other hand, if people arrive in groups it undercounts them as one person. If the number of people arriving in groups of different sizes is known, we can correct for the missing counts. For instance, if there are 5 pedestrians walking individually, 2 people walking side by side, and another group of 3 people, the counter will count 7 instead of 10. This is due to 1 undercount from the second group and 2 from the third group. This result is expected because this sensor is designed mainly for these kinds of trail and sidewalk conditions. However, in this study we hypothesize that the errors caused by more complex situations can be taken care of if appropriate calibration techniques are applied to the raw data. Moreover, even for trails and sidewalks, there will be different arrival patterns for which errors will be incurred.

Field survey results highlighted the strong correlation between the actual numbers of people in groups and the total counts as shown in Table 18. A similar correlation was found between sensor counts and actual numbers of people in groups. Although in reality only the pedestrian counts can be obtained from the sensors, group patterns can be estimated if a statistical relationship is established between the sensor counts and the numbers of people in groups using field results. Given the group information, the missing counts can be estimated. Together with the original sensor counts, the raw outputs can be calibrated to yield more reliable results.

Model Specification and Estimation

There is a strong linear relationship between pedestrian flows and group arrivals, as shown in Table 18. Thus, linear calibration models are proposed. Based on the findings presented in the previous section, the calibration models that were estimated in this study are specified as follows:

$$Group2 = \beta_{20} + \beta_{21} \times SensorCounts \quad (8)$$

$$Group3 = \beta_{30} + \beta_{31} \times SensorCounts \quad (9)$$

$$RealCounts = SensorCounts + \frac{1}{2} \times Group2 + \frac{2}{3} \times Group3 \quad (10)$$

where '*SensorCounts*' is the automatic counter output for each time interval, and '*Group2*' and '*Group3*' represent the estimated number of two pedestrians and three pedestrians simultaneously arriving with the time interval, respectively. '*RealCounts*' is the prediction of actual counts. β_{20}, β_{21}, β_{30}, and β_{31} are parameters to be estimated. "1/2" and "2/3" in equation (10) are correction factors for the missing counts of group 2 and group 3.

Ideally, data for counter calibration should be collected as much as possible. However, due to budget and time constraints, only a certain amount of data could be collected—for instance, several hours or several days. These short-term calibration data may be not sufficient to generate a better calibration model. To overcome this problem, a better procedure is necessary to maximize utilization of the limited data for calibration. As the periodic number of pedestrian arrivals is random and limited field data are collected, the procedure was built using bootstrap regression models to estimate β_{20}, β_{21}, β_{30}, and β_{31}[38]. Let the vector

$w_i = (y_i, x_i)'$ denote the values associated with the actual count y_i and sensor count x_i at the *i*th interval. A set of observations are the vectors $(w_1, w_2, \dots, w_n)$. The bootstrap calibration procedure based on resampling the pairs of sensor counts and the number of pedestrians in groups can be summarized as follows:

1) Draw an *n*-sized bootstrap sample $(w_1^*, w_2^*, \dots, w_n^*)$ with replacement from the observation giving 1/*n* probability to each w_i values and label the elements of each vector as $w_i^* = (y_i^*, x_i^*)'$, where *i* = 1, 2, …, *n*.
2) Use the vector $Y^* = (y_1^*, y_2^*, \dots, y_n^*)'$ and $X^* = (x_1^*, x_2^*, \dots, x_n^*)'$ to calculate the ordinary least-squares coefficients based on the bootstrap sample:
   $\hat{\beta}_1^* = ((X^*)'X^*)^{-1}(X^*)'Y^*$ (11)
3) Repeat steps 1 and 2 for k = 1, 2, …, B, where B is the number of repetitions. Obtain the probability distribution $F(\hat{\beta}^*)$ of bootstrap estimates $\hat{\beta}_1^*$, $\hat{\beta}_2^*$,…, $\hat{\beta}_B^*$ and use $F(\hat{\beta}^*)$ to estimate regression coefficients, variances, and confidence intervals as follows. The final bootstrap estimate of regression coefficient is the mean of the distribution $F(\hat{\beta}^*)$:
   $\hat{\beta}^* = \sum_{k=1}^{B} \hat{\beta}_k^* / B$ (12)
4) The basic format of the bootstrap regression model is equation (13). In this study, the specific variables of the model are denoted as X = the sensor counts and Y = the number of pedestrians arriving in a group of a given size (two or three).
   $\hat{Y} = X\hat{\beta}^* + \varepsilon$ (13)
5) The bootstrap variance from the distribution $F(\hat{\beta}^*)$ is:
   $var(\hat{\beta}^*) = \sum_{k=1}^{B} [(\hat{\beta}_k^* - \hat{\beta}^*)(\hat{\beta}_k^* - \hat{\beta}^*)'] / (B-1), \quad k = 1, 2, \dots, B$ (14)
6) The bootstrap confidence interval by a normal approach is obtained by:
   $\hat{\beta}^* - t_{n-p,\alpha/2} * S_e(\hat{\beta}^*) < \beta < \hat{\beta}^* + t_{n-p,\alpha/2} * S_e(\hat{\beta}^*)$ (15)
7) A nonparametric confidence interval—namely, percentile interval—can then be constructed from the quantiles of the bootstrap sampling distribution of $\hat{\beta}^*$. The $(\alpha/2)\%$ and $(1-\alpha/2)\%$ percentile interval is:
   $\ddot{\beta}_{lower}^* < \beta < \ddot{\beta}_{upper}^*$ (16)

   where $\ddot{\beta}_{lower}^*$ and $\ddot{\beta}_{upper}^*$ are the ordered bootstrap estimates of regression coefficient from step 4, β is the truth coefficient, $lower = (\alpha/2)B$, and $upper = (1-\alpha/2)B$.
8) The model in step 4 is used to estimate the group information by sensor counts. The exact models are shown in equations (8) and (9). The parameters were estimated by using the above bootstrap steps. $\hat{\beta}_{20}^*$ and $\hat{\beta}_{21}^*$ are estimated coefficients for estimating the number of pedestrians coming in a group size of two ($\widehat{Group2}$). Similarly, coefficients in equation (18) are for estimating the number of pedestrians coming in a group size of three ($\widehat{Group3}$).
   $\widehat{Group2} = \hat{\beta}_{20}^* + \hat{\beta}_{21}^* \times SensorCounts$ (17)

$$\widehat{Group3} = \hat{\beta}^*_{30} + \hat{\beta}^*_{31} \times SensorCounts \quad (18)$$

9) Estimate the real counts based on results of step 8 and the original sensor counts:

$$\widehat{RealCounts} = SensorCounts + \frac{1}{2} \times \widehat{Group2} + \frac{2}{3} \times \widehat{Group3} \quad (19)$$

The first part of the right side represents the raw counts, which treat all arrivals as single arrivals. The second part explains the missing counts due to two pedestrians arriving simultaneously. Similarly, the third part addresses the missing counts due to three people arriving simultaneously.
10) Use an additional data set to validate the above procedure.

Calibration Results and Analysis

The data collected on March 12, March 13, April 13, April 14, and April 15 were used as training data. This way all the training data capture pedestrian flow features during all weekdays. The original data were aggregated into two time intervals: 15 minutes and 1 hour. For each interval type, the calibration parameters were estimated by using the above bootstrapping procedure; 10,000 bootstrap samples, each of size of 100, were randomly generated to reflect the exact behavior of the bootstrap procedure. Figure 17 illustrates an example of the histograms of bootstrap regression parameters. All the histograms are found to follow the normal distribution for all regression coefficients.

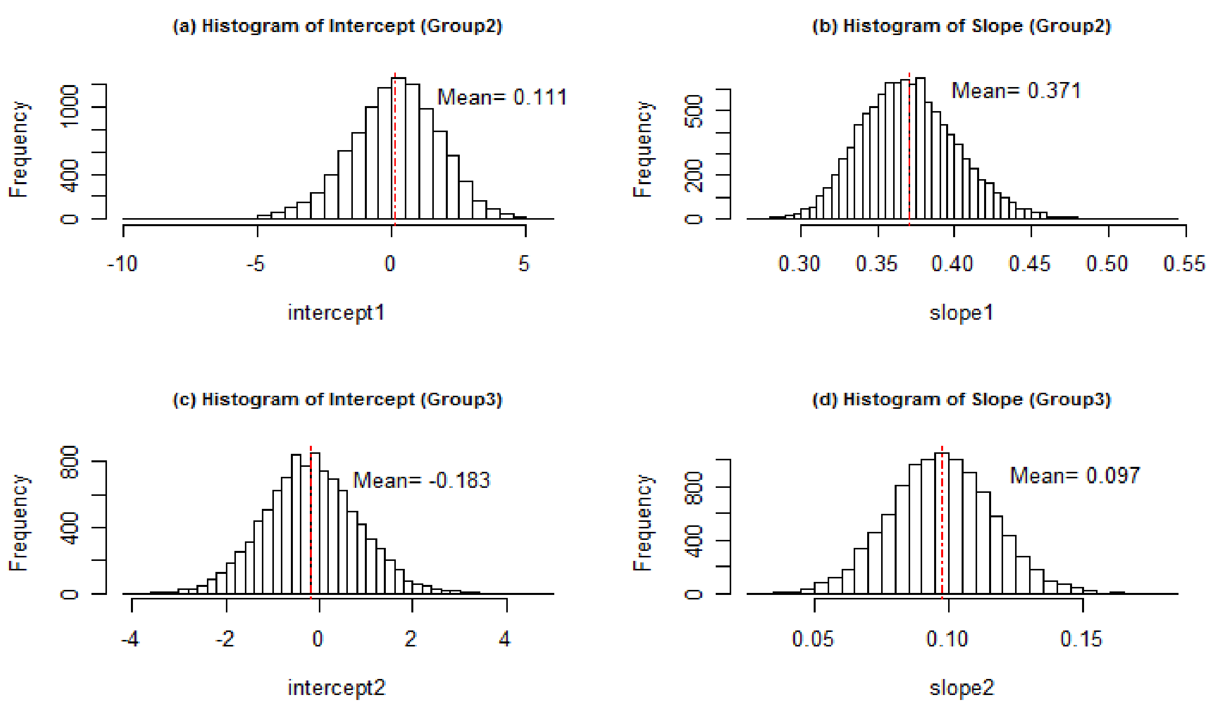

Figure 17. Histogram of estimated coefficients (15-minute intervals)

The scatter plots of bootstrap replications of the coefficients are shown in Figure 18. The concentration ellipses are drawn at the 50 percent and 95 percent levels using a robust estimation of the covariance matrix of the coefficients[39]. The larger time interval generated a smaller confidence interval for the slope.

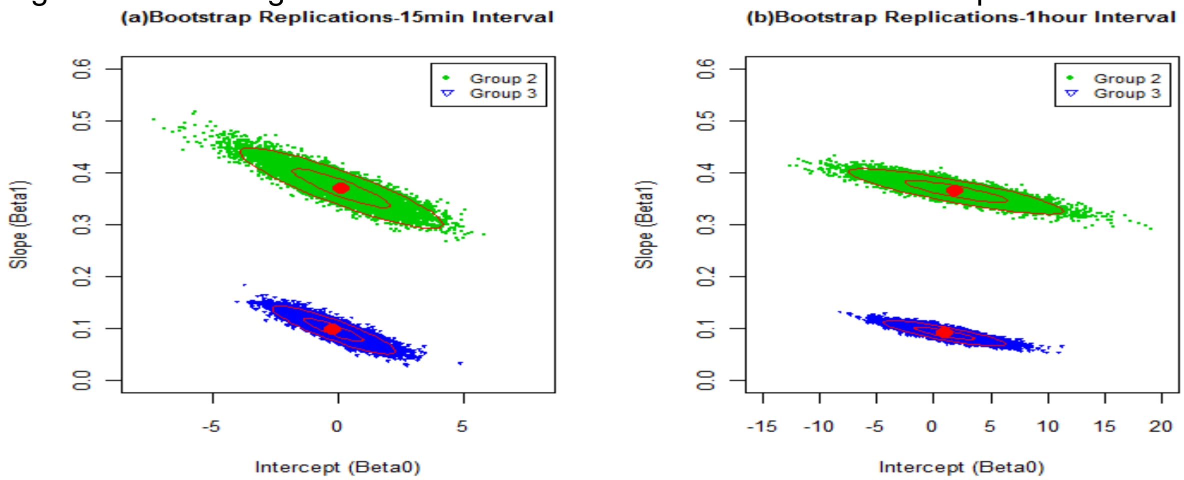

Figure 18. Bootstrap replications of regression coefficients

There are several ways to apply the information of estimated coefficients. Instead of sampling coefficients from their distributions, this study uses the estimated mean coefficients to establish the final calibration models. For 15-minute intervals, the estimated calibration models are:

$\widehat{Group2} = 0.111 + 0.371 \times SensorCounts$ (20)

$\widehat{Group3} = -0.183 + 0.097 \times SensorCounts$ (21)

For 1-hour intervals, the estimated calibration models are:

$\widehat{Group2} = 1.953 + 0.364 \times SensorCounts$ (22)

$\widehat{Group3} = 0.935 + 0.090 \times SensorCounts$ (23)

By combining equations (19) through (23), original counts from the counter can be calibrated. To test the performance of the proposed procedure, two additional data sets were used. This validation data set included data collected on April 10 (10:30 am to 10:30 pm) at the same location and data collected on May 22 (9:00 am to 5:00 pm) at a different intersection in Trenton. It should be noted that the first 15-minute counts of the second data set were invalid due to adjustment of the EcoCounter's mounting height. So when the data were integrated into 15-minute intervals, the first period was ignored. Similarly, when they were integrated into 1-hour intervals, the counts of the first hour were excluded.

