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Authors

Greene-Roesel, Ryan
Diogenes, Mara Chagas
Ragland, David R.
et al.

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**Effectiveness of a Commercially Available Automated
Pedestrian Counting Device in Urban Environments:
Comparison with Manual Counts**

Ryan Greene-Roesel, Traffic Safety Center;

Mara Chagas Diógenes, LASTRAN, Universidade Federal do Rio
Grande do Sul;

David Ragland, Traffic Safety Center;

Luis Antonio Lindau, LASTRAN, Universidade Federal do Rio
Grande do Sul

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Effectiveness of a Commercially Available Automated Pedestrian Counting Device in Urban Environments: Comparison with Manual Counts

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Authors:

Ryan Greene-Roesel

University of California, Berkeley
Traffic Safety Center
2614 Dwight Way-7374
Berkeley, CA 94720-7374
Phone: 510-642-0655
ryangr@berkeley.edu

Mara Chagas Diógenes (corresponding author)

Laboratório de Sistemas de Transportes, LASTRAN
Programa de Pós-Graduação em Engenharia de Produção - PPGEP
Universidade Federal do Rio Grande do Sul, UFRGS
Av. Osvaldo Aranha, 99 – 5° andar
Porto Alegre – RS, Brazil, 90035-190
+55-51-3308-3596
+55-51-3308-4007
maracd@yahoo.com

David R. Ragland

Adjunct Professor and Director
University of California, Berkeley
Traffic Safety Center
2614 Dwight Way-7374
Berkeley, CA 94720-7374
Phone: 510-642-0655
Fax: 510-643-9922
davidr@berkeley.edu

Luis Antonio Lindau

Laboratório de Sistemas de Transportes, LASTRAN
Programa de Pós-Graduação em Engenharia de Produção - PPGEP
Universidade Federal do Rio Grande do Sul, UFRGS
Av. Osvaldo Aranha, 99 – 5° andar
Porto Alegre – RS, Brazil, 90035-190
+55-51-3308-3596
lindau@producao.ufrgs.br

ABSTRACT

High-quality continuous counts of pedestrian volume are necessary to evaluate the effects of pedestrian infrastructure investments and to improve pedestrian volume modeling. Automated pedestrian counting devices can meet the need for continuous counts of pedestrian volume and reduce the labor cost associated with manual pedestrian counting and data entry. However, most existing automated pedestrian devices are not well suited to the task of counting pedestrians in outdoor environments, and little is known about their effectiveness and accuracy. This study addresses the lack of performance information on automated counting devices by providing a review of commercially available devices and by testing the accuracy of a promising device in an outdoor urban context. It finds that a dual sensor passive infrared device is capable of producing reasonably accurate pedestrian volume counts in the outdoor urban context. It also finds a high degree of inter-reliability between counts collected by field observers and through video recordings.

INTRODUCTION

Motorized travel is associated with negative externalities such as sedentary lifestyles and air pollution (1). To combat these effects, significant resources are focused on increasing the number of non-motorized trips, especially walking trips, by improving the safety and attractiveness of the pedestrian environment.

The literature suggests performance measures should be used to monitor the results of investments and to inform the decision-making process (2, 3, 4). Pedestrian volumes are a key performance measure necessary to evaluate the impacts of pedestrian infrastructure improvements, to develop estimates of pedestrian risk, and to understand the environmental correlates of walking. Yet high quality pedestrian volume data is scarce. The Bureau of Transportation Statistics has identified the collection of better pedestrian volume data as a major national need (5).

One of the most promising strategies for improving the amount and quality of pedestrian volume data is to employ automated counting devices. Automated devices are attractive because they have the potential to reduce the labor costs associated with traditional manual pedestrian counting methods, including the cost of data input and storage, and to produce long-term continuous counts of pedestrian activity. Without automated devices, the manual collection of counts of more than a few days in length is highly impractical.

