Methodology for Counting Pedestrians at Intersections

Use of Automated Counters to Extrapolate Weekly Volumes from Short Manual Counts

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Accurate methods of counting pedestrians are needed to quantify exposure for safety analysis, rank infrastructure improvements and safety programs by priority, evaluate the benefits of pedestrian projects, develop models of pedestrian volumes, and track changes in pedestrian activity over time. However, pedestrian counts are still much less common than motor vehicle counts in most communities. In addition, existing count methodologies are not standardized and rarely provide enough information to extrapolate to weekly, monthly, or annual volumes. This exploratory study presents a methodology for estimating weekly pedestrian intersection crossing volumes based on 2-h manual counts. The methodology, implemented in Alameda County, California, involves a combination of manual and automated counts to determine weekly volumes. More than 690,000 pedestrians were counted during the 13-week study period. Manual counts were conducted at a set of 50 intersections. Automated counts from sidewalk locations in close proximity to a subset of 11 intersections were used to adjust these counts for time of day and week, surrounding land use characteristics, and weather conditions. The extrapolated pedestrian volume estimates were then used to calculate the number of reported crashes per 10 million pedestrian crossings at each of the study intersections. The results of this study demonstrate how pedestrian volumes can be routinely integrated into transportation safety and planning projects.

Motor vehicle volumes have been incorporated into transportation safety and planning for decades. Various methods exist for counting and estimating vehicle volumes, as formalized in the FHWA *Traffic Monitoring Guide* (*1*). In contrast, pedestrian counting methodologies are much less established, making it difficult to accurately quantify pedestrian activity and safety and integrate these measures into transportation planning, engineering, design, and evaluation. More reliable, cost-effective methods of counting pedestrians are needed. Accurate pedestrian volumes can be utilized by planners, engineers, and public health practitioners to

- Quantify pedestrian exposure in safety analyses (express pedestrian risk as the rate of reported pedestrian crashes per pedestrian crossing);
- Set priorities for pedestrian engineering, education, enforcement, and encouragement projects (in conjunction with public input, safety data, and other inputs);
- Provide valid data for estimating pedestrian volume models;
- Determine whether a particular crossing location will meet an engineering warrant for a pedestrian crossing signal or other crossing treatment;
- Document the benefits of specific pedestrian projects by comparing volumes before and after implementation; and
- Track changes in pedestrian activity in different parts of a community over time.

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PURPOSE OF STUDY

The purpose of this study is to demonstrate how to estimate weekly intersection pedestrian volumes from 2-h pedestrian counts. Extrapolating such pedestrian counts to weekly volumes requires accounting for differences in time of day, surrounding land use characteristics, and weather. The methodological approach, tested in Alameda County, California, provides guidance on how to incorporate pedestrian volume estimates into local and state roadway databases.

This is an exploratory study. It is one of the first research efforts to quantify adjustment factors for estimating weekly pedestrian volumes from short pedestrian counts. Therefore, more research is needed to refine the factors that are used to account for time of day, surrounding land uses, and weather. In addition, the study will need to be repeated in many communities under different types of conditions to estimate the margin of error of these adjustment factors. Nonetheless, this study provides a useful methodological framework for communities seeking to collect more accurate pedestrian volume data and conduct more accurate assessments of pedestrian crash risk.

LITERATURE REVIEW

There is a growing body of research on manual and automated pedestrian counting methods. The first two sections of this review present lessons learned about different counting technologies. The second section presents research on different approaches for collecting counts and adjusting for time of day, location, and weather.

Manual Count Methods

Manual counts are commonly recorded by using data collection sheets or clickers in the field. Video technology allows for more careful and deliberate observation, since the video can be slowed down or replayed as necessary (*2, 3*). Whereas analyzing video may be the most accurate manual count method, it is more costly than using clickers or data sheets because it requires specific equipment and several hours of manual coding for each hour of video (*2*).

Manual count methods tend to be more accurate than automated count methods. However, human error can lead to inaccuracies (*4*). Count accuracy depends on the level of motivation and alertness of the observer. Reducing the number of characteristics being recorded by the observer may improve count accuracy (*2*). In addition, because most data collectors are subject to fatigue, continuous counts over lengthy periods of time are not feasible.

Automated Count Methods

Automated vehicle counting technology has been in use for many years, but automated pedestrian counting technology is less developed (*4, 5*). Pedestrians are more difficult to count than motor vehicles because their paths are much less constrained (*6*). Therefore, choosing an appropriate automated counter requires understanding the specific type or types of pedestrian movements that need to be counted. Other key considerations include accuracy, equipment costs, installation costs, maintenance costs, size and location of pedestrian detection zones, data storage, and legal restrictions (*5*).

A variety of automated pedestrian count technologies were considered for this study. Previous studies were reviewed to select the most appropriate technology (*4, 7*). Options included

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

Only a small number of studies have been conducted to test the accuracy of automated pedestrian counters (*4, 6, 8*). Accuracy rates vary widely and can depend on environmental conditions and pedestrian density. Most counters do not distinguish among a person walking, walking a bicycle, or riding a bicycle. Therefore, automated counter data need to be interpreted carefully (*4*).

The EcoCounter dual-sensor pyroelectric infrared counter, a passive infrared counter, was selected for this study. This device has a low rate of undercounting compared with other automated counters, can store data in 15-min intervals for up to a year, has a multiyear battery life, and can be installed quickly and easily.

Temporal, Spatial, and Weather Pedestrian Count Adjustment Factors

Accurate adjustment factors are needed to compare pedestrian counts that are taken for different lengths of time, at different times of day, in different locations, and under different weather conditions. These adjustment factors also make it possible to extrapolate short counts to a full day, week, month, or year. Temporal variations (e.g., differences in volume by time of day, day of the week, and season) have been captured in a number of pedestrian studies (*9–12*), but few have used continuous count data to account for differences over a full 24-h day, complete week, or entire year. Several studies have classified daily distributions of pedestrian volumes into different categories based on land use type (*9–12*). Few studies have examined the effects of weather (e.g., precipitation, clouds, temperature) (*9*) (Table 1).

Previous studies have explored several aspects of collecting pedestrian volume data, but there is a need for more research on pedestrian counting methodologies. This research should provide (*a*) more information about the technical capabilities and accuracy of new automated count technologies and (*b*) more comprehensive assessments of the effects of time, location, and weather on pedestrian volumes.

METHODOLOGY

To collect pedestrian counts at a sample of 50 intersections in Alameda County, California, field data collectors took manual counts at 50 locations, and five infrared sensors were rotated among 13 of these intersections to capture variations in pedestrian volume patterns due to time of day, location, and weather conditions. Manual counts were taken during specific observation periods in April, May, and June 2008. Adjustment factors developed from the infrared sensor data were applied to the 2-h manual counts to estimate weekly volumes.

