Title
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ABSTRACT

Better data on pedestrian volumes are needed to improve the safety, comfort, and convenience of pedestrian movement. This requires more carefully-developed methodologies for counting pedestrians as well as improved methods of modeling pedestrian volumes. This paper describes the methodology used to create a simple, pilot model of pedestrian intersection crossing volumes in Alameda County, CA. The model is based on weekly pedestrian volumes at a sample of 50 intersections with a wide variety of surrounding land uses, transportation system attributes, and neighborhood socioeconomic characteristics. Three alternative model structures were considered, and the final recommended model has a good overall fit (adjusted-R^2=0.897). Statistically-significant factors in the model include the total population within a 0.5-mile radius, employment within a 0.25-mile radius, number of commercial retail properties within a 0.25-mile radius, and the presence of a regional transit station within a 0.1-mile radius of an intersection. The model has a simple structure, and it can be implemented by practitioners using geographic information systems and a basic spreadsheet program. Since the study is based on a relatively small number of intersections in one urban area, additional research is needed to refine the model and determine its applicability in other areas.

INTRODUCTION

Pedestrian street crossings are among the most common movements in urban transportation systems. People walk and use wheelchairs to go to work and school, access bus stops and train stations, patronize neighborhood stores, travel from automobile parking spaces to buildings, and participate in many other activities. It is important for planners, engineers, designers, public health professionals and others to have reliable estimates of pedestrian activity. Pedestrian volumes can be used to:

- Quantify pedestrian exposure in safety analyses (express pedestrian risk as the number 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)
- Guide the design of sidewalks, trails, median islands, and other facilities to serve anticipated pedestrian volumes (beyond meeting minimum accessibility requirements)
- Predict the number of pedestrian crossings that will occur after a land use development, roadway project, or transit service change is implemented
- Analyze whether or not a crosswalk will meet an engineering warrant for a pedestrian crossing signal or other crossing treatment
- Predict the amount of pedestrian traffic near commercial businesses.

Study Purpose

The purpose of this paper is to present a preliminary model of pedestrian intersection crossing volumes. While many variables for predicting pedestrian volumes were analyzed, the recommended pilot model has a simple structure. The model uses inputs that are available from common data sources (the US Census, local transit agencies, local roadway databases, aerial photographs, etc.), so it can be implemented by practitioners using geographic information systems and a simple spreadsheet program.

The results demonstrate that it is possible to use a relatively small sample of intersection pedestrian counts to develop a basic, initial predictive model of pedestrian activity for other intersections in an urban area. Since the analysis was conducted in one urban area (Alameda County, CA), more research is needed to refine the model equation and determine the applicability of the results for other communities.

PREVIOUS STUDIES

A variety of methods have been used to estimate or approximate pedestrian volumes. Overlay mapping techniques, or sketch-plan methods, such as the Latent Demand Score, are useful for planning and prioritization (*1,2,3,4,5,6*). However, they are not typically calibrated to actual pedestrian volume counts. Instead, they rank locations of pedestrian activity on a relative scale. Regional traffic volume models have also been modified to include walking as a mode choice (*7,8,9*). Yet these regional models typically base trip generation on the characteristics of traffic analysis zones (TAZs). Since many pedestrian trips are made within a TAZ, the geographic scale of analysis is too large to capture fine-grained differences in pedestrian activity at individual intersections.

Several pedestrian models have been developed using regression modeling techniques. Cameron estimated a model of mid-day and evening pedestrian activity on sidewalk segments in

Manhattan. Variables in the model included square footage of office, retail, and restaurant uses on block faces, sidewalk width, streets (east-west direction) versus avenues (north-south direction), and distance to subway entrances ($R^2 = 0.23$ to 0.61, depending on street orientation and time of day) (*10*). Benham and Patel predicted noon-hour pedestrian activity in Milwaukee based on the total square footage of commercial, office, cultural and entertainment, and storage and maintenance uses on adjacent block faces. These land use factors explained approximately 60 percent of the variation in pedestrian volumes (*11*). These models were limited to very dense, central business districts and specific times of day.

Space Syntax models also use regression modeling. They include street and pedestrian network characteristics such as connectivity (number of street segment connections to a given intersection node), mean depth (average number of street segments between a given node and any other node in the network), visibility (the area visible by direct lines of sight from any location in the street network), and relative asymmetry/integration (the number of turns that would be required to travel from a given point in the street network to any other point in the network). Applications of the Space Syntax model have predicted pedestrian flows with a high level of accuracy on 7,000 street segments and 670 intersections in Oakland ($R^2 = 0.77$)(*12*), 82 sample count locations predicting 468 street segments and intersections in Boston ($R^2 = 0.81$)(*13*), and 237 sample sidewalk blocks predicting volumes on 7,526 blocks in Central London ($R^2 = 0.82$)(*14*). However, Space Syntax requires special software, such as Fathom Visibility Graph Analysis Software (*15*).

The dependent variables used in previous models have included pedestrians crossing intersections and pedestrians using sidewalks. Pedestrian counts have been taken during specific observation periods throughout the day (*10,11,12,13,14*) (TABLE 1). These counts are often converted to typical hourly volumes. One study extrapolated two-hour pedestrian counts to annual volume estimates (*12*). However, few studies to date have used continuous counts to account for daily, weekly, and seasonal variations in pedestrian activity or capture the effects of weather and other factors on pedestrian volumes. Therefore, few models can produce accurate estimates of full day, complete week, or total annual pedestrian volumes.