Long term, continuous pedestrian volume counts are valuable not only because they provide information about the specific site where they were collected, but because they can improve models of pedestrian volume. For example, it is common practice among state departments of transportation to estimate annual vehicle volumes using equations calibrated through the collection of continuous counts at a small number of sites (6). Researchers have used the same technique to estimate annual pedestrian volumes (7), but have generally had to rely on limited input data to calibrate their equations, since the collection of long term, continuous counts is not possible with manual observers.

A reliable, easy-to-use, and relatively inexpensive automated pedestrian counting device would fill the need for high-quality, continuous pedestrian volume data. However, at this time, automated pedestrian counting technologies are not very well developed, their effectiveness has not been widely researched, and most devices are used for detecting, rather than counting, pedestrians (8, 9, 10). Moreover, most of the existing automated pedestrian counting technologies are not well-adapted to counting pedestrians in outdoor urban environments, such as at sidewalks and pedestrian crossings, since most were developed for indoor environments (e.g. shopping malls, subway stations) or low-density outdoor environments (e.g. trails and parks).

This study aims to improve the state of knowledge regarding automated pedestrian devices. In it, we review commercially available devices, select a device for study, and report on the accuracy of the device in various conditions. The selection of the device was based on a review of existing pedestrian counting technologies usable in outdoor urban environments (11). The criteria used for the selection were cost, feasibility of use and commercial availability. The field test aimed to determine the accuracy and performance of the device at different urban locations. The accuracy of the device was established through comparison with counts collected by manual field observers and video recordings.

In addition, this study sheds light on the relative accuracy of commonly used manual pedestrian counting methods, providing a follow-up to a study conducted by Diogenes et al. (12).

This study and Diogenes et al. (12) emerged from a larger research effort aimed at developing a protocol for defining and measuring pedestrian exposure to accidents in the state of California. The research effort was entitled “Estimating Pedestrian Accident Exposure” and was funded by the California Department of Transportation.

AUTOMATED PEDESTRIAN COUNTING TECHNOLOGIES

Automated methods are commonly used to count motorized vehicles, but are not frequently used to count pedestrians. This is because the automated technologies available to count pedestrians are not very developed, and their effectiveness has not been widely researched. Much of the research on automated pedestrian tracking devices has focused on pedestrian detection, not pedestrian counting. Extensive reviews of pedestrian detection technologies were conducted by Noyce and Dharmaraju (9) and by Chan et al. (13). Technologies include piezoelectric sensors, acoustic, active and passive infrared, ultrasonic sensors, microwave radar, laser scanners, video imaging (computer vision).

Of the technologies developed for detecting pedestrians, the most adaptable to the purpose of pedestrian counting are: infra-red beam counters; passive infrared counters; piezoelectric pads; laser scanners; and computer vision technology. None of these devices are widely used for the purpose of counting pedestrians outdoors, but all have some potential to be adapted for that purpose.

A recent review of pedestrian and bicycle data collection efforts in local communities included several case studies in which the devices mentioned above were used. However, their use was confined to low-density environments, such as bicycle and pedestrian paths (14). One of the few studies of automated pedestrian counting technologies in outdoor urban environments was conducted by the Central London Partnership (CLP) in 2005. They identified and tested three commercially available technologies: computer vision, passive infra-red array, and vertical laser scanners. CLP verified the accuracy of the technologies with manual counts collected over three hour periods. All of the devices were found to function with good accuracy (within -2 and 3 percent of manual validation counts), with the exception of one of the computer vision systems which malfunctioned after installation (15).