Study Area

This study was conducted in Alameda County, California, part of the San Francisco Bay metropolitan region. Alameda County [Census Bureau 2007 estimated population 1.46 million (*13*)] is an excellent location for this study because it includes urban, suburban, and exurban areas that are similar to many built environments found throughout the United States. Oakland is the largest city in the county (population 401,000).

Intersection Selection

A strategic sampling process was used to select the 50 intersections for this study. First, 30 of the 528 intersections along state-maintained arterial roadways were chosen by using stratification on three variables: population density, median income, and proximity to commercial properties. These characteristics have been shown to be correlated with levels of nonmotorized transportation activity (*14–17*). The 20 remaining intersections for the study were chosen from a total of 6,938 intersections along other (non-state-maintained) arterial and collector roadways in Alameda County. These 20 intersections were chosen randomly subject to several constraints, to ensure that a variety of location types would be represented.

The 50 selected intersections had a wide variety of characteristics and were spread throughout the urbanized parts of the county (Figure 1). Although there was significant variation between sites, average values were similar for the county as a whole. The selected intersections included

- Nine intersections within 0.5 mi (805 m) of a Bay Area Rapid Transit (BART) station;
- Twenty intersections within 0.25 mi (402 m) of an elementary, middle, or high school;
- Thirty-three intersections with sidewalks on both sides of all roadways within 0.25 mi;
- Four trail–roadway intersections;

TABLE 1 Previous Studies Considering Effects of Time, Location, and Weather on Pedestrian Volumes

Author (year)	Location (sample size)	Dependent Variable	Time Effects	Location Effects	Weather Effects
Cameron (1977) (*9*)	Seattle, Wash. (several hundred days of pedestrian counts)		Analysis showed regular daily and hourly volume fluctuation patterns at count sites.	Different daily patterns of pedestrian activity were identified in the CBD, retail shopping districts, waterfront area, and other locations.	Fewer pedestrians were observed in cooler, rainier weather.
Davis et al. (1988) (*10*)	Washington, D.C. (14 crossings; 18,432 5-min counts and one 12-h count at each site)	Pedestrian crossing volume per 1-h, 2-h, 3-h, or 4-h period	5-min sample counts in the middle of an analysis period were better at predicting the total pedestrian volume over the entire analysis period than counts at the beginning or end of the period.	The 14 count sites showed six categories of daily pedestrian volume distributions.	
Hocherman et al. (1988) (*11*)	Haifa, Israel (86 crossings; 135 counts at 15-min intervals between 7 a.m. and 10 p.m.)	24-h pedestrian volume at roadway crossings	Pedestrian activity in residential areas had peaks between 7 a.m. and 8 a.m. (14% of daily volume), 4 p.m. and 7 p.m. (8 to 10% of daily volume), and 12 p.m. and 1 p.m. (9% of daily volume).	72 count sites were in residential neighborhoods, and the other 14 locations were in CBD locations.	Seasonality had little effect on pedestrian volumes in Israel.
Zegeer et al. (2005) (*12*)	28 cities and 2 counties in the United States (2,000 crosswalk locations; one 1-h count at each crosswalk)	24-h pedestrian volume using crosswalks	Developed adjustment factors to extrapolate 1h counts to 24 h.	Factors for extrapolating 1-h counts to 24 h were different in CBD, fringe, and residential areas.	

NOTE: CBD = central business district.

- Six central business district (CBD) intersections:
  – Oakland (four),
  – Hayward, and
  – Fremont; and
- A variety of site characteristics, including number of travel lanes, traffic volumes, speed limits, median islands, curb radii, and types of traffic control.

Additional detail about the intersection selection process is provided in a companion paper (*18*).

Data Collection

Manual Counts

Field data collectors were dispatched to count pedestrians at each of the 50 sites. Between one and four observers were used per intersection depending on a rough estimate of pedestrian activity at each site. Observations were made on one weekday (Tuesday, Wednesday, or Thursday) and on one Saturday for each location. These days were expected to have the most consistent pedestrian travel patterns from week to week. Each observation period was from 9:00 to 11:00 a.m., 12:00 to 2:00 p.m., or 3:00 to 5 p.m. Three back-to-back time periods were chosen so that the data collectors could observe three sites on the same day and use their time efficiently.

Observers were instructed on how to use the data collection sheet and to count pedestrians crossing any leg of the intersection. For the purposes of this study, a pedestrian was defined as a person walking, walking a bike, being carried, or using an assistive device such as a wheelchair. Skateboarders, in-line skaters, and people riding bicycles were not counted. Pedestrians were counted when they crossed within 50 ft (15 m) of the intersection on any of the legs, as long as they had crossed at least half of the roadway. Although pedestrian counts along sidewalk segments are important for planning and priority ranking, this study evaluated intersection exposure to vehicle–pedestrian collisions, so it focused specifically on roadway crossings at intersections. A single pedestrian could be counted multiple times if he or she crossed multiple legs of the intersection. The counts were logged in 15-min intervals across the 2-h period, and the counts for each leg were summed to get a total intersection count. T-intersections have only three roadway crossings. However, at these intersections, data collectors counted pedestrians who used the sidewalk on the fourth side of the intersection. This inclusion made it possible to make direct comparisons between the total intersection volumes at three- and four-way intersections.

Midblock crossings [more than 50 ft (15 m) from the intersection crosswalk] were not observed during this analysis. Taking midblock counts would require data collectors to focus simultaneously at the intersection and further down all approaching roadways. This type of count is difficult to do accurately without additional data collectors. Future studies should examine midblock pedestrian crash risk