The validation results are presented in Figure 19. Differences can be observed between the original sensor counts and the ground truth data. The calibration method reduced the errors and the estimated counts are closer to the ground truth data as shown in Figure 19. In particular, when the calibration procedure was applied to the data set of the same location, the results shown in Figure 19a and 19b matched the trend and the level of baseline counts. Though intersection counts were improved, Figure 19c and 19d indicated that there are still some differences between the sensor counts and the ground truth data. A possible reason could be the significant difference in pedestrian patterns at the two locations. Table 17 shows that 54% to 67% of pedestrians arrived individually at the trail. About 30% of the people arrived in group 2. Approximately 10% arrived with three people together. However, the corresponding percentages of each type of group arrival are 73.9 percent, 22.2 percent, and 3.4 percent at the intersection in Trenton. As the training procedure was built on the data collected at the trail, it is acceptable that the first validation performed better. In principle, more single arrivals should result in better performance of the EcoCounter, but the results at the intersection in Trenton did not support this hypothesis. When the video recordings were reviewed, it was found that many pedestrians were standing in front of the sensor waiting for the traffic signal. Some pedestrians blocked the sensor, resulting in undercounts.

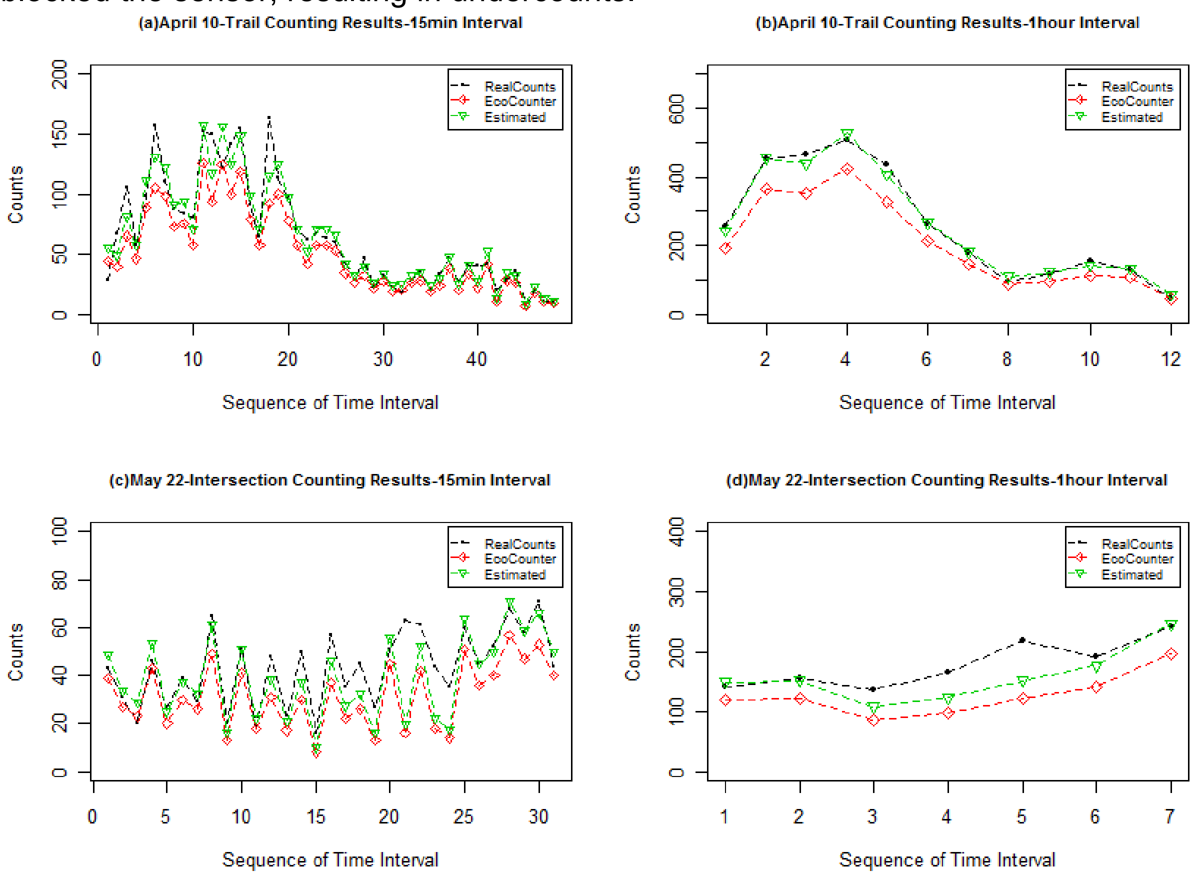

Figure 19. Comparisons of validation results

The Wilcoxon matched-pairs signed-ranks test was applied to compare the baseline data, original counts, and calibrated counts. This nonparametric test is helpful to illustrate the directional differences between groups of paired data. In this study, the null hypothesis assumed that a set of sensor count data are the same as the corresponding truth data. The alternative hypothesis is that the sensor counts were less than the ground truth counts. Table 19 presents the test results. At an alpha = 0.05 level of significance, the null hypothesis was accepted. The original EcoCounter counts were significantly less than the baseline data. The overall error rate was reduced below 1 percent at the trail when the calibration procedure was applied. For the intersection data from Trenton, the original error rate declined about 18 percent once the calibration procedure was applied.

The improvement in the EcoCounter results presents the capability of the proposed infrared sensor calibration methodology. However, the difference in the calibration performances at two sites indicates that in-depth investigation is necessary, especially for the location where the training was not conducted. Since the model is estimated from trail data, it should be used carefully for intersection data even though it could reduce errors. The model parameters should be adjusted for intersections as they may have different pedestrian flow patterns.

Table 19. Wilcoxon matched-pairs signed-ranks test

Date	Interval	Comparison	H0	H1	*p*-Value	Overall Error (%)
10 Apr	15 min	Counter vs. baseline	Difference=0	Difference<0	5.41E-08	-20.5
10 Apr	15 min	Calibrated vs. baseline	Difference=0	Difference≠0	0.3673	-0.7
22 May	15 min	Counter vs. baseline	Difference=0	Difference<0	8.20E-07	-27.6
22 May	15 min	Calibrated vs. baseline	Difference=0	Difference≠0	0.05524	-9.7
10 Apr	1 hour	Counter vs. baseline	Difference=0	Difference<0	0.0002441	-20.5
10 Apr	1 hour	Calibrated vs. baseline	Difference=0	Difference≠0	0.9697	-0.6
22 May	1 hour	Counter vs. baseline	Difference=0	Difference<0	0.01113	-29.3
22 May	1 hour	Calibrated vs. baseline	Difference=0	Difference≠0	0.1563	-11.3

CONCLUSIONS AND FUTURE WORK

Pedestrian counts are critical data that have been used as input into traffic engineering design, planning and safety analysis. Conventional methods such as manual counting and video reviewing can satisfy or partially satisfy only short-term data collection requirements. To collect data as strategic resources, long-term and extensive data collections are needed.

Emerging sensor technologies accelerated the shift toward applying automatic counters to collect reliable long-term pedestrian data. As the accuracy levels of current available sensors are still not well known to users or practitioners, this project conducted many field tests to reveal field performance of two commercially available automatic pedestrian sensors by rigorous comparisons. The results demonstrate the capabilities, and pros and cons of the automatic counting methods.

Based on the evaluation framework shown in Table 3, some of the overall findings of system performance of the two tested pedestrian counters can be summarized in the following:

Functional Satisfaction: Based on our interviews with the vendors, and our review of relevant studies in the literature before the purchase of the pedestrian counters, we knew that both counters were able to count pedestrians and identify the direction of pedestrian traffic. Neither counter can time-stamp the passing of individual pedestrians, but pedestrian counts are aggregated in predetermined time intervals. EcoCounter stores counts in 15-minute intervals, and it does not allow users change the interval. Thermal sensor allows users to aggregate pedestrian counts in the increments of one minute.

System Availability: Both pedestrian counters are commercially available, can be acquired within two weeks after purchase. Technical support from the vendor is necessary to install and deploy thermal sensor, to calibrate the counter and to retract data. EcoCounter's installation and deployment can be performed using the manuals that are provided by the vendor.

As described in detail in Appendix E, pedestrian counts collected by EcoCounter is extracted using a pocket PC or a smart phone that has infrared capability, and the EcoCounter software installed. Data are extracted easily and transferred to a PC in a tabulated format. Detailed steps of how to extract data from thermal sensor are presented in Appendix F. Thermal sensor setup is more complicated but it has the additional capability of remotely receiving real-time counts, and monitoring the status of the counter.

System Accuracy: EcoCounter performs best at trails and sidewalks as recommended by its manufacturer, because its performance is sensitive to pedestrian arrival patterns. For example, it undercounts if pedestrians are walking side by side. Therefore, EcoCounter performs well at trail settings where pedestrians usually arrive individually. Deployment of EcoCounter at high volume sites are not recommended by its manufacturer. Results of our field tests also showed that EcoCounter clearly undercounts pedestrians at high-volume sites with an overall error rate ranging between -5.26 percent and -27.9 percent. The errors were larger than those reported in previous studies(23, 26), as shown in evaluation results section. The results at the lower-volume sites show that EcoCounter performs much better, with the mean absolute percent error (MAPE) being below 14 percent.

The accuracy of both counters is sensitive to the time interval of data integration. Generally, it has been shown that the larger the time interval, the lower the counting error rate is. If there is no special need for data with shorter timer intervals, the larger interval is preferred. This not only improves the relative accuracy but also reduces the cost of data integration.

The field test results indicate that there are statistically significant differences between thermal and EcoCounter sensors in comparison with the baseline data. Thermal sensor has an overall error rate ranging between -14.61 percent and 1.3 percent. The largest overall error rate of -14.61 percent occurred at a crosswalk in New Brunswick where pedestrians stop at the detection area waiting for the traffic light. The error rate at the crosswalk in Trenton is -2.2 percent. At the trails or the intersections, the error of the thermal sensor appears to be lower than that of EcoCounter. The results show that the MAPEs of EcoCounter are 1.5 to 2.0 times larger than those of the thermal sensor if they were both deployed at high-volume sites and the data were aggregated into larger time intervals.

This study established a calibration procedure so that raw data from the EcoCounter can be calibrated to better reflect the ground truth data. Based on the estimated calibration model of 15-minute intervals, the overall error was reduced to -0.7 percent from -20.5 percent for the high-volume trail on the Rutgers Busch campus. The overall errors were reduced to -9.7 percent from -27.6 percent for the intersection in Trenton.

System Reliability: Both counters responded correctly given the single arrival. Missing counting and over counting will occur if the pedestrian arrival in a complex situation, for instance, large group arrive simultaneously, or pedestrian linger around the detection area. Thermal sensor failed three times because the battery used to power the sensor depleted earlier than expected due to cold weather in April, 2009.

Some other findings of the study are listed as follows:

- Both sensors could be deployed at various pedestrian facilities such as sidewalks, trails, crosswalks, or pedestrian bridges.
- EcoCounter has to be installed at the side of the facility, while thermal sensors can be mounted on a side pole or above the facility.

- EcoCounter, is easier to deploy than the thermal sensor. If the mounting facility is available, EcoCounter could be appropriately installed in 20 minutes. However, the thermal sensor takes at least 45 minutes to mount, connect components, and calibrate.
- Both sensors need corresponding software to retrieve and process the raw counts. The thermal sensor needs calibration software to adjust the detection zone.
- Different sensors require different accessories. Other than data retrieval and processing tools and mounting facilities, EcoCounter needs only screw drivers to be mounted. But the thermal sensor needs a data controller, transmitter, laptop, and even a battery if there is no on-site power supply.
- Power supply is a constraint for long-term deployment of the thermal sensor. But the internal battery of EcoCounter allows it to perform 10 years without charging. A steady power source needs to be established for long-term deployment of the thermal sensor.
- Although, the thermal sensor can perform outdoors perfectly and not affected by adverse weather conditions, its setup is still best suited for pedestrian counts outside of a building, where easy access to power and network is available.
- To calibrate a pedestrian sensor, baseline data are needed. However, this is a time-intensive task. If the baseline data are extracted from a video, analysis of a 1-hour video requires 3 to 4 hours to review. It is recommended that this data extraction be done more than once to reduce human error.
- Better performance at the trail suggests that location-based calibration is recommended. As different sites might have different pedestrian traffic patterns, the parameters of the calibration models should be adjusted accordingly.

This study has shed light on understanding the field performance of the two automatic pedestrian counters. There are still some tasks that warrant further research. Improving the calibration functions with additional data and verifying the sensor performance at other locations can be further investigated. As only two types of technologies are compared in this project, other types of sensors could be compared for accuracy and performance.