OBJECTIVES AND METHOD

The purpose of this research was to select a commercially available automated pedestrian counting device suited for outdoor urban environments and to test it in the field. Another objective of the research was to determine the accuracy of the equipment in comparison with manual counting. In order to reach these objectives, the research was divided in 3 phases:

1. Selection of the automated pedestrian counting device
2. Definition of data collection plan
3. Collection of data in the field

The first step, selection of an automated pedestrian counting device, began with an in-depth review of possible technologies. Information for the review was drawn from the studies cited in the previous section and directly from the manufacturers (company websites and telephone calls). Five candidate technologies were identified, including:

1. Infra-red beam counter, a device that counts the number of objects that break the path of an infra-red beam;

2. Passive infrared counter (may be made up of one or multiple sensors), a device that senses heat from passing objects;
3. Piezo-electric pad, a pressure-sensing device that counts footsteps;
4. Laser scanner, a device that emits a laser beams and analyzes the reflected beam to determine a count;
5. Computer vision, computer software that automatically recognizes and counts objects (e.g. vehicles, pedestrians), in video recordings.

Bu et al. (11) prepared a comparative table, presenting the pros, cons and cost of the potential technologies for counting pedestrians in urban environments (Table 1). As the table shows, each technology has strengths and weaknesses that make it particularly suited to different purposes, budgets, and counting environments.

TABLE 1 Summary of Automated Pedestrian Counting Devices

<i>Counter</i>	<i>Pros</i>	<i>Cons</i>	<i>Manufacturer and Cost</i>
Infra-red beam counter	Lower-cost and widely available commercially; Low power consumption; Easy installation; Highly portable.	Infrared beam counter cannot differentiate pedestrians and other objects, such as rain drops; Transmitter and receiver need to be aligned carefully to ensure the reception of 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 only registered as one count.	Jamar Technologies Inc \$790
Passive infra-red counter (dual-sensor)	Lower-cost and widely available commercially; Low power consumption; Not affected by wet or foggy weather; Single or double sensor can be mounted perpendicular to pedestrian movement, and can track direction of movement	Single or double sensor counter cannot distinguish between individuals and groups; Temperature can affect counter performance; Limited coverage area.	EcoCounter \$2000 for counter, \$600 for software
Passive infra-red counter (array)	Same as above but multiple sensor array can differentiate pedestrians walking in groups	Same as above but must be mounted overhead	Irisys \$1400 for counter with multiple sensor array
Piezo-electric pad	Low maintenance cost; Low power consumption; Capable of counting pedestrians on sidewalks.	Need physical contact between pedestrian and pad; Sub-surface installation is expensive; Limited coverage area; Some of products cannot differentiate between single pedestrian and group of pedestrians.	EcoCounter Cost estimate not available

<i>Counter</i>	<i>Pros</i>	<i>Cons</i>	<i>Manufacturer and Cost</i>
Laser scanner	Accurate range measurement; Can differentiate pedestrian according to their height; Easy setup; Large coverage area.	Expensive; Performance could be affected by different weather conditions.	LASE GmbH Around \$9000 for counter only
Computer vision	Large coverage area; Has the potential to count accurately in various conditions such as crowded pedestrians, different lighting conditions; Can be manually reviewed to collect pedestrian characteristics; Easy installation and setup; The video can be recorded for manual review.	Most commercially available products are intended for indoor setting; The difficulty of counting pedestrians in crowded settings has not yet been resolved; The performance can be affected by different environmental conditions if not designed properly.	Video Turnstile Start from \$1230

Selection of the Automated Pedestrian Counting Device

Selection of a device for study followed the following criteria: (1) commercial availability; (2) cost; and (3) ease of use. These criteria were emphasized because the ultimate purpose of the research effort was to help identify a device that could be readily put to wide use in the state of California.

The laser scanner was the first device to be eliminated from consideration, since its cost was very high relative to the other devices. The active infrared device was also removed from consideration because of concerns over its accuracy. Vehicles, insects flying close to the transmitter, or even rain drops could block the counting beam and trigger the counter (11).

Other issues that guided the selection of a device were the installation and ease of use. Devices that must be mounted overhead present difficulties because locations where overhead mounting is feasible are limited. In the CLP study (15), for example, passive infra-red array and computer vision devices were attached to a concrete overhang that covered only part of the sidewalk. Such locations with natural overhangs are rare in outdoor environments.