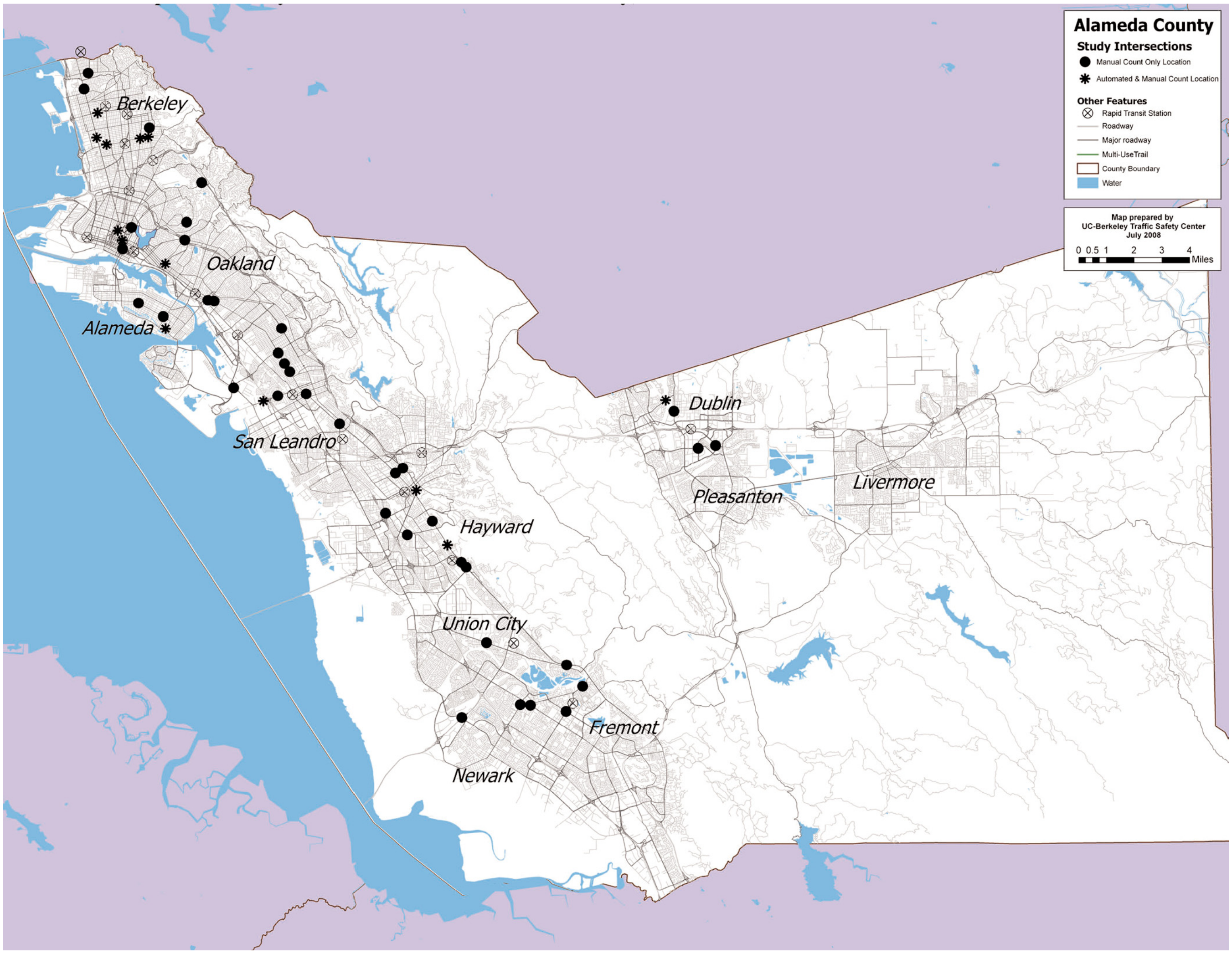

FIGURE 1 Map of 50 study intersections in Alameda County, California.

by using data collectors who focus solely on midblock crossing counts.

Automated Counts

EcoCounter pyroelectric dual infrared sensors (*19*) were installed at a subset of the 50 intersections to collect continuous pedestrian counts between April 1 and July 10, 2008. The purpose of these automated counts was to capture variations in pedestrian volume over time (day, week, and season), in areas with different land uses, and under a variety of weather conditions. In order to capture differences in pedestrian volume patterns between sites, four infrared counters were rotated among 12 locations on a monthly basis. A fifth counter remained in one place.

Ideally, automated counters would collect intersection crossing counts in the same way as manual data collectors did. However, such technology was not available for this study (*4*). Instead, an automated counter was installed on one sidewalk approach within 100 ft (30.5 m) of each intersection, with the assumption that the daily pattern of pedestrian sidewalk activity is similar to that of the adjacent intersection.

The devices were mounted by the research team on street signs or parking meters at approximately 30 to 40 in. (76 to 102 cm) above the ground. The sensors pointed away from traffic and were aimed across the sidewalk. They were placed as close to the curb as possible to minimize the chance of pedestrians passing behind the sensor. Areas in which pedestrians might gather (e.g., bus stops, outdoor cafes) and locations that would not be representative (e.g., entrances to retail businesses) were avoided. The research team also avoided pointing the automated counters toward windows or other reflective surfaces that might have interfered with the infrared signal. The range of the counters was 15 ft (4.6 m), which covered the full sidewalk width in all locations. It was necessary to obtain written permission to install the counters in several jurisdictions.

A structured process was used to select the 13 locations for the infrared sensors. To select the sites, the research team visited all 50 intersections and reviewed aerial photographs and parcel land use data to classify each intersection into one of five general land use categories: single-use residential, commercial retail corridor, mixed residential and commercial with small lot sizes, mixed residential and commercial with large lot sizes, and CBDs. One location was selected from the CBD sites, and three locations were selected from each of the other land use categories. Individual counter sites were chosen after visits to each intersection because site characteristics were critical for collecting reliable automated data.

Data from the counters were downloaded in the field by the research team using an HP Pocket PC equipped with EcoPocket software. Hourly count data were then uploaded and exported to spreadsheets for analysis.

ANALYSIS

Pedestrians were counted 694,661 times during the 13-week data collection period. Data collectors observed 20,034 pedestrian intersection crossings, and the infrared sensors recorded 674,627 pedestrians on sidewalks. In this section the raw manual counts are reported and how these counts were extrapolated to estimate weekly pedestrian volumes for all 50 study intersections is described.

Manual Counts

The 2-h weekday and 2-h weekend manual counts were summarized for all 50 intersections (Table 2). Before time of day, surrounding land use characteristics, and weather were adjusted for, observed pedestrian volumes tended to be higher on weekdays than on weekends. Weekday counts were higher at 33 of the 50 intersections. There were significant differences in the proportion of pedestrians crossing the mainline roadway (i.e., intersecting roadway with the highest motor vehicle traffic volume) at each intersection. Seventeen of the 50 intersections had less than 25% of pedestrians crossing the mainline roadway, and two of the intersections had more than 75% of pedestrians crossing the mainline roadway. Finally, 53% of all pedestrians counted were men, and more men than women were observed at 38 of the 50 intersections. The columns in Table 2 are examples of data fields that could be added to existing roadway databases to supplement motor vehicle traffic volume and composition information.

Using Automated Counts to Adjust for Temporal, Spatial, and Weather Factors

The automated counters were used to identify differences in patterns of pedestrian activity by time of day, day of the week, location type, and weather condition. Reliable data for analysis were provided by 11 of the 13 counter locations; one location provided unreliable data because the sensor was too close to a heavily used bus stop, and the other location was not used because the permit process delayed its installation.

Time of Day and Day of Week

To capture the influence of temporal patterns on pedestrian volumes, the hourly pedestrian counts recorded by each infrared sensor were sorted by hour of the week (one week includes 168 total hours). If a counter was in place for 4 weeks, it would count each distinct hour of the week (e.g., Tuesday from 1:00 to 2:00 p.m.) four times. The counts for each distinct hour were then averaged to generate a weekly pedestrian volume profile for each counter location (Figure 2).