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APPENDIX A: SUMMARYS OF KEY INFORMANT INTERVIEWS

Initial Interview List

Interview Group	Name	Organization/ Division	Status
NJDOT Data Development Bureau	Louis Whiteley	NJDOT	Interview completed.
NJDOT Section Chiefs	Douglas Bartlett	Traffic Engineering	Informal interview completed
	Tim Bourne	Traffic Operations	Interview completed
Other DOTs	Sarah Chesborough	CalTrans	Referred to Richard Haggstrom
	Richard Haggstrom	CalTrans	Referred to Teresa Gabriel and Bob Schneider.
	Teresa Gabriel	CalTrans	Informal interview completed
	Patrick McMahon	MassHighway	Informal interview completed
	Casey Matthews	Colorado DOT	Declined interview, Colorado DOT does not conduct pedestrian counts
	Help Desk	Georgia DOT	Could not find anyone involved in pedestrian counting
	Megan Forbes	Minn/DOT	Declined interview, Minnesota does not conduct pedestrian counts
Consultants	Gina DelVecchio	Michael Baker	Interview completed.
	Mike Dannemiller	RBA Group	Interview completed
	David Cox	Urban Engineers	Interview completed
Researchers/ Experts	Charlie Zeeger	UNC	Referred to co-author, Bob Schneider
	Bob Schneider	UC Berkeley - TSC	Interview completed
	Andy Griffiths	Central London Partnership	Interview completed
	David Ragland	UC Berkeley - TSC	Reached out to him, but did not receive a response. Have not followed up because we interviewed another expert from the same group.

Additional Interview List

Interview Group	Name	Organization/ Division	Status
Other DOTs	Thomas Huber	Wisconsin DOT	Responded to Bike/Ped coordinator email, declined interview
	Michael O'Loughlin	Indiana DOT	Responded to Bike/Ped coordinator email, declined interview because INDOT does not count peds.
	Dan Stewart	Maine DOT	Responded to Bike/Ped coordinator email, conducted informal interview
	Jakob Helmboldt	VDOT	Responded to Bike/Ped coordinator email, declined interview because VDOT does not count peds.
	Craig McIntyre	SD DOT	Responded to Bike/Ped Coordinator email. Referred to Steve Gramm
	Steve Gramm	SD DOT	Interview completed
Consultants	Michael Jones	Alta Planning + Design	Interview completed

Interview – Summary Findings
As part of the Automated Pedestrian Counter project, interviews were conducted with a list of key informants identified by the project team. Interviewees were divided into five groups: the data development bureau at NJDOT that conducts pedestrian counts for other units within the agency; section chiefs of other units at NJDOT that had requested pedestrian counts in the past; consultants who had conducted pedestrian counts for NJDOT, personnel from other state DOTs who had experience with pedestrian counting; and researchers who had expertise in the field of automated pedestrian counting. The table above outlines those groups and the individuals who were contacted. In addition to the individuals that had originally been scheduled to be interviewed, several interviews resulted in referrals to others who could provide helpful information. Those individuals are listed in the additional interview list.

Most of those who were contacted were very accommodating and agreed to be interviewed. However, some people did not feel that they had enough knowledge or experience with pedestrian counting to be helpful, and declined a formal interview. Of those cases, several were willing to speak briefly about their limited experiences; those are noted in the table above as informal interviews.
The original strategy when contacting state DOTs outside of New Jersey was to request interviews of individuals in state DOTs that had produced or sponsored research on automated pedestrian counting. After speaking with several staff members from those states, it was clear that even those state DOTs that had sponsored research in pedestrian counting or automated pedestrian counting had never established pedestrian counting programs. In most cases, staff was unaware of the research sponsored by their agency. The next action was to send an email out to the Bike/Ped coordinators of all fifty states to ask if anyone had experience with pedestrian counting and if they would be willing to be interviewed. Five people ultimately responded to that email, four of which stated that they do not regularly conduct pedestrian counts and did not feel they had any information to offer; one agreed to a formal interview.
Ultimately, nine formal interviews were conducted. Each group was given a list of questions tailored to their expertise. In a few cases, the interviewees were given more than one list if they had experience with pedestrian counts in more than one capacity. The key informant interview guides are attached as Appendix B. The key findings of the interviews are summarized below.

Summary Findings of Key Informant Interviews:

- **How is data used?:**

Generally for DOT project staff, the data is used to fulfill warrants required when adding traffic signals or installing sidewalks, crosswalks and other similar facilities. In some cases, the data is gathered only because it is required, and facilities are installed whether the information gathered meets the warrants or not. An example of this would be cases in rural areas, where there may be safety issues despite low pedestrian traffic volumes that don't meet the pedestrian count warrants required for facility construction by the MUTCD.

Data analysis at NJDOT typically consists of plugging the data into a specialized program that produces specific outputs. The program that NJDOT uses is called Synchro.

- **How can data be used?:**

Bob Schneider of UC Berkeley has looked into this question and outlined the following key uses for pedestrian count data:
Engineering

- Measuring the amount of exposure to potential vehicular conflicts
- Satisfying signal and other warrants
- Providing description of use, for planning and design purposes
- Research
- Providing the ability to document trends over time
- Creating a pedestrian flow model
- Political
- Justification of spending public resources on pedestrian facilities
- Verify/disprove anecdotal claims

- **Where is data collected?**

Pedestrian safety is the main concern when dealing with pedestrian issues and as a result pedestrian counts are usually requested where a pedestrian safety issue exists. All respondents collected data at intersections, where pedestrians and vehicles share the same space and conflicts occur most frequently. Some respondents collect data at intersections exclusively, others, especially consultants, have collected data at many different types of locations. David Cox of the consulting firm Urban Engineers has collected data at intersections, trails, and mid-block locations as well as indoor locations. In the case of South Dakota, pedestrian count data was collected at any location where pedestrians had been identified as frequently crossing along a corridor, whether or not the location was an intersection or mid-block crosswalk.

- **Opinions/thoughts on automated counters:**

The interviews produced varied responses with respect to feelings about automated counts. Some respondents, mainly those who worked for DOT's and who collected pedestrian data to fulfill warrants, did not feel as though automated counters would provide much help to them because they typically hired consultants to collect the data and, as long as the data was accurate, were not concerned with how it was collected.

Consultants, including Regina DelVecchio of Michael Baker Jr, Inc., and Mike Dannemiller of the RBA Group, had considered using automated counters in the past but had found, in their limited experience with automated counters, that they tended to be unreliable and inaccurate and generally not worth investing in. Most respondents who felt this way also expressed interest in using automated counters in the future if the technology advanced to the point of being reliable and accurate in complicated environments.

The researchers interviewed had a different opinion of automated counters. All of them had in depth knowledge of the latest developments involving automated counters and were confident that they would eventually reach the point, if they have not already, where they could provide substantial benefits. Andy Griffiths, a researcher in London with the consulting firm Faber Maunsell, has tested several CCTV systems and has received encouraging results. He stated that CCTV, a video based automated detection system, is in use throughout the UK, but that some still considered it inaccurate and unreliable. He personally feels as though the technology has made much recent progress and overcome the deficiencies that had been associated with the technology. Bob Schneider and Michael Jones, both based in the U.S., feel that video technology has the most potential for reliable and accurate automated pedestrian counts but feel that the technology is still several years away from being widely accepted and used.

The main difference in opinions between DOT staff interviewed and others conducting counts for purposes of gathering data, and those working with automated counters for purposes of research is that the researchers tend to see pedestrian count data as something that should be gathered on a much wider basis to get a better understanding of pedestrian flow and facility use, similar to the way that vehicular count data is used in relation to vehicular traffic patterns. As the cost of manual counts would be far too great to justify their systematic use, automated counters would have to fill that need.

DOT staff members were generally of the opinion that pedestrian counts were useful on a site specific basis. They also felt that manual counts were an effective tool for this use. These opinion probably reflect the project based concerns of the staff interviewed as opposed to agency staff concerned with policy development and modeling.

- **Issues with pedestrian counts:**

The biggest issue with pedestrian counts is that the data is only as reliable as the counter, people in the case of manual counts and devices in the case of automated counts.

With manual counts, human error is always a concern. Those who had hired outside contractors to perform manual counts were not always pleased with the results that they received. Some of the consultants had measures to mitigate concerns related to accuracy and reliability. David Cox of Urban Engineers replied that his firm uses mid level staff to conduct the counts, which adds more reliability to the results because of the experience levels of the data collectors. Regina DelVecchio of Michael Baker Jr. Inc., provides the counters with JAMAR intersection counting machines, which makes counting pedestrians easier by allowing data collectors to simply push a button for each person seen rather than manually recording observations. This can help reduce human error in data recording.

Automated counters have not been developed to the point where they are considered reliable in all environments. Different counters have strengths and weaknesses. In certain, more complicated environments, such as plazas and open areas, some devices have been known to have errors rates of up to 30%. Even at simpler locations, such as sidewalks, heavy traffic causes problems with counters that are unable to distinguish the number of pedestrians in a group. Another issue with automated counters are potential limitations concerning where they can be mounted.

- **Policies/warrants for use:**

Most respondents, and all of those that work for DOT's, referenced the MUTCD's warrant for traffic signals. David Cox of Urban Engineers pointed out that other states also have warrants calling for pedestrian counts for midblock crosswalks. It was also stated that pedestrian count data is gathered as a data element for consideration at locations where pedestrian safety is an issue or where through professional judgment it is considered desirable to have the data, even if not explicitly required by departmental policy or warrant.

- **Is a protocol used/ what are the standard procedures?:**

Most respondents replied that there was no written or formal procedure or protocol when conducting pedestrian counts. The specifics of each case depend on the needs of the project. Manual counts are generally conducted on a one time basis. In special cases, the project in Deadwood South Dakota in particular, they are conducted several times over a longer period of time. This is typically done when a better understanding of pedestrian flow is needed, as opposed to a simple count. Counts can last from one to two hours or can range up to twelve hours at a time. Counts can be gathered during both peak and off-peak hours.

- **Are counts conducted on a regular basis?:**

Generally, no DOT staffers all replied that they only request or conduct counts when a specific project requires it, generally to fulfill a warrant. The consultants responded that they typically conduct several counts per month, but that they are all individual cases. None of the interviewees responded that they had been involved in a project that called for ongoing pedestrian counts.

- **What automated technologies are best suited for pedestrian counts:**

This question was asked of the researchers, who had experience using a variety of different automated pedestrian counting devices. The unanimous answer is that it depends a great deal on the situation. Different counters have different characteristics and thus, are better suited for certain environments. For instance, Bob Scheider, a researcher at UC Berkeley is currently working on a project involving the use of Eco-counter infrared sensors. These counters are simple to use and set up and suited his research design where data is collected at several different places for short periods of time. Another reason for the selection of this technology was that it fit within the budget parameters of the project. However, these counters have some trouble accurately counting people walking in groups, and so are better suited for less complicated, light traffic environments.

Andy Griffiths, a researcher in London working for Faber Maunsell, has worked extensively with CCTV technology. The benefits of these devices are that they are designed to be mounted up high, so they are essentially vandal proof and do not interfere with traffic flow. Several of the CCTV devices also work off of batteries and transmit data wirelessly, so they do not require a power source or constant attention. They are also designed to count pedestrians in complicated environments, so they work just about anywhere. However, they are expensive compared to other automated counting technology and, thus, do not make sense to use in trails or other areas where cheaper devices can be used effectively under the less challenging factors associated with trail counts.

- **What costs/resources are involved in performing pedestrian counts, manual and/or automated:**

Generally, the cost of conducting counts differs according to several variables. For manual counts, the pay rate for the data collectors, the number of count locations, the duration and frequency of the counts and the time spent inputting data determines the costs. All of these factors vary from project to project with a resulting variation in cost. Automated counts may require a larger upfront investment, but the devices can then be used for as long as necessary at no additional cost outside of the time required for setup and maintenance. Also, many automated counters provide data in electronic formats, such as excel, and do not require manual entry.

APPENDIX B: KEY INFORMANT INTERVIEW GUIDES

B1. Automated Pedestrian Counter
Data Development Bureau Interview Guide

- What is the role of the Data Development Bureau in obtaining pedestrian count data?

- Are you aware of any department policies or warrants that require the collection of pedestrian count data?

- How does the department use pedestrian count data? Do you analyze the data yourselves or do you give the raw data to those who request the counts?

- Is there a protocol that has to be followed or a request form that has to be submitted for pedestrian count data from your department? If so, can you provide us with a copy of this form or protocol?

    - Does the collection of pedestrian count data have to flow through your bureau or do other units conduct counts independently?

- We are trying to understand which divisions/units at NJDOT request pedestrian counts and under what circumstance so that we can choose automated pedestrian counters for testing that would best meet the needs of the department. Can you provide us with a list or spreadsheet that tells us which units have requested pedestrian counts, the number of time counts were requested over the last year(s), and the locations where the pedestrian counts were conducted?

- Do you have information on the costs and resources that were required for each job? (i.e., XX number of personnel for XX hours, at XX locations)

- Does your bureau conduct pedestrian counts?

    - If your bureau conducts counts, do you have a pedestrian counting protocol that you follow? If so can we get a copy of this protocol?

        - What methods or technologies are used to conduct the counts?

        - Do you test for accuracy periodically?

- Does your bureau use consultants to conduct counts?

    - If consultants are used, are they obligated to follow a protocol? If so can we have a copy of this protocol?
        - Can you provide us with a list of consultants who the department uses? We would like to contact consultants who conduct pedestrian counts on the behalf of NJDOT and interview them. Can you provide us with contact information?

- Does your bureau or the consultants you employ use automated pedestrian counters to collect pedestrian count data?
    - If yes, which types of counters do you use and why? (e.g., price, reliability, ease of use, etc.)
        - Are you generally satisfied with the result you obtain using automated pedestrian counters?
        - Are they used in special cases (e.g., night counts, trails, etc.), and why?
    - If no, we would like to take this opportunity to obtain your thoughts on automated counters and their potential use for the Department and understand if there is a type of counting technology that you would like evaluated.

- From your perspective, has the number of pedestrian counts NJDOT conducts increased or decreased over the past few years? If there has been a notable variance, why? (e.g., policy directive or changes to design guidance/warrants?)