Mounting requirements may also create liability problems. Cities contacted for this study required special permits and commercial liability insurance for mounting of any permanent device in public areas. These requirements held for any fixed device, whether it is mounted overhead (as with the infrared array or computer vision devices) or if it is buried underfoot (as with the piezo-electric pad). Only a non-fixed device would be exempt.

In addition, permanent installation of devices, whether overhead or underfoot in the pavement, often requires trained engineers and equipment. In the CLP study, several engineers and a crane (along with the accompanying permissions to deploy it) were needed to complete installation of the overhead-mounted devices (15). For some prospective users of automated pedestrian counting devices, these obstacles may be insurmountable unless technically qualified consultants are engaged. For the trial sets realized in the CLP study, two specialized firms were needed to install the devices and download data.

Although the computer vision, passive infrared-array, and piezo-pad technologies were all tested with very good results in the CLP, their mounting requirements proved to be an insurmountable obstacle given the time constraints of the study and the need to identify a device that could be readily deployed throughout the state.

Elimination of these devices left the dual-sensor passive infrared technology as the final choice. The counter consists of two pyroelectric infrared sensors that detect the infrared radiation emitted by the human body and transmit counts to a recording device (Figure 1). The device uses a sophisticated algorithm to avoid false counts generated by moving vegetation or the sun. Extraneous counts are further limited when the detection zone is bounded by a fixed object, such as a wall (17). The counter is contained within a small protective box that can be installed on a sign post (such as a traffic or parking sign) within the pedestrian right-of-way and left for long periods of time, since the battery lasts up to ten years. The installation is easy and does not require specialized workforce, since the attaching hardware adapts well to objects of varying size and shape (16). Moreover, the device had the advantages of being waterproof, very easy to install and transport, and inconspicuous once installed.

Existing information on the accuracy of the dual-sensor device is limited. The manufacturer claims accuracy within 5 percent (17), but acknowledges the device may miss adjacent pedestrians. An informal, 2-hour long check of the counter was undertaken by the Vermont Agency of Transportation (16) on sidewalks in the state capital Montpelier. It showed a high accuracy, since manual counts confirmed accuracy of 98%.



FIGURE 1 Double pyroelectric sensor developed by Eco-counter.

Definition of Data Collection Plan

In the second phase of the research, the data collection plan was developed. For this purpose, the researchers listed the data collection needs and determined the characteristics of data collection sites.

Since it is not possible to know the exact number of pedestrians on the roadway at any given time, the precise accuracy of the device could not be measured. Instead, the inter-reliability between the device and two manual methods of counting pedestrians (field observations using clickers and video recordings) was used as a proxy for accuracy. The researchers decided to engage a private consulting firm specializing in data collection to collect the field observations and the video recordings. Setup and installation of the device and analysis of the video recordings was conducted by the researchers themselves.

The researchers decided to collect data at three distinct sites in an outdoor urban environment. The selection of sites was guided by two basic requirements: (i) difference in pedestrian flows; and (ii) presence of a suitable place for installing the automated counter. The device needed to be placed perpendicular to pedestrian movement so that it would detect pedestrians as they cross an imaginary line on the sidewalk.

Collection of Data in the Field

The counter was installed for four-hour periods (12:00 PM to 4:00 PM) at three sites in the city of Berkeley, California on three consecutive weekdays in May, 2007. The three test sites were selected to represent varying pedestrian flows, with values ranging between 56 and 654 pedestrians per hour (Table 2). One of the three data collection sites is pictured in Figure 2. The EcoCounter is contained in a small metal box attached to a signpost at the right of the image. Installation and removal of the counter were accomplished within approximately five minutes, and no tools, specialized expertise, or insurance were required.

Manual counts were recorded simultaneously by two contracted persons. One individual recorded pedestrian volumes regardless of direction using a clicker. She was instructed to record the count displayed on the clicker on a data sheet at the end of every 15-minute period. The direction of pedestrian movement was not recorded by the field observers, although the automated counter is capable of sensing direction. The other contracted person videotaped the pedestrian flow. The video recordings were then carefully analyzed in by the study researchers, and were sometimes watched multiple times or at slow speeds to ensure accuracy.