The weekly pedestrian volume distributions from the 11 counter locations were averaged to create a composite weekly pedestrian volume profile (Figure 3). This weekly profile shows a regular pattern of pedestrian activity. Midday hours on weekdays each account for approximately 0.9% to 1.2% of the total weekly volume; late night hours account for approximately 0.05% to 0.15% of the total weekly volume. Monday through Friday have the highest volumes, whereas Sunday has the lowest. By comparison, if pedestrian activity levels were constant throughout the week, each hour would have 1/168 (0.595%) of the weekly volume.

The composite weekly pedestrian volume pattern was used as the basis to extrapolate the 2-h pedestrian counts to an estimated weekly crossing volume for each intersection. Accounting for time of day is critical for developing an accurate estimate. For example, if no adjustment is made for temporal patterns, the Wednesday 3:00 to 5:00 p.m. counts would be assumed to represent 1.19% of the total weekly volume (0.595% for each hour). However, since afternoon is typically a peak time for pedestrian activity, a more accurate assumption would be that the Wednesday 3:00 to 5:00 p.m. time period includes 2.21% of the total weekly volume (see Figure 3: the Wednesday 3:00 to 4:00 p.m. hour is 1.18% and 4:00 to 5:00 p.m. is 1.03% of the weekly volume).

Location Type

Pedestrian activity patterns also vary by type of location. For example, intersections in the Oakland CBD tended to have higher pedestrian volumes than other locations during weekday lunch hours and intersections close to neighborhood commercial retail properties tended to have more activity on Saturday afternoons. Adjustments were developed for several common types of land uses based on the characteristics of the 11 automated counter locations (Table 3). Since the sample of counter locations was small, location-type adjustments were calculated by comparing the differences in mean values for counter locations with a particular land use characteristic and those without the land use characteristic. Time was controlled by comparing only across the same hours of the week. Further research is needed to develop land use classifications with more robust statistical methods.

Weather Conditions

Weather conditions also affect pedestrian volumes. Fewer people walked when it was cloudy and when temperatures were cool or hot (Table 4). Because there was only one late evening with measurable rainfall during the April 1 to July 10, 2008, study period, more data are needed to draw reliable results for rainy conditions. Windy conditions were evaluated, but their effect on pedestrian volume was not clear. It is likely that other weather conditions could also affect pedestrian volumes.

Extrapolation of 2-h Counts to Weekly Volumes

Adjustment factors from the automated counters were used to extrapolate the 2-h manual counts to typical weekly pedestrian volumes at all 50 study intersections. Since pedestrians were counted during two different time periods at each intersection, two different weekly volume estimates were available. These two estimates were averaged to create the final weekly pedestrian volume estimate.

RESULTS

The 50 intersections yielded a wide range of estimated total weekly pedestrian volumes. The lowest weekly volume estimate was 323 at an intersection surrounded by open space, hotel, and industrial land uses near Oakland International Airport. The highest was 113,000 at an

TABLE 2 Two-Hour Manual Pedestrian Crossing Counts at 50 Study Intersections

Mainline Roadway	Intersecting Roadway	Location Note	Weekday Count[a]	Saturday Count[b]	Total Pedestrians Counted	% Female	% Crossing Mainline Roadway[c]
Broadway	12th Street	Employment center	3,577	1,374	4,951	45.3	27.5
Webster Street	7th Street	Employment center and commercial area	936	1,131	2,067	47.8	47.6
Webster Street	21st Street	Employment center	1,843	137	1,980	48.2	39.3
Encinal Avenue	Oak Street	Neighborhood commercial area	1,165	297	1,462	53.5	49.6
College Avenue	Derby Street		319	628	947	59.6	36.0
Solano Avenue	Masonic Avenue	Neighborhood commercial area	514	397	911	52.4	48.2
Ashby Avenue	Benvenue Avenue	Employment center and commercial area	332	412	744	55.0	38.7
Ashby Avenue	Telegraph Avenue	Employment center	410	191	601	55.6	58.6
International Boulevard	46th Avenue	Neighborhood commercial area	287	286	573	40.3	15.9
International Boulevard	99th Avenue	Neighborhood commercial area	381	174	555	47.0	28.8
University Avenue	Bonar Street		229	225	454	39.2	27.3
Encinal Avenue	Benton Street		206	238	444	53.5	35.6
Paseo Padre Parkway	Mowry Avenue		229	83	312	50.3	48.4
San Pablo Avenue	Ward Street	Neighborhood commercial area	182	103	285	34.7	15.8
East 14th Street	Maud Avenue	Neighborhood commercial area	179	145	324	50.5	7.1
Martin Luther King, Jr. Way	17th Street	Employment center	152	76	228	44.3	49.1
Chatham Road	13th Avenue		222	18	240	48.3	89.2
Mission Boulevard	Jefferson Street		171	27	198	45.5	46.0
San Pablo Avenue	Harrison Street	Neighborhood commercial area	99	114	213	35.7	39.4
High Street	East 12th Street		89	82	171	17.5	21.6
East 14th Street	Bellview Drive		66	107	173	40.5	19.1
International Boulevard	107th Avenue		89	69	158	34.2	27.2
East 14th Street	Hasperian Boulevard		78	69	147	45.6	24.5
Fremont Boulevard	Peralta Boulevard	Neighborhood commercial area	73	90	163	41.7	34.4
Foothill Boulevard	Cotter Way		64	68	132	33.3	6.1
Ashby Avenue	Acton Street	Residential area	70	68	138	47.1	24.6
Bancroft Avenue	Auseon Avenue		56	76	132	26.5	25.8
Mission Boulevard	Overhill Drive		101	36	137	50.4	5.8
Mission Boulevard	Grove Way		69	58	127	44.9	46.5
Foothill Boulevard	15th Avenue		69	50	119	40.3	35.3
Broadway	Calhoun Street	Residential area	72	34	106	57.5	42.5
Santa Clara Street	Ocie Way		10	63	73	41.1	32.9
Owens Drive	Andrews Drive		49	31	80	46.3	31.3
Davis Street	Warden Avenue		40	24	64	42.2	51.6
Ardenwood Boulevard	Newark Boulevard		55	15	70	27.1	77.1
Davis Street	Pierce Avenue		28	33	61	45.9	54.1
Thornton Avenue	Oak Street	Residential area	42	20	62	32.3	12.9
Mission Boulevard	Valle Vista Avenue		22	31	53	30.2	20.8
Mandana Boulevard	Carlston Avenue	Residential area	28	30	58	39.7	44.8
Alvarado Niles Road	Western Avenue	Near multiuse trails	29	15	44	52.3	22.7
Mission Boulevard	Torrano Avenue		16	28	44	38.6	11.4

(continued)