- Do you conduct regular counts in any areas (e.g., annually or semi-annually)?

- How long do you typically gather data for pedestrian counts?
    - Is the duration different for automated counts as compared to manual counts?

- Do you gather any data on the characteristic of the pedestrians you are counting? (e.g., gender, age, etc)
    - If yes, how often is the additional data collected?

- Would you mind if I contacted you with follow up questions in the future, if necessary?

B2. Automated Pedestrian Counter
NJDOT Interview Guide

- Do you or staff in your section conduct or request pedestrian counts?
  - If yes, what are the factors that would trigger a request?
- Who conducts the counts, does your unit conduct them or do you have consultants or some other agent for data collection?
  - If your unit conducts counts, do you have a pedestrian counting protocol that you follow? If so can we get a copy of this protocol?
  - If consultants or another agent are used, are they obligated to follow a protocol? If so can we have a copy of this protocol?
    - Can you provide us with a list of consultants who the unit uses? We would like to contact consultants who conduct pedestrian counts on the behalf of NJDOT and interview them. Can you provide us with contact information?
- At what types of locations have you or your staff requested/conducted pedestrian counts? (e.g., intersections, trails, other)
- Does your unit use Automated Pedestrian Counters?
  - If yes, which types of counters do you use and why? (e.g., price, reliability, ease of use, etc.)
    - Are they used in special cases (e.g., night counts, trails, etc.), and why?
    - Are you generally satisfied with the result you obtain using automated pedestrian counters?
  - If no, we would like to take this opportunity to obtain your thoughts on automated counters and their potential use for your department and understand if there is a type of counting technology that you would like evaluated.
- What are the primary reasons why you request/collect pedestrian count data?
  - Are there NJDOT warrants or policies that call for pedestrian counts?
    - If yes, please describe

- How does your unit use pedestrian count data?
    - Do you analyze the data yourselves?
    - How do the results of counts factor into decision making?
- Have you requested or collected pedestrian count data at night?
    - If yes, are they done any differently from other counts?
    - If not, do you think that information would be useful?
- How long do you typically gather data for pedestrian counts?
    - Is the duration different for automated counts as compared to manual counts?
- Do you have information on the costs and resources that were required for pedestrian count data collection requests through your department? (i.e., XX number of personnel for XX hours, at XX locations)
- Do you request/gather data on the characteristic of the pedestrians who are being counted? (e.g., gender, age, etc)
    - If yes, how often is the additional data collected?
- Would you mind if I contacted you with follow up questions in the future, if necessary?

B3. Automated Pedestrian Counter
Transportation Agency Interview Guide

- Are you aware that your agency sponsored a research report on automated pedestrian detection and counting devices?

- Are you familiar with the report?

- Were the results of the report used to inform a decision on how pedestrian counts are performed by your agency?

- Does your agency use automated pedestrian counters?

    - If yes, which types of counters do you use and why? (e.g., price, reliability, ease of use, etc.)

        - Are they used in special cases (e.g., night counts, trails, etc.), and why?

        - Are you generally satisfied with the result you obtain using automated pedestrian counters?

- Does your agency conduct/request manual pedestrian counts?

- If yes, who conducts the counts, does your department conduct them or do you have consultants or some other agent for data collection?

        - If your department conducts counts, do you have a pedestrian counting protocol that you follow? If so can we get a copy of this protocol?

        - If consultants or another agent are used, are they obligated to follow a protocol? If so can we have a copy of this protocol?

- How long do you typically gather data for pedestrian counts?

    - Is the duration different for automated counts as compared to manual counts?

- Where do you request/conduct pedestrian counts? (e.g., intersections, trails, sidewalks, crosswalks, other)

- What are the primary reasons why you request/collect pedestrian count data?

    - Are there policies or warrants for your department that require this data?
        - If yes, please describe.

- How does the department use pedestrian count data?
    - Do you analyze the data yourselves?
    - How do the results of counts factors into decisions making?

- Have you requested or collected pedestrian count data at night?
    - If yes, are they done any differently from other counts?
    - If not, do you think that information would be useful?

- Do you request/gather data on the characteristics of the pedestrians who are being counted? (e.g., gender, age, etc.)
    - If yes, how often is the additional data collected?

- Do you have any thoughts on the advantages and disadvantages of automated pedestrian counts vs. manual counts? When would you use one over the other?

- Would you mind if I contacted you with follow up questions in the future, if necessary?

B4. Automated Pedestrian Counter Consultant Interview Guide

- How often does your company conduct pedestrian counts?

- Who do you conduct pedestrian counts for?

- Do you have a protocol that you use to conduct the counts, either developed by your company or the agency requesting the count? Can we have a copy of the protocol?

- At what types of locations have you conducted pedestrian counts? (e.g., intersections, trails, other)

- Do you employ Automated Pedestrian Counters?

    - If no, we would like to take this opportunity to obtain your thoughts on automated counters and their use.

        - Have you considered using automated counters?

            - Is there a reason why you choose not to use automated counters?

            - Do you believe that they could help to improve data collection?

    - If yes, which types of counters do you use and why? (e.g., price, reliability, ease of use, etc.)

        - Are they used in special cases (e.g., night counts, trails, etc.) and why?

        - Are you generally satisfied with the results that you get from the automated counters?

- What are some typical issues that arise when conducting counts, manual or automated?

- What is the typical arrangement between your company and an agency needing a count to be done? (i.e., who decides where and when to conduct the counts, how they are done, etc.?)

- How long do you typically gather data for pedestrian counts?

  - Is the duration different for automated counts as compared to manual counts?

- Do you conduct pedestrian counts in adverse conditions? (e.g., night, cold weather, etc.)

- Do you gather data on the characteristics of the pedestrians who are being counted? (e.g., gender, age, etc.)

  - If yes, how often is the additional data collected?

- Do you have information on the costs or resources that were required for each job that you could share with us? (i.e., XX number of personnel for XX hours, at XX locations.)

- Do you test for accuracy periodically?

- Are you ever asked to analyze the pedestrian count data you collect?

  - If yes, how is the data used?

- Are you aware of any policies or warrants that call for pedestrian count data?

  - How are pedestrian counts used in transportation decision making?

- Would you mind if we contacted you with follow up questions in the future, if necessary?

B5. Automated Pedestrian Counter Expert/Researcher Interview Guide

- What automated technologies do you think are best suited for pedestrian counts?
    - In complicated environments such as intersections with heavy pedestrian volumes?
    - At simpler linear locations such as trails?
- Are there any emerging technologies that you know of or existing technologies that you think warrant further evaluation?
- Have you noticed any recent trends in the use of automated pedestrian counting, or in pedestrian counting in general?
- What are your thoughts on automated pedestrian vs. manual counts?
    - Do they both have their place?
        - Under what circumstances would you choose one over the other?
- Do you have any insights or thoughts on how pedestrian count data can be used to inform transportation decision making?
- Are you aware of any government agencies that use automated pedestrian counters?

APPENDIX C: CASE STUDIES

Case Studies

In recent years, several studies have been published on pedestrian counts with the explicit intent of measuring the reliability and accuracy of pedestrian counting technology. Similar to this report, the methodology used in these studies typically included choosing one or more pedestrian counting products, setting it up in a chosen location for a specified period of time and comparing the results against a baseline count. Many of the studies were sponsored by or prepared for state transportation departments. This supports the findings that pedestrian data is a key input for transportation decision makers and that there is increased interest on their behalf in acquisition of pedestrian counts and interest in evaluating automated pedestrian counters to fill this role.

California

Estimating Pedestrian Accident Exposure (5)

In 2007, two studies were published by the Traffic Safety Center at University of California, Berkeley that focused on automated pedestrian counters. The first, “Estimated Pedestrian Accident Exposure: Automated Pedestrian Counting Devices Report”, reviewed several pedestrian detection devices based on their ability to be used as pedestrian counters. The researchers examined infra-red beam counters, passive infra-red counters, piezoelectric pads, laser scanners and computer vision technology. While the report did not consist of a field test of the equipment, it included a detailed description of the technologies and a discussion of the strengths and weaknesses of each, summarized in Table 1. It should be noted that the prices given for equipment may have changed since those given were found; however they are useful for comparative purposes.

Effectiveness of Commercially Available Automated Pedestrian Counting Devices in Urban Environments: Comparison with Manual Counts (23)

The second study, “Effectiveness of a Commercially Available Automated Pedestrian Counting Device in Urban Environments: Comparison with Manual Counts”, was published shortly after the previous one, and was written by many of the same authors. It picks up where the first left off by using the automated pedestrian counter review matrix to select a device for field evaluation in an outdoor urban context.

In this study, the dual-sensor passive infrared technology was chosen based on cost, feasibility of use and commercial availability, relative to the other devices reviewed. The counts were conducted at three different outdoor locations, with varying levels of pedestrian traffic, and each was installed for a four-hour period during a weekday afternoon. The site was video taped and manual counts were recorded simultaneously with each of the automated counts. Since manual counts are not considered 100% accurate, the inter-reliability between the device and the two manual counts were used to gauge the accuracy of the automated device.

The results of the study showed that the automated device consistently undercounted pedestrians, with an overall error rate between -9 percent and -19 percent, pointing out that it was well above the 2 percent error rate found in a previous study. The researchers concluded that the error rated was not affected by pedestrian volumes as much as they were affected by pedestrians' tendency to walk closely together. However, the researchers also found that the error rate was fairly stable at -13.2 percent on average, which might allow for an upwards adjustment for a more accurate count. It is clear that more work in this area is needed to test other devices and technologies, especially at intersections. The study also showed that the results of counts obtained by manual hand counts are not necessarily less accurate than those obtained by video recording.

Many of the issues that arose from the study deal with the pedestrian behavior and the difficulties associated with those actions. For instance, people tended to linger while talking in groups or on the cell phone. In cases where this occurred in front of the sensor, it likely caused undercounting or counted people more than once. This study is particularly significant because much of the literature to this point has either dealt with automated detectors, and not counters; or has dealt with counters is a less complex setting, such as a trail or a walkway, where low densities of pedestrians pass through an area along one axis.

<u>Massachusetts – Mass Highway</u>

An Evaluation of Technologies for Automated Detection and Classification of Pedestrians and Bicyclists [28]

A study was conducted by the Massachusetts Highway Department to identify and evaluate existing technologies for purposes of accurately and efficiently detecting, counting and classifying non-motorized modes of transportation. Additional criteria include applicability to on-road and off-road locations, flexibility in detecting and classifying non-motorized activity under multiple conditions, portability, and cost effectiveness. Technologies investigated in the report include microwave, ultrasonic, acoustic, video image processing, piezoelectric, passive infrared, active infrared, magnetic, and traditional inductive loop and pneumatic traffic classifiers. Of these, active infrared and video image processing were selected as the most promising for the purposes of the study. Ultimately, the Autosense II Active Infrared Imaging Sensor was selected and purchased because it was determined to be portable and easy to install. It also did not require a lot of staff and technical support.

Data was collected on a trail on random days during the fall and summer, and the results from the two collection efforts, manual and automated were compared for accuracy. Autosense II was found to be effective at detecting pedestrians, but not classifying them. Approximately 92 percent of pedestrians were successfully detected, but none were successfully classified. The authors determined that because the technology was developed for detecting and classifying automobiles, it is only able to classify large metal objects, such as automobiles or bicycles, and is not able to specifically recognize pedestrians. However, when compared to the baseline counts, it was found that objects classified as 'unknown' were almost always pedestrians. The authors did not explicitly discuss counting results, but it appears that a successful detection would translate to a successful count. The authors determined that the device required a few changes that would improve accuracy and allow it to classify pedestrians. Once these changes were made, future studies would be needed to retest the device.

Development of a Bicycle and Pedestrian Detection and Classification Algorithm for Active-Infrared Overhead Vehicle Imaging Sensors (29)

Based on the findings from the previous study, the authors felt that they could significantly improve the performance of the active-infrared sensors in pedestrian and bicycle classification by altering the algorithm. As was determined in the previous study, pedestrian classification was unsuccessful with the sensor because it was designed to classify vehicles by their size, a scale which does not include pedestrians. The sensor is set based on the assumption that the vehicle, because of its length, would first enter beam one, then would enter beam two, then leave beam one before finally leaving beam two (Figure 20). The length between the two beams is approximately ten feet at the widest point; short enough for a car to pass through each beam in the assumed order, but too long for a pedestrian to do so.

To enable the device to classify pedestrians, researchers changed the algorithm based on the assumption that the pedestrian would enter and leave the first beam before entering the second beam, as illustrated in Figure 20. The redeveloped device was tested at two sites, each along a trail, against manual counts using data sheets. The tests were done over the course of a month, with efforts made to collect data in varying light, temperature and weather conditions.