TABLE 2 Data Collection Schedule and Pedestrian Flow

<i>Name</i>	<i>Location</i>	<i>Date</i>	<i>Volume (ped)</i>	<i>Period (hours)</i>	<i>Flow (ped/hour)</i>
Site 1	East side of Shattuck Ave. at Kitteridge St.	05/22/2006	2614	4	654
Site 2	South side of Durant Ave. at Fulton St.	05/23/2006	223	4	56
Site 3	North side of Durant at Bowditch St.	05/24/2006	1467	4	367



FIGURE 2 Data collection site 2 – low volume site.

The counter was installed perpendicular to the direction of pedestrian flow so that it could count pedestrians as they moved across an imaginary line on the sidewalk (Figure 2). The field observer and video camera were positioned very close (within a few feet) of the automated counter to ensure each crossing of the counter's path was recorded. Field and video observers also recorded a count any time a pedestrian crossed this imaginary line. Individual pedestrians could be counted multiple times if they crossed the imaginary line more than once. This could happen, for example, if an individual wandered across the counter's path three times while talking on a cellphone. In this case, the field and video observers would each count the pedestrian three times since the automated device would do the same.

All individuals crossing the line were counted, even if they were riding bicycles or were babies being pushed in a stroller. These individuals were counted in order to match the behavior of the counter, which is not capable of differentiating between pedestrians and individuals using other kinds of transportation such as bicycles or wheelchairs (16).

Care was taken to synchronize the recording of counts between the three methods being used. Because the video tapes lasted slightly less than one hour, it was necessary to adjust the video counts to make meaningful comparison possible. This was accomplished by adding to the video counts the number of pedestrians recorded by the field observer while the tape was being changed.

DATA ANALYSIS

The purpose of the data analysis was to compare the accuracy of the methods. The inter-reliability analyses assumed the counts derived from the video tapes to be closest to the actual

pedestrian volume, since they were reviewed multiple times by the researchers for assure their accuracy and reliability. However, there was some inherent ambiguity in determining the true count because of the difficulty in judging precisely when a pedestrian crossed in the path of the sensor (imaginary line in Figure 2). For example, pedestrians occasionally lingered around the sensor while talking on cell phones, and could have been registered multiple times or even blocked the sensor from registering other passers-by. Thus some discrepancy is to be expected between the video, field, and automated counts.

The comparison used the relative difference between the counts taken through each method to calculate the error:

$$Error = \frac{NP_x - NP_v}{NP_v} \quad (1)$$

where NP_x is the number of pedestrians counted by the field observers or the number of pedestrians registered by the counter, and NP_v is the number of pedestrians counted using the video images. The error was calculated for each data collection period (15 minutes) as well as for the total counting period (4 hours) at the site. In addition, the absolute discrepancy between counts was calculated to reveal how many pedestrians were missed.

A few disruptions made it necessary to remove several of the 15-minute video counts from analysis. These disruptions occurred when the view of the video camera was blocked or when the field observers forgot to record the number of pedestrians who passed when the video tape was being changed, making it impossible to compare the video and manual counts for that periods.

Because some of the video recording periods needed to be eliminated, data from the field observations were used to determine the average hourly pedestrian volume (Table 1). This data was necessary for evaluating the relationship between accuracy of methods and pedestrian flow.

RESULTS

The results of the comparison between methods are presented on Table 3. Error calculated for field counts can be considered low, varying from -0.9% to 1.4%. Comparison of the automated and video observation counts revealed that the passive infra-red device appeared to systematically undercount pedestrians, presenting an overall error rate of between -9% and -19%. This error rate is significantly greater than the rate of 2% found when the counter was used in Vermont (16). A more detailed analysis of the methods used by the Vermont Agency of Transportation to evaluate the counter is needed in order to understand the discrepancy between the results.