TABLE 2 *(continued)* **Two-Hour Manual Pedestrian Crossing Counts at 50 Study Intersections**

Mainline Roadway	Intersecting Roadway	Location Note	Weekday Count[a]	Saturday Count[b]	Total Pedestrians Counted	% Female	% Crossing Mainline Roadway[c]
Amador Valley Boulevard	Stagecoach Road	Residential area and near multiuse trails	21	14	35	48.6	8.6
Daugherty Road	Scarlett Dive	Near multiuse trails	25	26	51	43.1	56.9
W. Harder Road	Tarman Avenue	Near multiuse trails	22	12	34	45.6	32.4
Stoneridge Drive	Hacienda Drive		18	7	25	52.0	44.0
Foothill Boulevard	D Street	Neighborhood commercial area	20	4	24	33.3	54.2
Mission Boulevard	Nichols Avenue		7	14	21	38.1	23.8
Mowry Avenue	Cherry Lane		9	11	20	45.0	40.0
Moraga Avenue	Masonic Avenue	Residential area	7	3	10	10.0	0.0
Doolittle Drive	Airport Access Road		9	4	13	30.8	0.0
Total			12,786	7,248	20,034		
Mean			256	145	401		
Standard deviation			579	261	799		

[a]Counts taken during one of the following time periods: Tuesday 12–2 p.m., Tuesday 3–5 p.m., Wednesday 12–2 p.m., Wednesday 3–5 p.m., Thursday 12–2 p.m., and Thursday 3–5 p.m. (April through June 2008).
[b]Counts taken during one of the following time periods: Saturday 9–11 a.m., Saturday 12–2 p.m., and Saturday 3–5 p.m. (April through June 2008).
[c]Mainline roadway is intersecting roadway with highest motor vehicle volume.

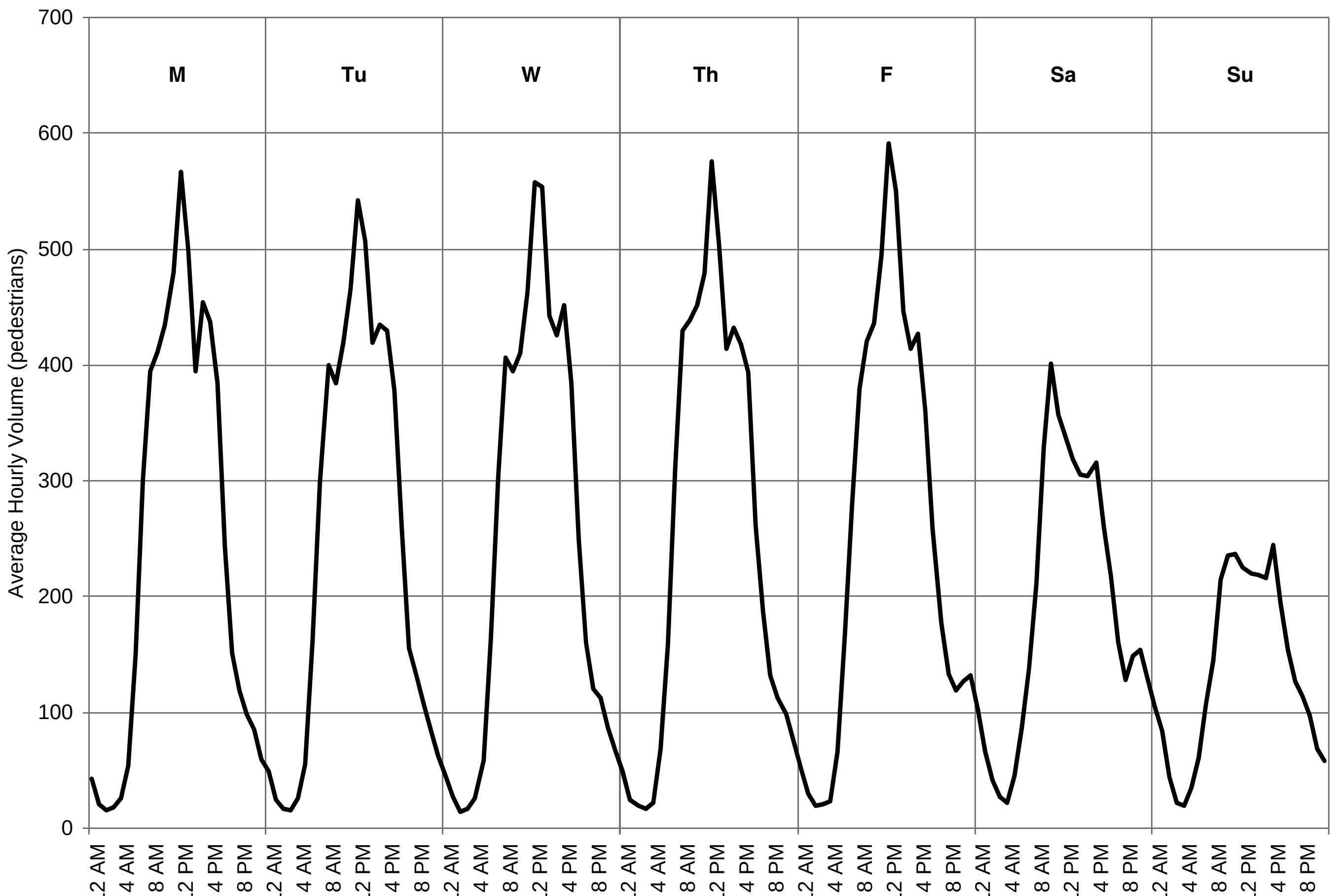

FIGURE 2 **Example of typical weekly pedestrian volume pattern, April 1 to July 10, 2008: Broadway and 12th Street, Oakland, California.**