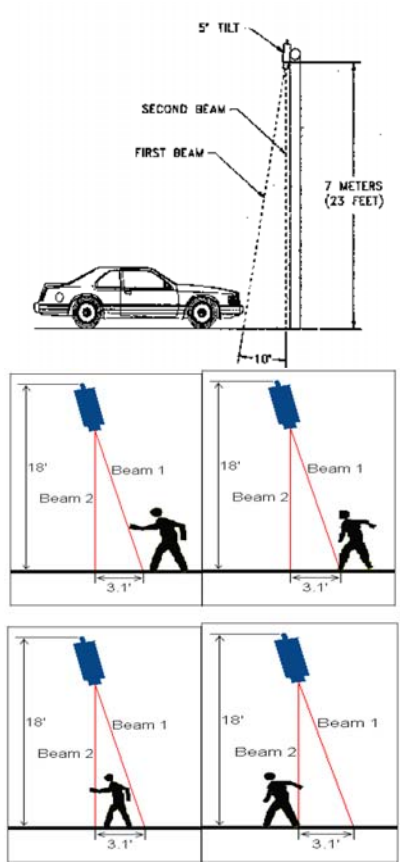


Figure 20. Typical configuration of an overhead sensor (29)

The new algorithm allowed the active-infrared sensor to accurately detect and classify pedestrians, making the technology much better suited for pedestrian counting that it would be using the other algorithm. Whereas the previous study resulted in none of the pedestrians being successfully classified, the new algorithm allowed the device to successfully classify 92 percent of the pedestrians that passed through the beams. The device also performed well when multiple pedestrians passed through at the same time, but was not as accurate when multiple pedestrians and multiple bicycles passed through the devices simultaneously. The author concluded that it would be feasible to combine all of the developed algorithms to create a device that could work on trails, sidewalks and roadways and detect both motorized and non-motorized travelers, although it was not explored.

Minnesota – Mn/DOT

In 2003, the Minnesota Department of Transportation published the report, "Bicycle and Pedestrian Detection". (16) Similar to the other case studies, the Mn/DOT report conducted a field test to evaluate the performance of automated pedestrian detection devices. The pedestrian detection technologies evaluated were passive infrared/ultrasonic (ASIM-DT 272), infrared (Diamond-Traffic Counter), microwave (MS Sedco-Smartwalk 1400), and video (Autoscope-Solo).

Manual counts were used as the baseline against which the automated devices were compared.

Testing methods in this report were different from the methods chosen in other reports. Each device was paired with a manual counter and each pair was placed at a different location, where data gather by the automated counters was compared to its paired manuals counter. The devices were tested at the same time along a single pedestrian and bicycle path over the course of several hours in a single day. The field trials resulted in no difference from the baseline counts for the Autoscope-Solo, MS Sedco-Smartwalk 1400 and the ASIM DT272, while the Diamond Traffic Counter differed from the other counts and the baseline counts by 7 percent.

While the devices performed very well, the performance can be mostly contributed to the fact that the tests put very little strain on the devices in terms of flow volume or complexity. Specifically, all of the devices were field tested on a pedestrian and bicycle walkway. While this would still allow for a legitimate evaluation of the device's performance if the traffic were heavy, the actually flow during the testing was low and relatively simple, unlike the flow that would normally occur at an intersection or a similar area with less constrained travel paths. In fact, researchers often resorted to passing through the path themselves in order to have enough data to present a relevant sample. As there were only a few researchers at the site, the result was that the devices were presented with a simple and light flow of pedestrians, not the normal traffic that the devices would likely be used to count.

Texas – Southwest Region University Transportation Center

The study, "Testing and Evaluation of Pedestrian Sensors," was conducted with the purpose of evaluating several different pedestrian detectors, and an ultimate goal of creating a test bed that can be used to evaluate future pedestrian safety applications [(27)]. Five different devices were tested. Three of the devices were used at an intersection-based test setting: MS SEDCO Smart Walk 1400 (curbside detection) and Smart Walk 1800 (crosswalk detection), both based on microwave detection; and ASIM IR 201 (curbside detection) and IR 207 (crosswalk detection) based on passive infrared. Three other devices were used for a trail-based test: Jamar Scanner, based on infrared technology; TrafX Infrared Trail Counter, based on infrared technology; and Diamond Traffic TTC-4420, based on pulsed infrared with a reflector. The automated detection devices were each tested for several hours over the course of a single day, and each was compared to a baseline count obtained by a video recording with a manual verification

The ASIM and MS SEDCO intersection sensors produced error rates from 9 to 39 percent, and appeared to be more reliable in areas in which travel is constrained or when the pedestrian detection area is well defined. The typical error rates were in the 20 to 30 percent range, not accurate enough for most pedestrian counting applications. The trail sensors were evaluated in variety of conditions and the researchers concluded that no one device stood out. All three of the devices accurately detected a single pedestrian walking at a normal speed. When the conditions became more complex the errors rates went up substantially. All three scanners had difficulty detecting pedestrians walking in groups with little spacing and also had difficulty detecting pedestrians who had stopped near the detection area or passed through quickly.

London – Central London Partnership

The report published by the Central London Partnership in 2003, "Automated Pedestrian Counting Trial: Stage Three," gives evidence that the effort toward a more efficient method of data collection is more than just a national trend [(40)]. The purpose of the study is to evaluate automated pedestrian counters in order to gain a better understanding while promoting further technological developments. Ultimately two technologies were chosen: CCTV and passive infrared. In addition, researchers also chose to use microcomms units for each of the devices. The report does not specify the purpose of the microcomms unit, but it is likely used for getting information to and from the detection device.

Two sites were chosen for the study, both in busy urban areas. The passive IR detector and a CCTV system were installed at one site and two CCTV systems were installed at the other site. The devices were compared to a baseline manual count that was conducted at each site simultaneously with the automated counts. Although four devices were installed, three CCTV systems and a passive infrared system, one of the CCTV systems failed, leaving only three devices available for comparison to the baseline data.

The Footfall passive infrared system displayed a deviation of three percent from the manual counts, the Footfall CCTV system displayed a two percent deviation from the manual counts and the Springboard CCTV system showed a three percent deviation from the manual counts. The Footfall passive infrared system displayed a variation of three percent from the baseline data. In the findings, the author noted that further evaluation is necessary because the evaluation was limited to the site requirements of the devices. Site had to be chosen that could provide power to the devices, had poles or other structures upon which the devices could be mounted and where researchers were granted permission to install the devices. Further testing should be done once the devices have been redeveloped to be more self-contained and can be used at a greater variety of locations. It is worth noting that that the devices operated at night and under conditions of poor illumination. This is a significant advantage when compared to manual counts which are not typically conducted under these conditions.

London – Transport for London

The report, "Automated Pedestrian Counting Trials: Stage Two Trials," published by Transport for London (TFL) in 2007, expands upon the paper previously released by the Central London Partnership, and was written by the same author

[41]. As the CLP study and previous phases of the TFL study confirmed that the Springboard CCTV, Footfall CCTV and LASE PeCo systems proved to be the most promising, this study focuses on those three devices and tests them in real life situations. Additionally, previous version of the CLP and TFL studies has identified problems with these devices that limited their usefulness. The manufacturers took the recommendations and updated the devices to overcome those shortcomings. The new developments for the Springboard CCTV system included the addition of wireless data transmission capability. For the Footfall CCTV system, the developments included a housing unit that is floor mounted and secured to a lamppost, using the lamppost as a power supply. These two developments, along with its wireless data transmission capability, limit the number of site requirements, allowing for usage in a wider variety of locations. For their laser scanner, LASE PeCo developed a special mounting pole that straps to a lamppost and cantilevers the devices out over the subject area. Along with the device's wireless capability and built in battery, the device is practically self sufficient.

In previous phases of the study, sites were chosen based on ability to quickly gain permission from the site managers and according the site requirements of the devices. With the newly developed systems, sites were chosen for this study based on their ability to test the maximum capabilities of the devices. In the end, two sites were chosen on busy streets with complex travel patterns and a variety of obstacles. The Springboard CCTV system was tested at one location in three intervals for one hour each, one of which was during the evening, and at the second location during a two-hour interval. All of the intervals were considered peak times.

The device performed very well, with an average error rate of approximately 3%, which ranged from 0% to (+/-)11%. The LASE PeCo Laser Scanner System was tested at both sites as well, over the course of one day at varied intervals ranging from thirty minutes to an hour, all during peak time periods. The laser scanner performed well, with an average error rate of 5%, which ranged from 0% to 17.1%. The Footfall CCTV system was evaluated at one site over the course of one day in three one-hour increments. The device performed slightly unfavorably compared to the other two, with an average error rate of 8%. However, as the devices were tested at separate locations, a direct comparison is not conclusive.

APPENDIX D: GENERAL RECOMMENDATIONS

Automatic Pedestrian-Counter Selection:

- A series of commercially available counters including passive infrared counters, thermal sensors, microwaves, laser scanners, and computer vision technologies can be used for pedestrian data collection.
- The essential function of any selected sensor should be the capability to record directional pedestrian counts. The need for various other functionalities such as presence detection and speed recording depends on the application.
- It is recommended that counters that are capable of storing data for small time intervals such as 15 minute, 30 minutes, and 1 hour are selected. Although the smaller time intervals are preferable—e.g., 1 minute or 5 minutes—for long-term deployment, collected data take up more space than the sensor can handle.
- Extreme weather should not affect the performance of the selected counter.
- To increase the value and consistency of the collected data for a network application (e.g., multiple intersections), it is recommended that the same type of counter be used across the network. If different counters are used, data extracted from them must be able to be aggregated into the same time interval.

Deployment:

- As a general principle, the counter needs to be deployed at a location that does not block pedestrians or bicyclists.
- The pedestrians using the facility should not notice the counter.
- Specifically, counters should be deployed where pedestrians do not stop. Locations where pedestrians wait—for instance, the waiting area of a crosswalk at a signalized intersection—should be avoided.
- Avoid installing counters close to parking lots and bus stops where the counter can be interrupted by vehicles.
- Avoid selecting wide trails or open spaces where the direction of pedestrians cannot be easily determined—e.g., squares in a city. Therefore, it is recommended that places where people move on a trail or between painted lines be chosen.
- Deployment location should be easy to access.

Preinstallation:

- Check with the local authorities to determine whether the location is state or city property. Contact the city engineer to get permission for installing counters. Make sure to give one day’s advance notice to the local police.
- Finalize the mounting facilities and prepare tools for installation.

Counter Installation:

- The vendor's technical support should be consulted before counter installation.
- Counters should be installed at a height recommended by the manufacturer.
- For EcoCounter, select a suitable section of the path where pedestrians are likely to walk in single file.
- Depending on the range of the EcoCounter, install it in the direction of the path, and make sure there is no movable obstruction within the range, see Figure 21a.
- The sensor could face directly against a wall; see Figure 21b.
- Avoid installing the infrared sensor facing directly into plants as it can yield false counts, see Figure 21c.
- Avoid facing directly into the roadway where the sensor may be interrupted by vehicles, see Figure 21(d).
- Check the unit regularly to ensure that the sensor is not obstructed.
- The thermal sensor can be mounted either on a pole or overhead as shown in Figure 22.
- The components such as data controller and transmitter should be put in a safe place—for instance, locked in a metal box.
- Make sure the thermal sensor has a long-term power supply.
- Follow detailed installation instructions for each product.
- Check regularly to make sure the counters have not gone out of alignment.

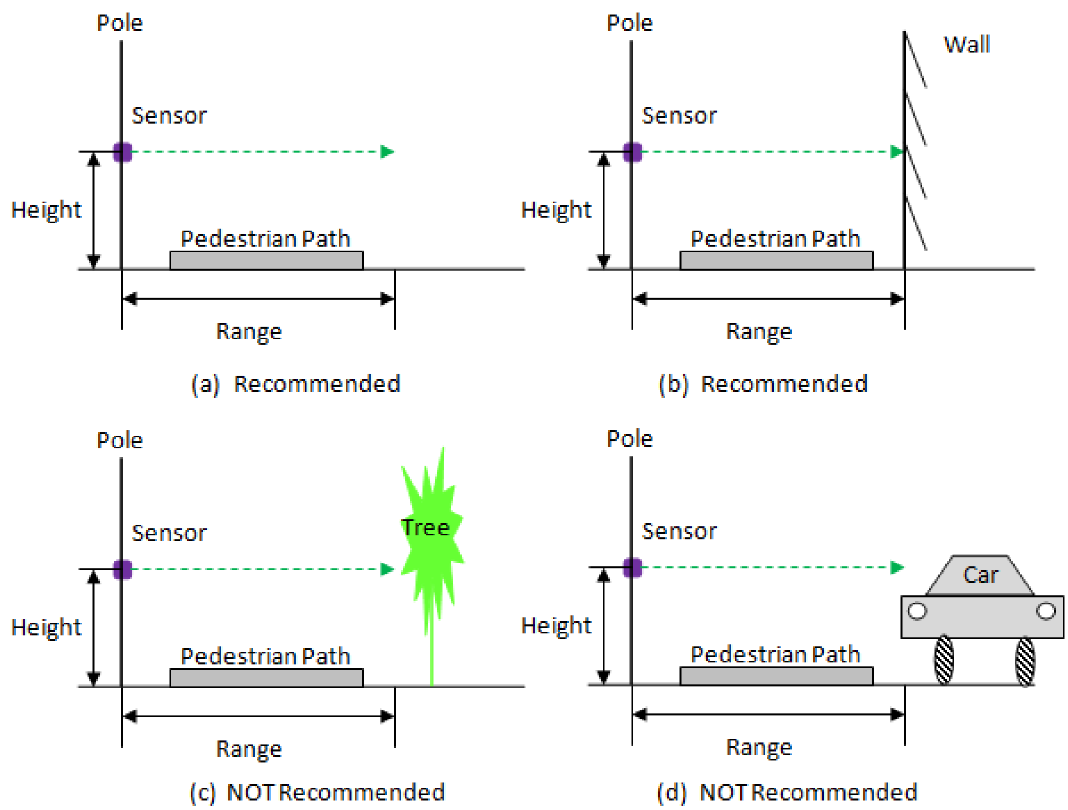


Figure 21. Installation of EcoCounter

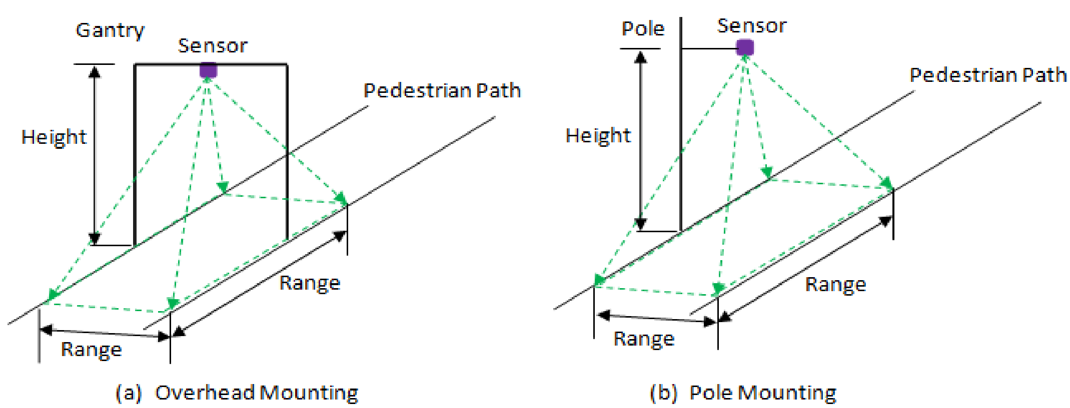


Figure 22. Installation of thermal sensor

Calibration:

- Sensor calibration should be conducted before data collection starts.
- The sensor should be tested before calibration by walking across the detection area several times to identify the area of detection and adjust the angle and height if necessary.