In three of the 15 minute periods, the counter appeared to over count pedestrians, as highlighted on Table 3. A possible explanation is that someone lingering around the sensor crossed its path more times that the field or video observers were able to perceive. More in-depth analyses are needed to determine the reasons for the over count.

Pedestrian volume did not appear to have a strong effect on the counter's performance. The overall 4-hour error rate was lowest (-9%) at site 2, the lowest volume site, but a scatter plot (Figure 3) of pedestrian volume and error for each 15-minute data collection period reveals no consistent relationship between error and volume, presenting a weak data correlation ($R^2 = 0.04$).

It is important to point out that the scatter plot did not include the over counted periods, aiming to avoid wrong conclusions.

The results suggest that the error rate is most directly related not to pedestrian volumes but to the tendency of pedestrians to walk closely together, since the counter was observed to miss pedestrians walking in groups. The error rate of the automated counts, with a few exceptions, is fairly consistent at -13.2% on average, with a standard deviation of .14. The relative stability of the error rate suggests that automated counts obtained from the Passive infrared device could be adjusted upwards by a constant percentage to produce reasonably accurate estimates of pedestrian volume. It is also possible that the error could be adjusted on a case-by-case basis by determining the percentage of pedestrians at the site who walk in groups.

TABLE 3 Comparison of Counting Methods (Video vs. Automated and Video vs. Field)

	<i>Video-Automated</i>			<i>Video-Field</i>		
	Site 1	Site 2	Site 3	Site 1	Site 2	Site 3
12:00-12:15	-22%	0%	-11%	0%	0%	0%
12:15-12:30	-46%	-6%	-22%	0%	12%	1%
12:30-12:45	8%	0%	-20%	-1%	0%	-1%
12:45-1:00	-21%	0%	Not Counted	0%	0%	Not Counted
1:00-1:15	-15%	43%	-19%	-1%	0%	2%
1:15-1:30	-3%	-44%	-18%	-1%	0%	3%
1:30-1:45	-5%	-22%	-26%	0%	0%	0%
1:45-2:00	-18%	13%	-24%	-2%	-6%	2%
2:00-2:15	-18%	-13%	-14%	0%	0%	-1%
2:15-2:30	-19%	-25%	-23%	-1%	8%	0%
2:30-2:45	-13%	-10%	-15%	-1%	0%	1%
2:45-3:00	-7%	-7%	-13%	0%	7%	0%
3:00-3:15	Not Counted	-14%	-14%	Not Counted	0%	0%
3:15-3:30	-4%	Not Counted	-17%	-3%	Not Counted	0%
3:30-3:45	-13%	-14%	-22%	1%	-14%	4%
3:45-3:00	-14%	-11%	Not Counted	0%	6%	Not Counted
Total Error (4 hr)	-14%	-9%	-19%	0.4%	-1.4%	-0.9%