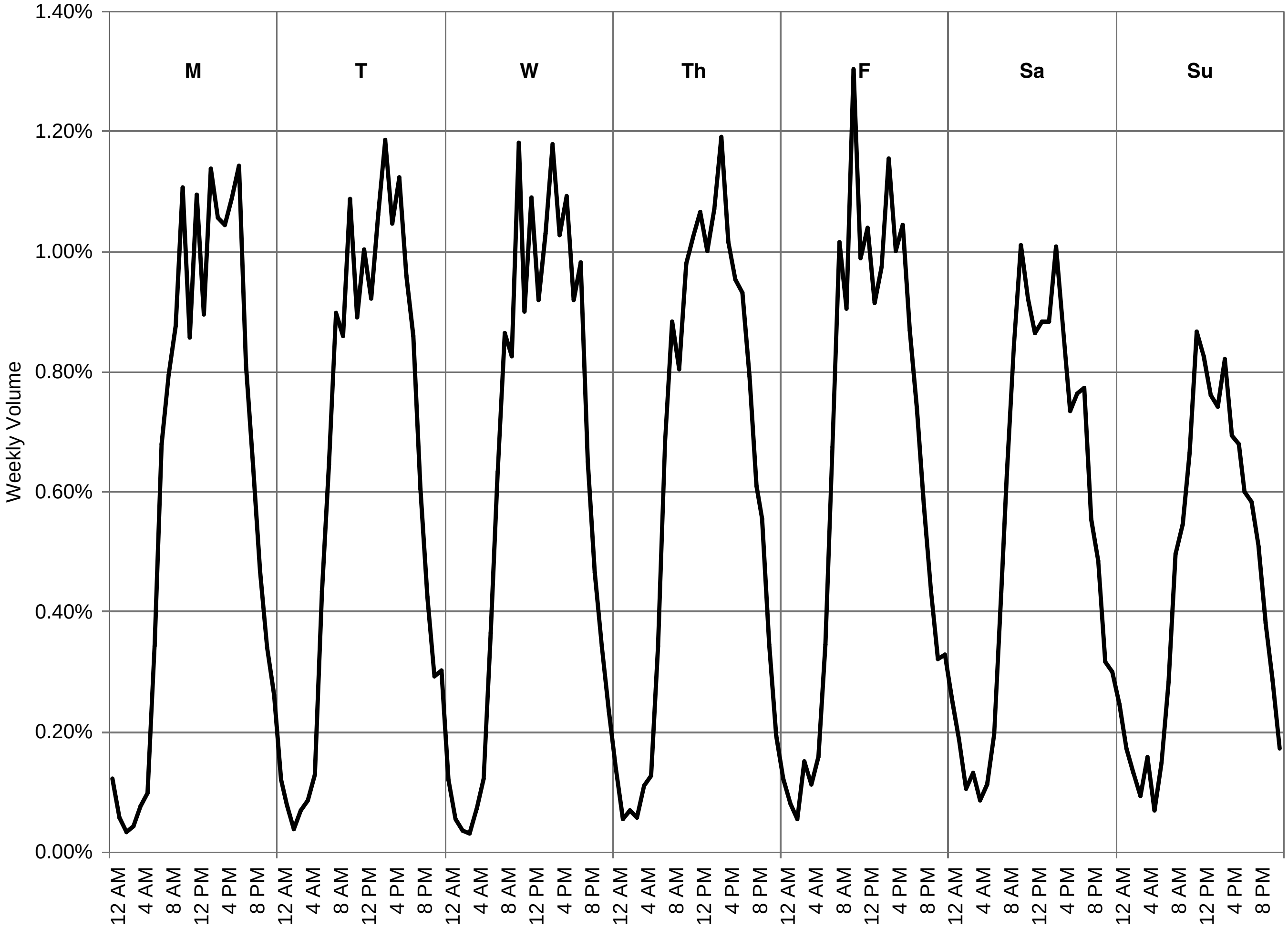

FIGURE 3 Percentage of weekly volume by hour (composite of 11 automated count sites).

TABLE 3 Land Use Adjustments for Pedestrian Volume Estimates

Land Use Category	Definition	Manual Count Time When Land Use Adjustment Is Applied	% of Weekly Volume for Intersections in Category: Count[a]	Mean	SD	% of Weekly Volume for All Intersections: Count[a]	Mean	SD	Adjustment to Manual Count to Match Composite Volume Distribution
Employment center	≥2,000 jobs within ¼ mi[b]	Weekdays 12–2 p.m.	12	2.52	0.29	33	2.00	0.61	Multiplied manual count by 0.795
Residential area	≤500 jobs within ¼ mi[b] and no commercial retail properties within ⅒ mi[c]	Weekdays 12–2 p.m.	9	1.44	0.38	33	2.00	0.61	Multiplied manual count by 1.39
Neighborhood commercial area	≥10 commercial retail properties within ⅒ mi[c]	Saturday 12–2 p.m.	3	2.43	0.50	11	1.75	0.52	Multiplied manual count by 0.722
Neighborhood commercial area	≥10 commercial retail properties within ⅒ mi[c]	Saturday 3–5 p.m.	3	2.63	0.89	11	1.88	0.67	Multiplied manual count by 0.714
Near multiuse trail	≥0.5 centerline miles of multiuse trails within ¼ mi[d]	Weekdays 3–5 p.m.	3	3.42	0.64	33	2.22	0.01	Multiplied manual count by 0.649
Near multiuse trail	≥0.5 centerline miles of multiuse trails within ¼ mi[d]	Saturday 9–11 a.m.	1	2.42	N/A	11	1.86	0.49	Multiplied manual count by 0.767

NOTE: N/A = not applicable.
[a]Count indicates the number of different observations used to calculate the mean percentage weekly volume for each land use category.
[b]SOURCE: Traffic Analysis Zones from San Francisco Metropolitan Transportation Commission, 2005 (Census Transportation Planning Package 2000).
[c]SOURCE: Land Use Parcels from Alameda County Tax Assessor's Office, 2007.
[d]SOURCE: Bay Area Multiuse Trail Centerlines from San Francisco Metropolitan Transportation Commission, 2007.

TABLE 4 Weather Condition Adjustments for Pedestrian Volume Estimates

Weather Condition[a]	Definition	Manual Count Time Requiring Weather Adjustment	% Difference Between Mean Pedestrian Count During Time Periods with Weather Condition and Mean Pedestrian Count During All Time Periods: No. of Count Periods[b]	% Difference: Mean Difference	Adjustment to Manual Count to Match Composite Volume Distribution
Cloudy	Ratio of solar radiation measurement to expected solar radiation is ≤0.6.[c]	All time periods	63	−5.28	Multiplied manual count by 1.05
Cool temperature	≤50 degrees Fahrenheit	All time periods	36	−2.30	Multiplied manual count by 1.02
Hot temperature	≥80 degrees Fahrenheit	Times between 12 and 6 p.m.	40	−3.63	Multiplied manual count by 1.04
Hot temperature	≥80 degrees Fahrenheit	Times other than 12 to 6 p.m.	27	0.43	Multiplied manual count by 0.996
Rain	Measurable rainfall ≥0.01 inches	All time periods	8	−7.10	Multiplied manual count by 1.07

[a]SOURCE: California Irrigation Management Information System, 2008 (Mills College, Union City, and Pleasanton weather stations).
[b]Number of 1-h time periods observed with the particular weather condition. To calculate the mean difference, observations from the periods with the weather condition were compared with the same time periods from other weeks where weather conditions were normal. Observations were not included if the average count for the specific hour of observation for a particular site was less than 10 pedestrians.
[c]Solar radiation measurements from the previous 4 to 10 years at each of the three Alameda County weather stations were used to calculate the expected solar radiation measurement for every hour of the year. The weather condition was determined to be "cloudy" if the ratio of the current measurement was ≤0.6 of the expected solar radiation for that specific hour. The threshold was set at 0.6 to match as closely as possible to field data collectors' subjective determinations of when the weather was cloudy.

intersection in the Oakland CBD. For all 50 intersections, the average weekly pedestrian volume was approximately 9,260 (Table 5).