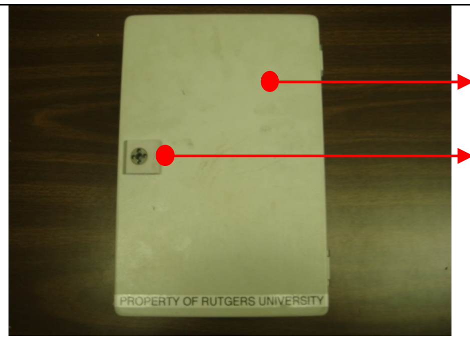
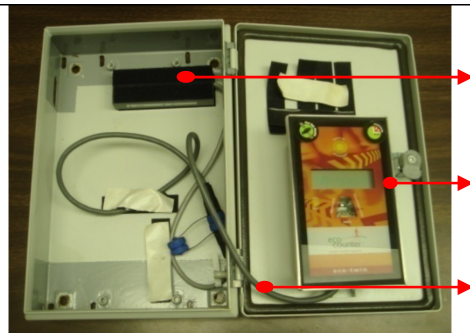
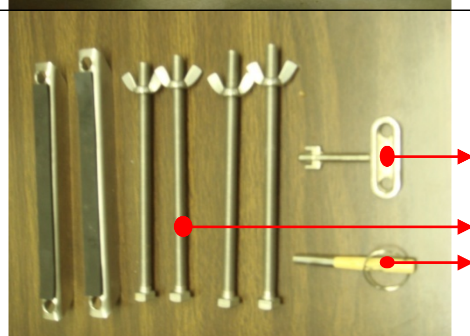
- Subsequently, calibrate the counter by observing how it performs when pedestrians cross the detection area. Set up the counter so that it can respond correctly.
- As no counter will be 100 percent accurate, it is necessary to develop a correction procedure to improve the quality of raw counts.
- To develop the correction procedure, baseline data collection is necessary. It is suggested that as much of the base data as possible be collected, given allowable time and budget.
- Each site may have its own correction figure as pedestrian traffic patterns may be different.

Maintenance and Data Collection:

- Regular visits should be scheduled to download the raw data. Record and report the status of the counters.
- The collected data should be managed and processed by the same person. Both the raw data and the processed results should be stored in a database.
- Replacement batteries or a new counter should be scheduled at a time when few users appear, to reduce the risk of counts not being collected. Also record the maintenance time and duration to disregard that time period from the counts, if required.

APPENDIX E: ECOCOUNTER DEPLOYMENT GUIDELINES

Sensor Descriptions

Instruction	Item	Name of the Item
1.Overview of the EcoCounter		External metal protection ox lock
2. Overview of the internal configuration		Dual lens Sensor logger Connection cable
3. Accessories		Box key Mounting screws sensor activation key
4. PDA for data transmission		PDA USB cable PDA for data retrieval

Step 1: Sensor Mounting at an Ideal Height

The sensor should be mounted so that the height of the dual lens is ideally above the top of the legs (70 cm/27.5 inch (80 cm/31.5 inch for bikes).

Examples	Demo	Instructions
Example 1: (Recommended)		▪ Example of ideal mounting height.
Example 2: (Recommended)		▪ Example of field installation nearby a trail. The sensor was mounted at an ideal height. It is applicable for long-term data collection.
Example 3: (NOT Recommended)		▪ Example of incorrect mounting height. The sensor may count legs of pedestrians, causing multiple reads.

Step 2: Sensor Mounting at an Ideal Direction

- The dual lens must always be laid horizontally and close to the target area.
- Do not face the roadway if it is within the detection range. It is better to install it opposite static objects such as walls.
- Avoid installing the sensor in the direction of moving objects, such doors and vehicles.

Examples	Demo	Instructions
Example 1: (Recommended)		▪ Sensor faces toward a wall.
Example 2: (Recommended)		▪ Sensor faces toward a wall. Do not face the window since opening/closing window may affect sensor counting.
Example 3: (Recommended)		▪ Avoid directing the counter toward moving objects within the detection area.
Example 4: (NOT Recommended)		▪ Facing the roadway, the counter will detect vehicles.

Step 3: Sensor Performance

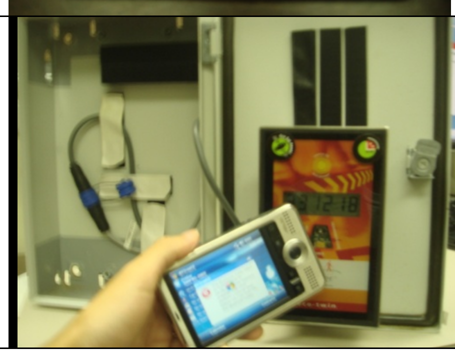
- EcoCounter performs better when pedestrians arrive individually.
- When there are pedestrians walking side by side, or in groups, or when the sensor is blocked, it will likely undercount pedestrians. It is better to install the sensor where these scenarios can be avoided or frequency can be reduced.

Examples	Demo	Instructions
Example 1: (Ideal Case)		▪ A single pedestrian crossing the detection area on a pedestrian bridge.
Example 2: (Ideal Case)		▪ A single pedestrian crossing the detection area at a crosswalk of an intersection.
Example 3: (NOT Ideal)		▪ Two people walking side by side. The sensor will detect only one count in this case.
Example 4: (NOT Ideal)		▪ Pedestrians wait next to the sensor and block the sensor. It will result in incorrect counts.

Step 4: Raw Data Acquisition

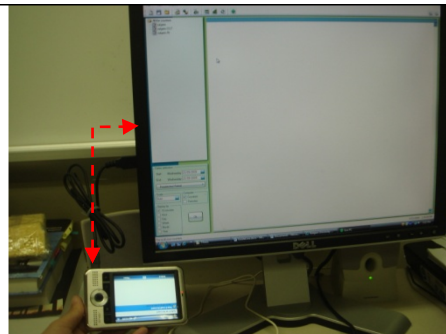
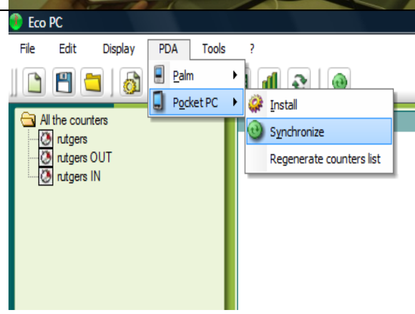
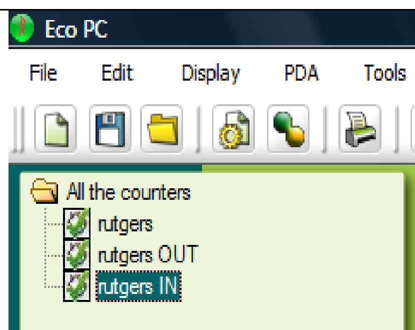
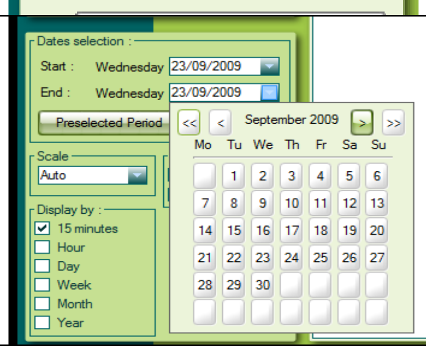
- The sensor will store the raw counts in its logger.

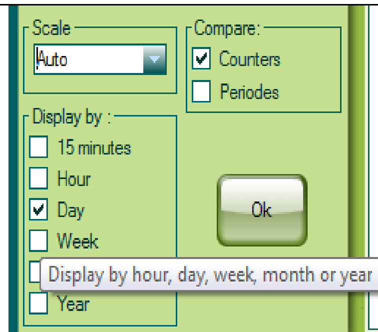
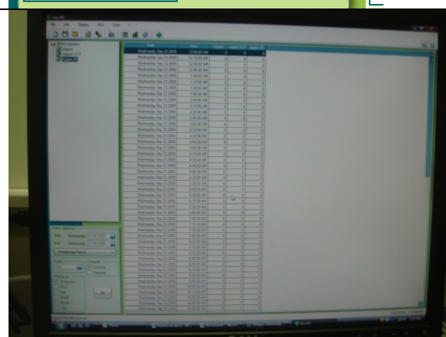
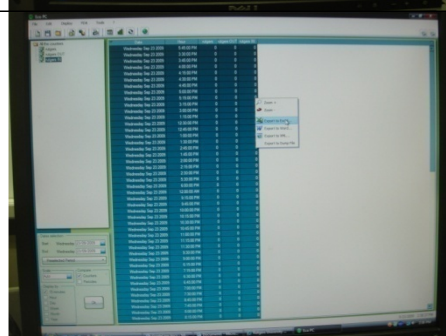
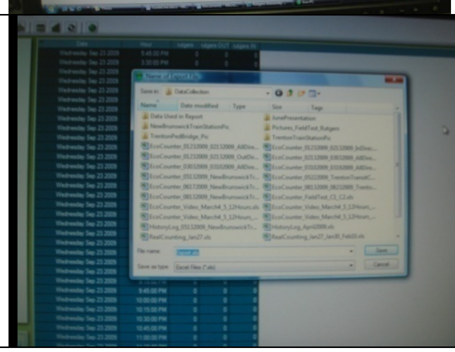
- To download the data and store them in a PDA, the PDA should be connected with the sensor through infrared transmission.
- The time of the sensor and PDA should be synchronized.
- The following substeps should be applied.

Substeps	Demo	Instructions
Substep 1: (Open Box)		▪ Open the metal box, and find the sensor logger.
Substep 2: (Activate Logger)		▪ Activate the sensor logger using the magnetic activation key. Total counts will be shown on the LED screen.
Substep 3: (Start EcoPocket)		▪ Start PDA. ▪ Start the EcoPocket program. ▪ Some initial setting such as time and date will be necessary.
Substep 4: (Download Data)		▪ Connect the PDA with the EcoCounter. Infrared sensor of PDA must face the infrared transmission area of the logger to download the data of the selected period.

Step 5: Data Retrieval

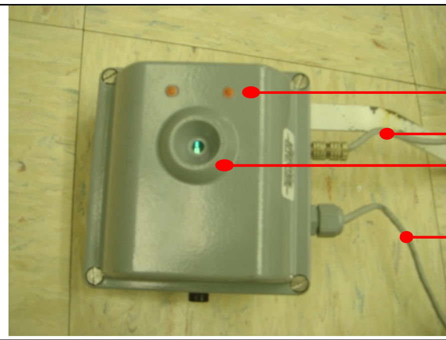
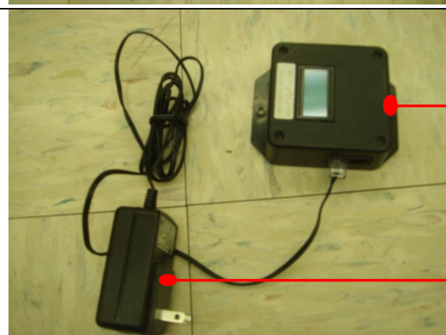
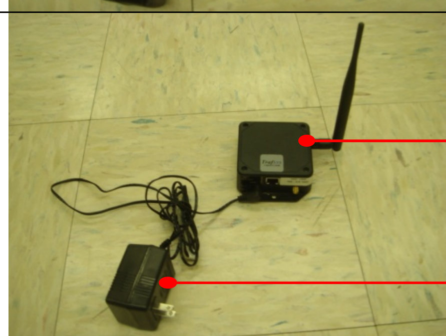
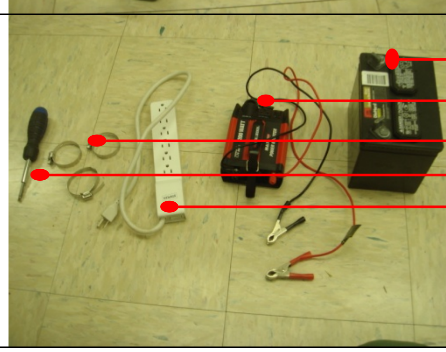
- Connect PDA with a PC that has the EcoPC program installed.
- Select the target counter, and define time period and time interval to display the data.
- Export and save the displayed data.