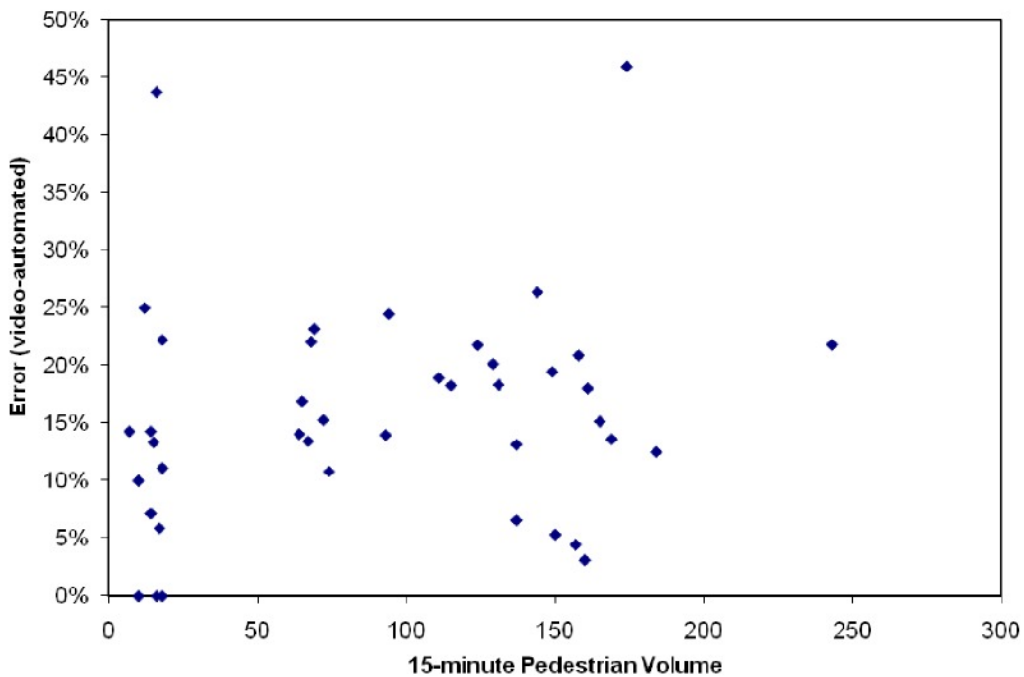


FIGURE 3 Scatterplot of 15-minute pedestrian volume and error.

The fact that the video and field counts were very similar is also a significant finding that nuances previous research on the subject of the inter-reliability of video and field counts (Diógenes et al, 2007). In the previous study, the field observer, faced with counting pedestrian age, gender, and direction of movement at signalized intersections in San Francisco systematically undercounted pedestrians relative to video observations by between 9 and 25%. The observer also undercounted pedestrians when collecting only volumes, though not enough data was collected to draw robust conclusions.

In contrast to the previous study, the observer in this study collected seemingly perfectly accurate counts of pedestrians. This may be explained in part by the fact that in the first study, the observer was tasked with more complex data collection, and many of the intersections were signalized, meaning that the observer was required to count platoons of pedestrians. In the second study, the observer had a much simpler task of counting a steady stream of pedestrians moving along the sidewalk, rather than large groups bunched together. Although the differing counting requirements certainly played a role in explaining the discrepancy in error rates, observer motivation undoubtedly played an equally, if not more significant role, since the observer in the first study took unscheduled breaks and did not follow directions carefully.

CONCLUSIONS

This study aimed to improve the state of knowledge regarding the relative accuracy and effectiveness of automated counting devices. It showed that although several devices have the potential to be adapted to the task of counting pedestrians in outdoor environments, most suffer from practical limitations, especially cost and complex mounting requirements.

A practical, relatively cost effective device was identified in a dual passive infrared sensor. The device may be used to obtain reasonable estimates of pedestrian volume in outdoor environments provided the counts are adjusted upwards by a standard percentage to reflect the fact that pedestrians walking in groups will be missed. Another complicating issue is the devices' inability to distinguish between sidewalk users, such as bicyclists, pedestrians and strollers. However, the manufacturer has indicated that in order to determine just the pedestrian flow, a pneumatic tube can be used simultaneously with the passive infrared device. One device would count all users and the other just the wheeled ones (16).

A secondary purpose of this study was to investigate the relative accuracy of two manual methods of counting pedestrians (field observations and manual counts from video-recordings). In contrast to the findings of a previous study (12), it was found that pedestrian counts obtained from field observers are not necessarily less accurate than those obtained by manual review of video recordings. The relative accuracy of the two methods seems to depend on the complexity of the counting task and the level of observer motivation. However, in situations where accuracy is imperative, video recordings are advantageous in that they can be reviewed multiple times to ensure a reliable count is obtained.

Continued work in this area is needed to characterize the performance of emerging pedestrian counting technologies relative to traditional counting methods. In addition, more work is needed to develop and test devices that can be used to count pedestrian flows at intersections, where many pedestrian-vehicle collisions occur.

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