Data collected during future months could be used to identify seasonal pedestrian volume trends. The typical weekly pedestrian volume estimate for each intersection can be multiplied by a different factor for each month or season to develop annual pedestrian volume estimates. However, if it is assumed that the average weekly pedestrian volumes from April 1 through July 10 represent the average weekly volume for the entire year, an annual pedestrian volume can be estimated to account for exposure in pedestrian risk analysis.

Preliminary annual volume estimates were calculated for all 50 intersections and compared with police-reported intersection pedestrian crashes. Since 10 years of pedestrian crash data were available (1996 through 2005), the annual volumes were multiplied by 10 to create an exposure estimate for the decade. The number of reported crashes was then divided by the exposure estimate to derive an estimated pedestrian crash rate (Table 5).

Estimated pedestrian crash rates vary greatly among the 50 sites. For intersections with at least one reported pedestrian crash, the pedestrian risk factor ranged from 0.48 to 82.2 crashes per 10 million pedestrian crossings. Each intersection has a relatively small number of reported crashes, so a single pedestrian crash can cause a sizable change in the crash rate. Although complete seasonal data and additional statistical analyses are needed, a cursory analysis suggests that the highest pedestrian risk is at intersections on multilane roadways with high traffic volumes. As with Table 2, the columns of Table 5 are examples of data fields that could be added to existing roadway databases and used for pedestrian safety analysis.

CONSIDERATIONS

Collecting data and extrapolating 2-h manual counts to weekly pedestrian volumes involved multiple steps. Several important considerations about the study process and ideas for future research are provided next.

Manual Counts

Before collecting manual counts, the research team conducted a training session for data collectors to help ensure accurate data collection. The observers were instructed on where to stand, who to count, and how to use the data collection sheet. The researchers also explained the purpose of the study and how the data would be used, emphasizing the importance of accuracy. The researchers remained on site for the beginning of manual data collection to answer any questions about the counting process or the data collection sheet.

The researchers also checked completed data sheets regularly to verify proper data collection and resolve any problems. The data collection team was initially confused by instructions to count the fourth, "sidewalk" side of three-leg T-intersections. In-progress review of the data brought this issue to the attention of the researchers, who were then able to clarify the instructions. The data collectors then repeated observations at the intersections that were initially observed incorrectly. Manual count data were reviewed, but resources were not available to compare the manual counts with video or other independent manual counts and test for accuracy. Therefore, the final pedestrian volumes may include errors made by data collectors. Data collector reliability could be assessed in future research.

Automated Counts

EcoCounter pyroelectric dual infrared pedestrian sensors were determined to be the best automated counting technology available for the study. Like other infrared sensors, they tend to undercount pedestrians. Previous studies have found that this brand of counter records between 9% and 19% fewer pedestrians than actually pass the counter location (*4*). Validation tests for this study showed consistent rates of undercounting during high-volume (>400 pedestrians per hour) and low-volume (<100 pedestrians per hour) periods, at locations with different sidewalk widths, and during sunny, cloudy, rainy, and dark conditions. Although undercounting occurred, the percentage of the

TABLE 5 Preliminary Pedestrian Risk Analysis at 50 Study Intersections

Mainline Roadway	Intersecting Roadway	Estimated Total Weekly Pedestrian Crossings[a]	Annual Pedestrian Volume Estimate[b]	10-Year Pedestrian Volume Estimate[b]	Reported Pedestrian Crashes (1996–2005)[c]	Pedestrian Crash Rate (crashes per 10,000,000 crossings)
Mission Boulevard	Torrano Avenue	1,169	60,796	607,964	5	82.24
Davis Street	Pierce Avenue	1,570	81,619	816,187	4	49.01
Fremont Boulevard	Peralta Boulevard	3,594	186,906	1,869,056	6	32.10
Foothill Boulevard	D Street	632	32,862	328,624	1	30.43
W. Harder Road	Tarman Avenue	672	34,918	349,182	1	28.64
Thornton Avenue	Oak Street	1,516	78,848	788,479	2	25.37
Davis Street	Warden Avenue	1,717	89,264	892,639	2	22.41
Mission Boulevard	Jefferson Street	5,236	272,246	2,722,464	5	18.37
East 14th Street	Belleview Drive	4,505	234,243	2,342,434	4	17.08
Mission Boulevard	Valle Vista Avenue	1,436	74,647	746,473	1	13.40
University Avenue	Bonar Street	11,175	581,113	5,811,127	7	12.05
Ardenwood Boulevard	Newark Boulevard	1,635	85,038	850,382	1	11.76
Ashby Avenue	Acton Street	3,395	176,557	1,765,572	2	11.33
International Boulevard	107th Avenue	3,985	207,243	2,072,429	2	9.65
High Street	East 12th Street	4,518	234,944	2,349,438	2	8.51
Ashby Avenue	Telegraph Avenue	13,587	706,539	7,065,390	6	8.49
San Pablo Avenue	Harrison Street	4,930	256,357	2,563,572	2	7.80
Paseo Padre Parkway	Mowry Avenue	7,849	408,169	4,081,694	3	7.35
Foothill Boulevard	15th Avenue	3,050	158,604	1,586,036	1	6.31
Mission Boulevard	Grove Way	3,126	162,552	1,625,523	1	6.15
Bancroft Avenue	Auseon Avenue	3,375	175,488	1,754,875	1	5.70
East 14th Street	Hasperian Boulevard	3,777	196,410	1,964,102	1	5.09
Ashby Avenue	Benvenue Avenue	16,272	846,125	8,461,253	4	4.73
International Boulevard	46th Avenue	12,303	639,752	6,397,522	3	4.69
International Boulevard	99th Avenue	12,387	644,112	6,441,117	3	4.66
Encinal Avenue	Oak Street	34,483	1,793,140	17,931,397	4	2.23
Encinal Avenue	Benton Street	11,075	575,884	5,758,839	1	1.74
Solano Avenue	Masonic Avenue	22,203	1,154,559	11,545,589	2	1.73
Webster Street	7th Street	44,452	2,311,483	23,114,835	4	1.73
College Avenue	Derby Street	24,986	1,299,269	12,992,689	2	1.54
Broadway	12th Street	112,896	5,870,590	58,705,898	5	0.85
Webster Street	21st Street	40,091	2,084,717	20,847,172	1	0.48
Doolittle Drive	Airport Access Road	323	16,783	167,829	0	N/A[d]
Broadway	Calhoun Street	2,553	132,738	1,327,378	0	N/A
Mowry Avenue	Cherry Lane	505	26,248	262,476	0	N/A
San Pablo Avenue	Ward Street	6,838	355,583	3,555,832	0	N/A
East 14th Street	Maud Avenue	6,811	354,187	3,541,866	0	N/A
Mission Boulevard	Nichols Avenue	577	30,017	300,172	0	N/A
Mission Boulevard	Overhill Drive	3,256	169,294	1,692,938	0	N/A
Foothill Boulevard	Cotter Way	3,535	183,841	1,838,408	0	N/A
Santa Clara Street	Ocie Way	2,141	111,335	1,113,354	0	N/A
Alvarado Niles Road	Western Avenue	1,181	61,402	614,021	0	N/A
Mandana Boulevard	Carlston Avenue	1,433	74,497	744,973	0	N/A
Martin Luther King, Jr., Way	17th Street	5,590	290,678	2,906,785	0	N/A
Moraga Avenue	Masonic Avenue	328	17,055	170,552	0	N/A
Owens Drive	Andrews Drive	1,999	103,930	1,039,296	0	N/A
Daugherty Road	Scarlett Drive	907	47,147	471,472	0	N/A
Amador Valley Boulevard	Stagecoach Road	1,099	57,167	571,668	0	N/A