Substeps	Demo	Instructions
Substep 1: (Connect PC)		▪ Connect PDA with PC with the USB cable.
Substep 2: (Start EcoPC)		▪ Start EcoPC program. ▪ Use *PDA->Pocket PC->Synchronize* option to synchronize the PDA and the computer program. ▪ Then associate counter name with direction, for instance "rutgers", "Rutgers OUT", & "Rutgers IN" will be shown on the right list.
Substep 3: (Select Counters)		▪ Click and select the target data to be retrieved. ▪ rutgers: represent total counts of both directions; ▪ rutgers OUT: represent counts of direction 1; ▪ rutgers IN: represent counts of direction 2.
Substep 4: (Define Period)		▪ Select the start and end dates to define the target retrieve period; ▪ Or use the preselected period.

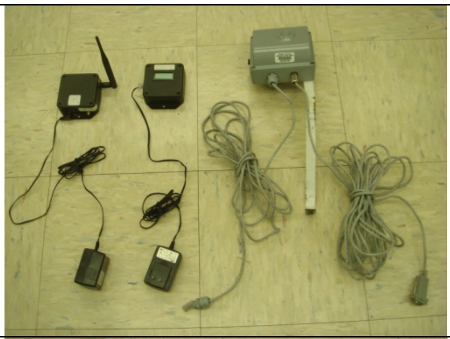
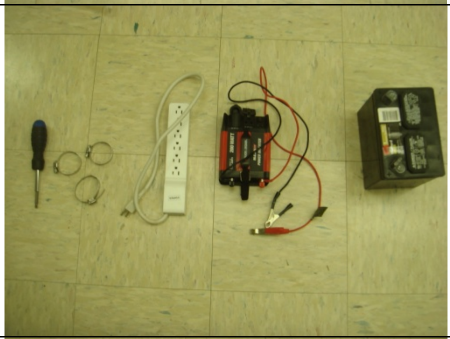
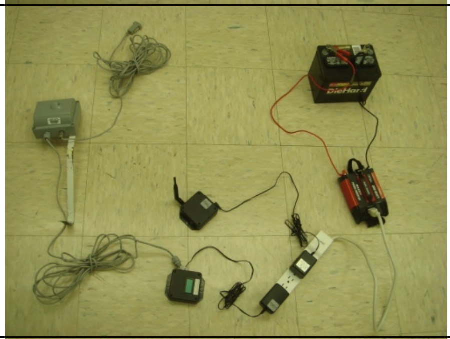
Substeps (cont'd)	Demo	Instructions
Substep 5: (Time Interval)		▪ Integrate raw data into different time intervals, such as 15 minutes, 1 hour, 1 day. ▪ Press "OK" to retrieve data.
Substep 6: (Display Data)		▪ The data will be shown in columns.
Substep 7: (Export Data)		▪ Select the data and right click to export and save the data to another format such as Excel, Word, and xml, etc.
Substep 8: (Save Data)		▪ Select the target folder to save the exported data file.

APPENDIX F: THERMAL SENSOR DEPLOYMENT GUIDELINES

Sensor Descriptions

Instruction	Item	Name of the Item
1. Sensor overview		Flashing lights PC connection cable Thermal sensor Data transmission cable
2.Major component 1		Wireless transmitter Power adapter
3.Major component 2		MIU-1000 data controller Power adapter
4. Accessory items for field deployment		Portable battery (or alternative power source) Power adapter Braces Screwdriver Power surge

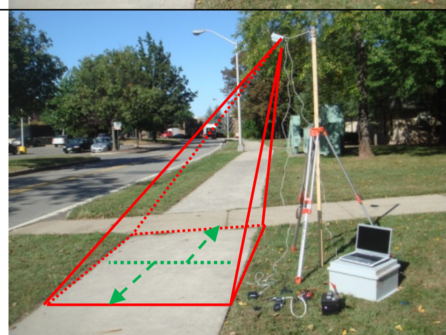
Step 1: Connection of Components

Substeps	Demo	Instructions
Substep 1: (Major Items)		▪ Prepare the sensor and cables.
Substep 2: (Accessories)		▪ Prepare accessories. ▪ If there is no power source, the portable battery should be used.
Substep 3: (Structure Demo)		▪ Demonstration of the connection structures of each component.
Substep 4: (Mounting Tools)		▪ If there is no mounting facility, such as a light pole or overhead mounting facility, then self-designed mounting equipment should be used.

Substeps (cont'd)	Demo	Instructions
Substep 5: (Protection Case)		▪ It is used to store controllers, transmitter, battery, power outlet.
Substep 6: (Check List)		▪ A check list shows all the possible items that will be used in field data collection.
Substep 7: (Sensor Mounting)		▪ Example of mounting the sensor on a light pole.
Substep 8: (Case Application)		▪ Metal protection case is useful for keeping the equipment safe during long-term data collection.

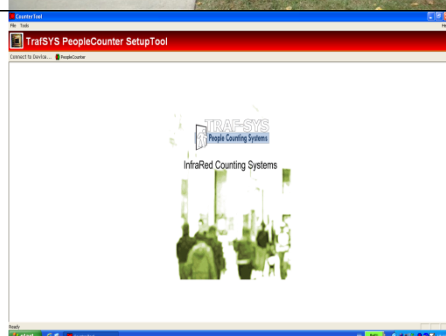
Step 2: Sensor Installation

- Correctly connect the components.
- Mount sensor at an ideal height and angle.
- Initially test the installation: power on/off to see the status of the flashing lights.

Substeps	Demo	Instructions
Substep 1: (Mounting Height)		▪ Optimum mounting height: 11.5 feet for 60° version; 20 feet for 40° version; 27 feet for 20° version. ▪ Sensor angle will determine the detection area (shown in next step).
Substep 2: (Detection Area)		▪ Adjustable pedestrian detection area. ▪ The green dashed line represents a screen line. If a pedestrian crosses the line toward a direction, the sensor will count it.
Substep 3: (Connection)		▪ All the connections follow the structure described before. ▪ When calibrating sensor, the laptop is connected to the sensor through the connection cable.
Substep 4: (Working Signal)		▪ Switch on the power, the two red lights of the sensor will start flashing for a few minutes. ▪ Once all the components perform well, the lights will stop flashing unless a pedestrian is detected.

Step 3: Sensor Calibration

- The sensor should be calibrated before real data collection starts.
- Adjusting the detection area, sensor sensitivity, etc., is required.

<table>
<tr><th>Substeps</th><th>Demo</th><th>Instructions</th></tr>
<tr><td>Substep 1:
(Connection)</td><td></td><td>▪ A laptop with the calibration software is required.
▪ Connect the sensor and the laptop through the communication cable.
▪ Make sure to find the correct USB port of the laptop.</td></tr>
<tr><td>Substep 2:
(Software)</td><td>
</td><td>▪ Start the TrafSYS People Counter Setup Tool to calibrate the sensor.
▪ Use “Connect to People Counter” and set the sensor step by step.</td></tr>
<tr><td>Substep 3:
(Real Testing)</td><td></td><td>▪ Cross the detection area to identify the boundaries of the area and the potential screen lines.</td></tr>
<tr><td>Substep 4:
(Adjustment)</td><td></td><td>▪ Test the sensor performance under different configurations.
▪ Change some parameter settings to get the best feedback.</td></tr>
</table>

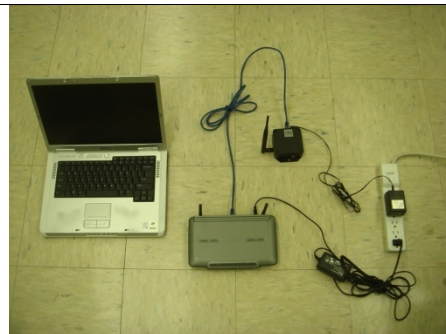
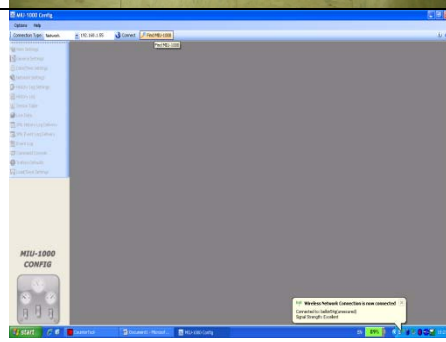
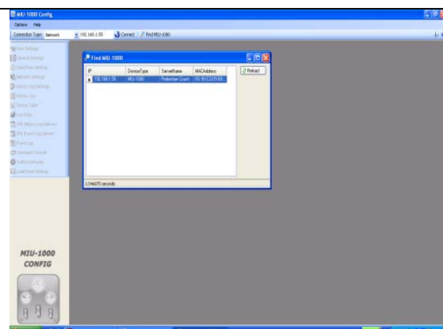
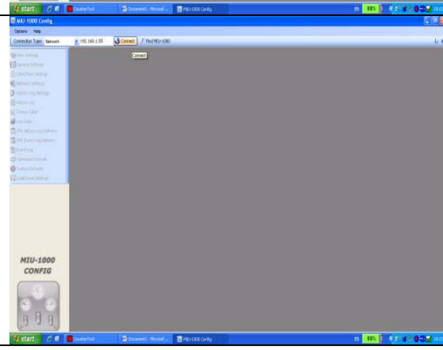
Step 4: Field Deployment

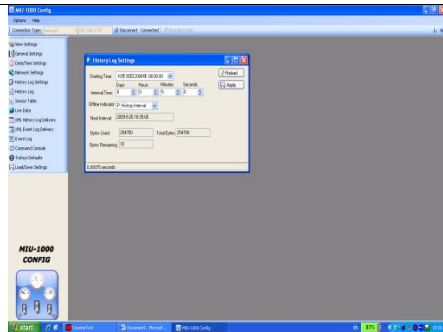
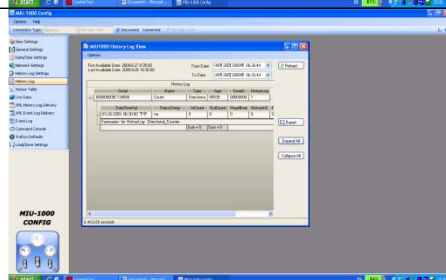
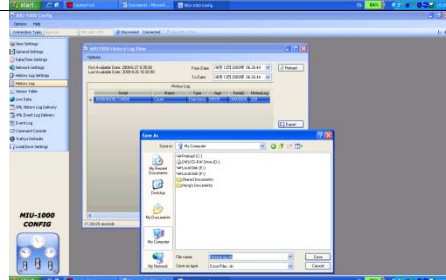
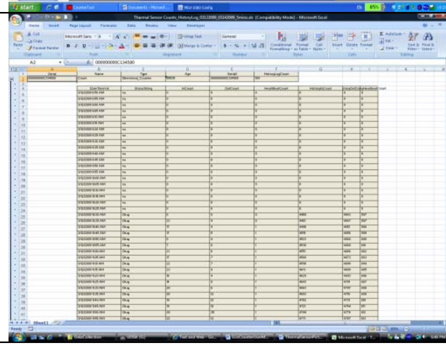
- The sensor could be installed near trails, crosswalks, sidewalks, and pedestrian bridges.

Examples	Demo	Instructions
Example 1: (Single Pedestrian)		▪ Example of a single pedestrian crossing the crosswalk at an intersection.
Example 2: (Single Pedestrian)		▪ Example of a single pedestrian walking along a trail.
Example 3: (Same Direction)		▪ Two pedestrians on a pedestrian bridge walk side by side in the same direction.
Example 4: (Two Directions)		▪ Two pedestrians going different directions arrive simultaneously in the detection area of the crosswalk.

Step 5: Data Acquisition and Process

- Tools needed: Laptop, Wireless Router, MIU-1000 Data Controller MIU-1000 CONFIG Software

Substeps	Demo	Instructions
Substep 1: (Connections)		▪ The raw data are stored in the data controller on site. ▪ Prepare tools for retrieving the raw data periodically or after the survey. Laptop that has MIU-1000 CONFIG software and wireless router is needed.
Substep 2: (Software)		▪ MIU-1000 CONFIG software will be started once all components are well connected. ▪ Make sure the computer is connected to the correct wireless network through the router. ▪ Click “Find MIU-1000” to find the data controller.
Substep 3: (Find Controller)		▪ Make sure the right controller is found and reload its data.
Substeps 4: (Connect Controller)		▪ Click “Connect” to synchronize the data controller to the software.

Substeps (con't)	Demo	Instructions
Substep 5: (Settings)		▪ Adjust some initial settings such as time, date, time interval, etc.
Substep 6: (Retrieve Data)		▪ After all the settings have been done, use the "History Log" to retrieve the historic data of a selected period.
Substep 7: (Export Data)		▪ Use "Export" to save the data in an Excel file.
Substep 8: (Data Format)		▪ The outputs are saved in an Excel file with date, time, and directional counts available. ▪ Also the status of the sensor can be checked.