(continued)

TABLE 5 *(continued)* **Preliminary Pedestrian Risk Analysis at 50 Study Intersections**

Mainline Roadway	Intersecting Roadway	Estimated Total Weekly Pedestrian Crossings[a]	Annual Pedestrian Volume Estimate[b]	10-Year Pedestrian Volume Estimate[b]	Reported Pedestrian Crashes (1996–2005)[c]	Pedestrian Crash Rate (crashes per 10,000,000 crossings)
Stoneridge Drive	Hacienda Drive	667	34,679	346,793	0	N/A
Chatham Road	13th Avenue	5,503	286,148	2,861,477	0	N/A
Total (for all 50 intersections)		462,841	24,067,724	240,677,241	89	
Mean (for all 50 intersections)		9,257	481,354	4,813,545	1.78	
Standard deviation (for all 50 intersections)		17,960	933,926	9,339,260	1.95	

[a]Total estimated weekly volume is adjusted for time of day, day of week, land use type, and weather.
[b]Annual and 10-year pedestrian volume estimates do not account for potential seasonal variations.
[c]Police-reported intersection pedestrian crashes were compiled by the Alameda County Public Health Department.
[d]N/A indicates that no crash rate could be estimated at locations with no crashes.

undercount was not related to pedestrian volume (e.g., as pedestrian volumes increased, the rate of undercount remained in the same range). This result is consistent with findings of the previous study (*4*). Therefore, there is no evidence to indicate that the distribution of hourly pedestrian volumes throughout the week should be adjusted. Although the total number of pedestrians recorded by a sensor over a week may be slightly lower than the true count, the proportion of pedestrians counted during each hour will remain the same. Therefore, the proportional adjustment of the manual count will still result in an accurate weekly volume estimate.

Although more than 98% of the hourly counts from the infrared sensors were included in the analysis without adjustment, some of the automated sensor data required cleaning. This cleaning was necessary because several incorrect counts were recorded due to bicycles parked in front of the counters, people standing in front of the counters, and people walking back and forth in front of the counters. Data entries were cleaned by comparing each hourly count with corresponding pedestrian counts at the same sensor and same hour of the week. If a count for a particular hour of one week was determined to be incorrect, the average value from the remaining weeks was substituted for further analysis.

Data from two of the automated pedestrian count sites were not used in the analysis. One of the counters was located within approximately 30 ft (9.1 m) of a bus stop. During times of the day with high bus ridership, some of the people waiting at the bus stop congregated around the pole where the automated counter was mounted. This situation resulted in regular overcounting at the site. Installation of one counter was delayed because of permit processing, so its data were not available at the time of analysis.

The assumption that the daily pattern of pedestrian sidewalk activity is similar to that of the adjacent intersection requires additional testing and validation. Future studies should compare the 24-h sidewalk counts with adjacent 24-h crossing counts to determine how much variation exists between these pedestrian volume distributions at different types of locations. Variation between pedestrian volume distributions for crosswalks and adjacent sidewalks may be due to differences in land use on each corner of the intersection, differences in the difficulty of crossing a particular intersection leg at different times of day, or other site-specific differences.

Other Considerations

Because this was an exploratory study conducted at a sample of locations, more research is needed to refine the factors that are used to account for time of day, surrounding land uses, and weather. The margin of error for the adjustment factors is unknown. In order to estimate the margin of error of the adjustment factors, the methodology will need to be repeated in other communities under different types of conditions.

Specifically, although the automated counters captured differences in daily pedestrian volume patterns in several different location types, there are likely to be other land use factors that affect pedestrian volume patterns. The activity near many schools, colleges, transit stations, tourist attractions, and waterfronts tends to occur at particular times of day. Further research is needed to identify and account for daily activity patterns near these types of pedestrian trip attractors.

More research is also needed to refine the adjustment factors for weather characteristics. For example, there was only one day with measurable rainfall in Alameda County between April 1 and July 10, 2008. This characteristic provided very few hourly data points to develop the pedestrian adjustment factor for rainfall. Additional data will be gathered in the future (including the rainy winter months) so that the effect of rain can be documented and used to develop more accurate estimates of pedestrian volumes for the entire year. More data from other times of year may also result in refined estimates of the impacts of temperature and cloud cover.

The effects of weather may be perceived differently in California than in other parts of the country. For example, temperatures below 50°F (10°C) are associated with lower pedestrian volumes in Alameda County, but in other parts of the United States pedestrian volumes may not be affected until much lower temperatures are reached. In addition, the range of weather conditions available for analysis in Alameda County rarely includes conditions such as thunderstorms, high winds, snow, and rapid fluctuations in temperature.

Gas prices may also affect pedestrian volumes, and gas price data were collected as a part of this study. During the 3 months that the automated counters were in operation, gas prices generally increased. Since people are more likely to be outside and to choose to walk during summer months, it was difficult to establish whether increasing pedestrian volumes were the result of summer weather or rising gas prices or both. More comparisons between gas prices and pedestrian volumes will be made in the future as seasonal trends are documented.

CONCLUSIONS

The methodology described demonstrates how data from automated counters can be used to extrapolate total weekly pedestrian intersection crossing counts from manual counts. Adjustments for temporal, surrounding land use, and weather factors are critical for developing accurate weekly pedestrian volumes. Although this exploratory analysis in Alameda County, California, presents preliminary adjustment factors, additional research is needed to identify the accuracy of these factors in different communities and under different conditions. Nonetheless, this methodological framework is useful for communities seeking to collect more accurate pedestrian volume data. Reliable weekly pedestrian volume estimates can be used by planners, engineers, designers, public health professionals, and others to improve the safety and convenience of pedestrian transportation.

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