APPENDIX G: RAW SENSOR COUNTS AND BASELINE DATA

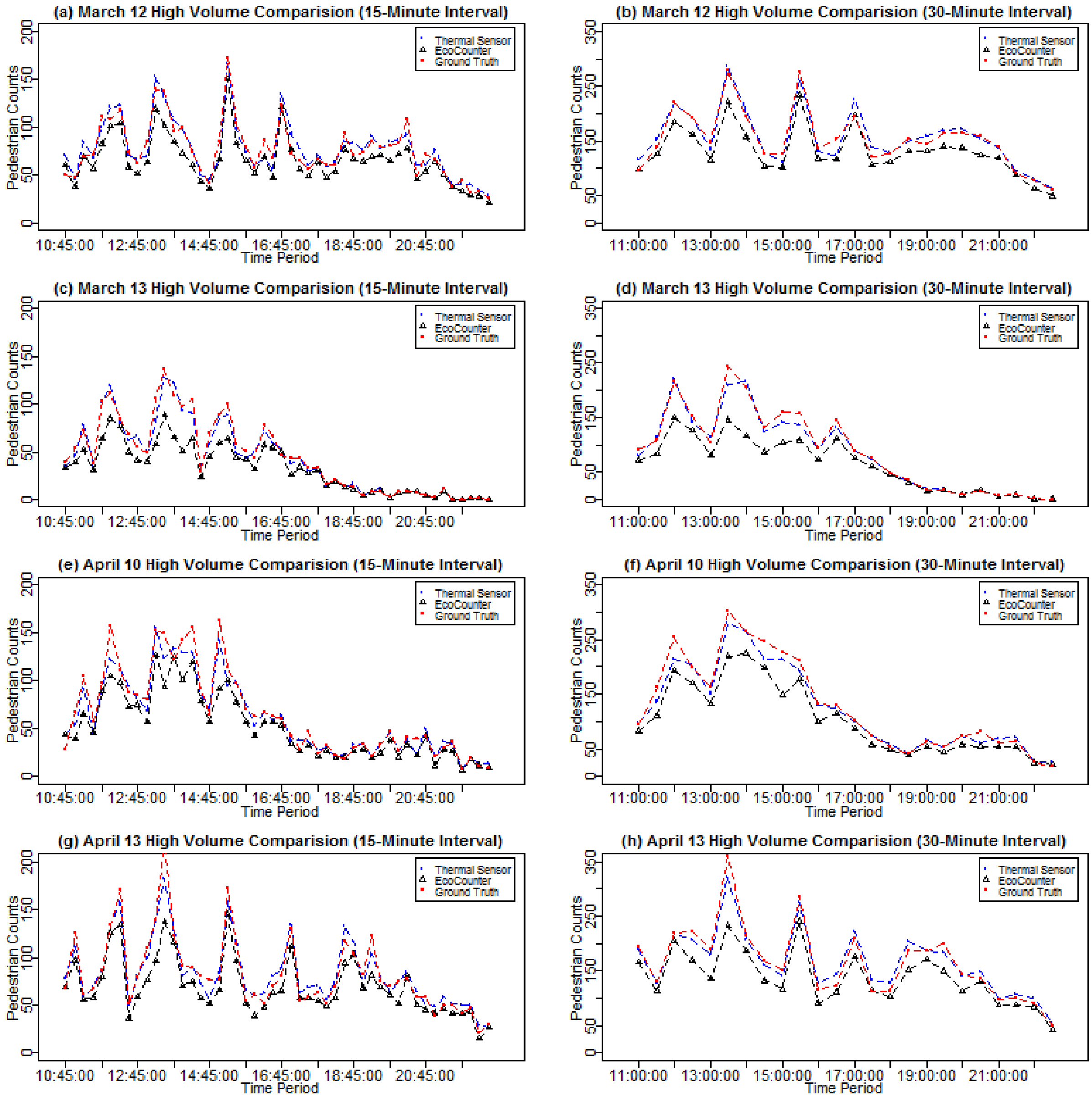


Figure 23. Comparisons of sensor counts at site 1

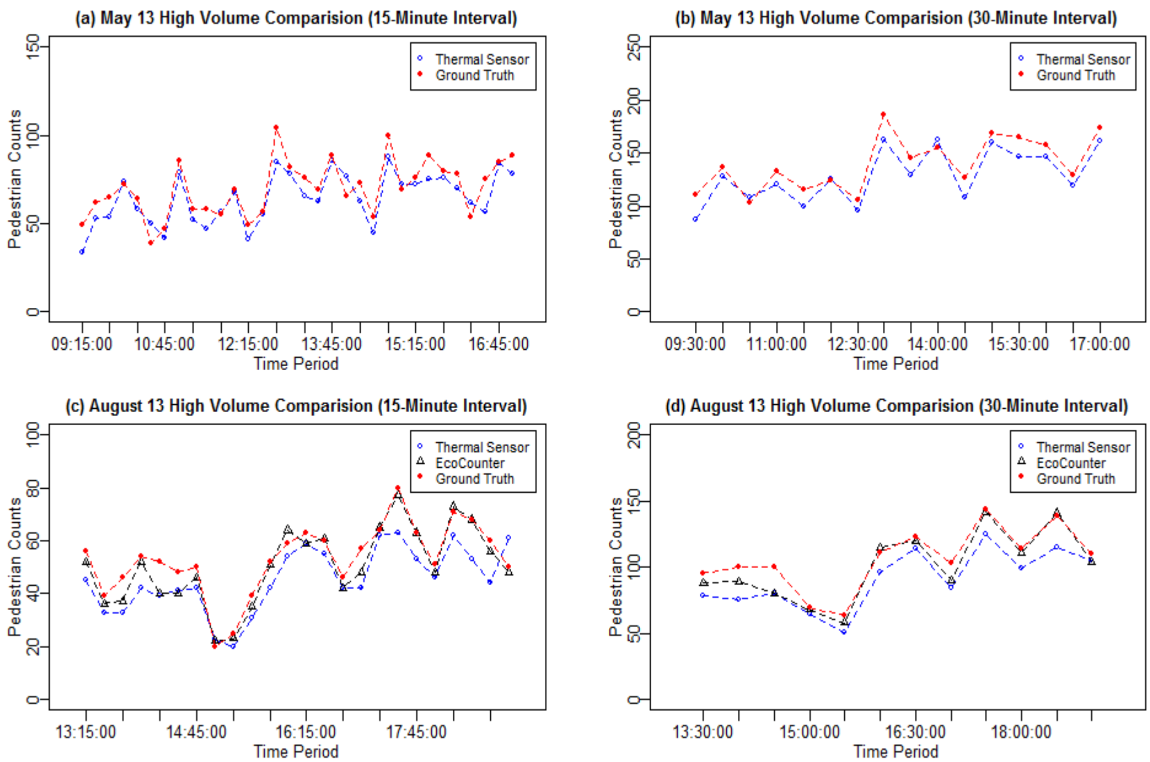


Figure 24. Comparisons of sensor counts at site 2

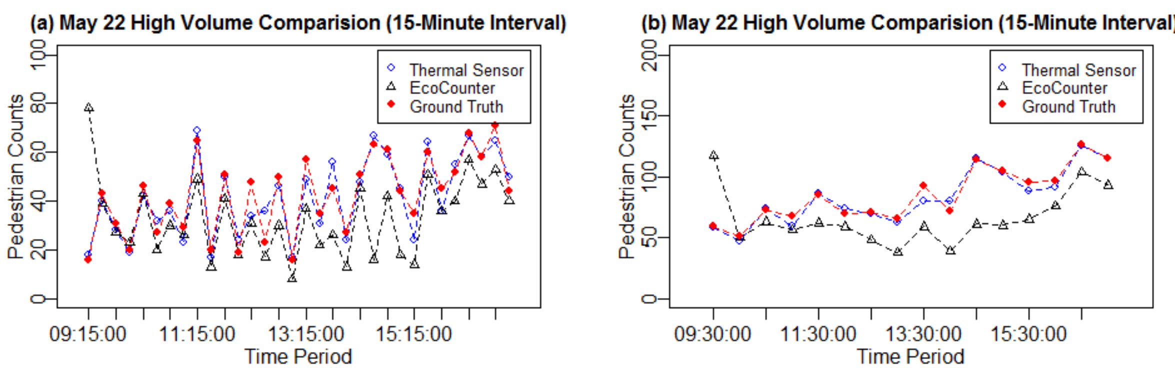


Figure 25. Comparisons of sensor counts at site 3

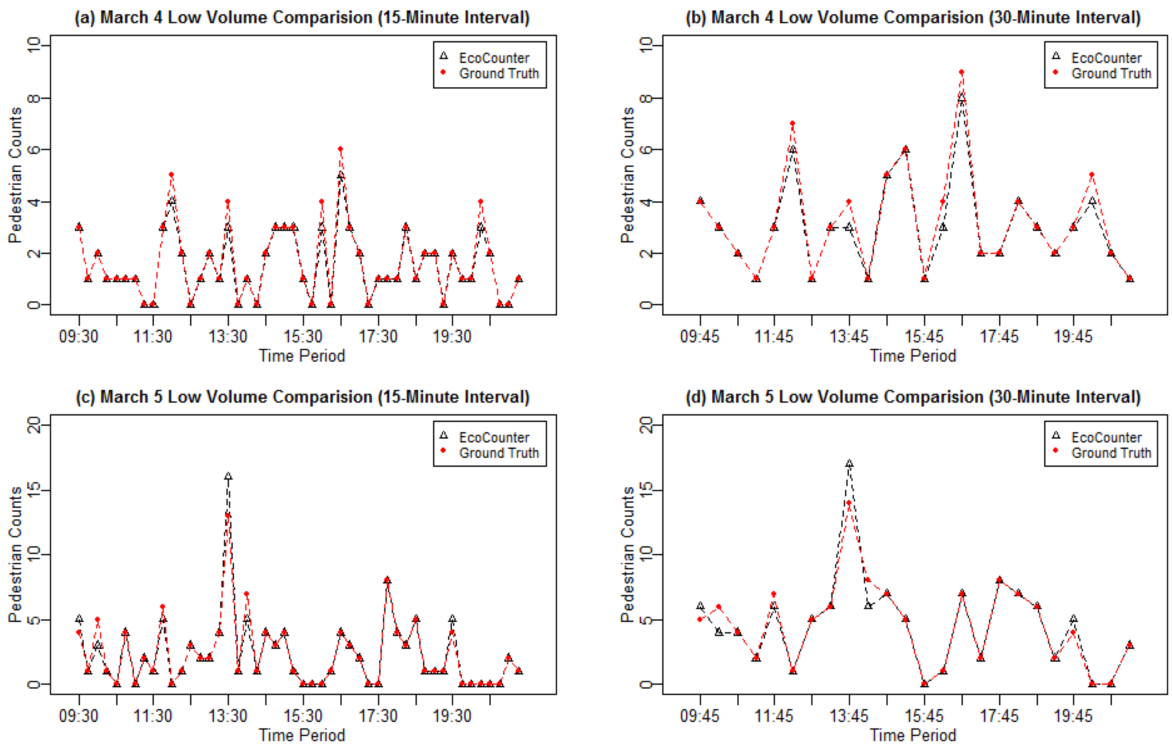


Figure 26. Comparisons of sensor counts at site 4

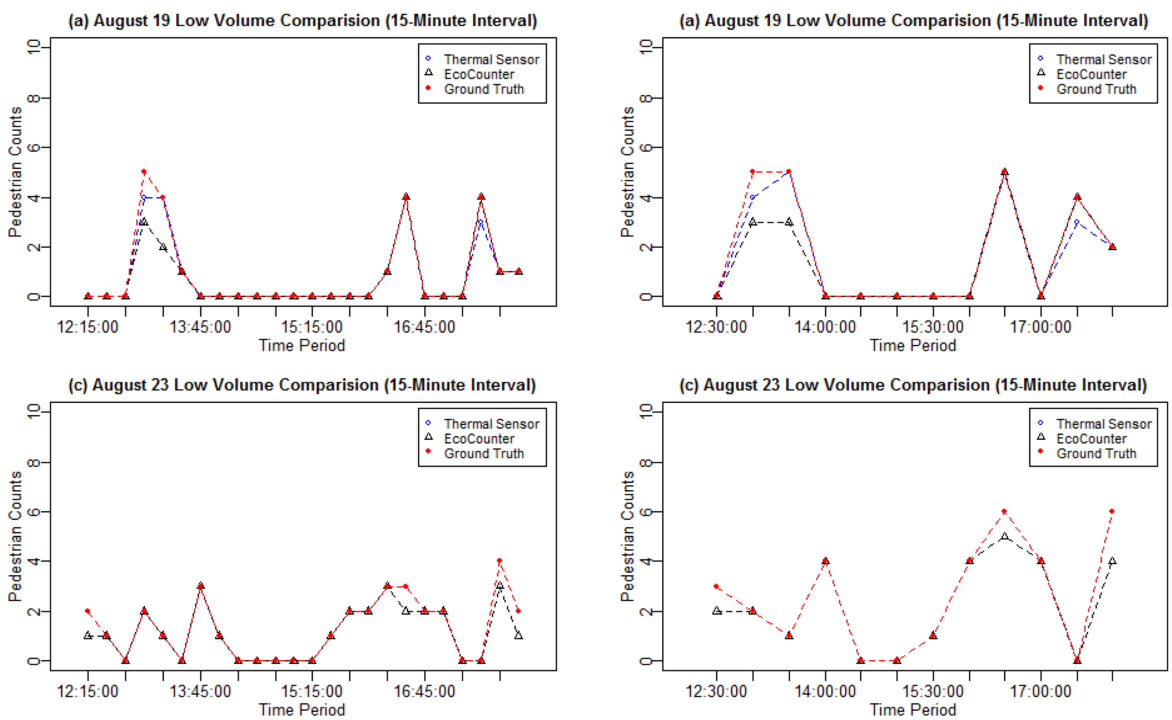


Figure 27. Comparisons of sensor counts at Site 5