Independent variables associated with pedestrian volumes include land use factors, transportation system attributes, and neighborhood socioeconomic characteristics (TABLE 1). Many studies over the last 15 years have identified variables that are associated with different levels of pedestrian activity (though not all of the variables have been included in pedestrian models). The results of these studies are summarized in several comprehensive literature reviews (*16,17,18,19*).

Several other factors have also been used to evaluate pedestrian activity in communities. Time and cost variables are found in regional transportation demand modeling and elasticity studies (*7,8*). Environmental factors, such as weather and topography, are also considered in several studies (*9,16,17,18,20*).

TABLE 1 Previous Research on Factors Associated with Pedestrian Volume

DEPENDENT VARIABLES		
Variable	**Time Period**	**Source (Year)**
Pedestrian volumes on sidewalk segments (block faces) in Manhattan	Instant captured in aerial photos during the mid-day and evening peak periods	Cameron (1976)
Pedestrian volumes on sidewalk segments (block faces) in Downtown Milwaukee	6-minute cnts. during the noon hr. extrapolated to the full hr.	Benham & Patel (1977)
Pedestrian volumes crossing intersections and using sidewalk segments in Oakland	Two-hr. morning and evening peak counts extrapolated to annual volume	Raford & Ragland (2004)
Pedestrian volumes crossing intersections and using sidewalk segments in Downtown Boston	5-minute counts extrapolated to morning, mid-day, evening peak hrs.	Raford & Ragland (2005)
Pedestrian volumes at mid-points of sidewalk segments in Central London	5-minute counts extrapolated to a one-hr. volume	Desyllas, et al. (2003)
INDEPENDENT VARIABLES		
Land Use Variable	**Relationship with Ped. Volume**	**Source(s)**
Nearby population density	+	Ewing & Cervero (2001), Handy (2005), Krizek (2003)
Nearby housing unit density	+	Krizek (2003)
Nearby employment density	+	Ewing & Cervero (2001), Handy (2005)
Nearby land use mix	+	Handy (2005), Shriver (1997)
Proximity to mixed-use buildings	+	Ewing & Cervero (2001)
Proximity to multi-story buildings	+	Ewing & Cervero (2001)
Proximity to commercial buildings	+	Ewing & Cervero (2001)
Proximity to parks	+	Ewing & Cervero (2001)
Proximity to activity destinations	+	Handy (2005)
Proximity to vacant lots	-	Ewing & Cervero (2001)
Nearby building setback distances	-	Shriver (1997)
Transportation System Variable	**Relationship with Ped. Volume**	**Source(s)**
Sidewalk presence on nearby streets	+	Ewing & Cervero (2001), Handy (2005)
Nearby sidewalk connectivity	+	Ewing & Cervero (2001), Shriver (1997)
Access to multi-use trails	+	Handy (2005)
Nearby multi-use trail connectivity	+	Shriver (1997)
Access to transit	+	Shriver (1997)
Nearby street network connectivity	+	Handy (2005), Shriver (1997)
Nearby intersection density	+	Ewing & Cervero (2001), Krizek (2003)
Nearby four-way intersections	+	Ewing & Cervero (2001)
Buffer between sidewalk and street on nearby streets	+	Ewing & Cervero (2001)
Presence of street trees on nearby streets	+	Ewing & Cervero (2001)
Presence of street lighting on nearby streets	+	Ewing & Cervero (2001), Handy (2005)
Nearby street block length	-	Ewing & Cervero (2001), Krizek (2003)
Amount of arterial roadways nearby	-	Ewing & Cervero (2001)
Auto speeds on nearby residential streets	-	Handy (2005)
Automobile parking spaces in nearby area	-	Ewing & Cervero (2001)
Difficulty of crossing nearby streets	-	Ewing & Cervero (2001)
Socioeconomic Variable	**Relationship with Ped. Volume**	**Source(s)**
Student status	+	Shriver (1997)
Larger household of unrelated individuals	+	Shriver (1997)
Household automobile availability	-	Handy (2005), Shriver (1997)
Household income	-	Shriver (1997)
Age	-	Shriver (1997)

The literature indicates that there is a need for a pedestrian volume model that incorporates land use, transportation system, socioeconomic, and other factors. Ideally, this model should be able to predict the pedestrian volume at specific locations for an entire day, week, or year. The approach used in this study addresses both of these needs. First, a thorough method was used to develop accurate pedestrian counts. Second, a large number of possible explanatory factors were documented and considered in the statistical modeling process. In addition, the recommended pilot model has a simple structure that will make it straightforward for practitioners to test.

METHODOLOGY

This section describes the study area and methodology used to develop the pedestrian crossing model. The model is based on pedestrian counts taken at 50 intersections along arterial and collector roadways in Alameda County, CA.

Study Area

Alameda County, CA is part of the San Francisco Bay Metropolitan Region. The county (Census Bureau 2007 estimated population 1.46 million) is an excellent location for this pilot study because it includes urban, suburban, and exurban communities—many of the built environments in the county can be found throughout the United States. Oakland is the largest city in the county (population 401,000). Alameda County includes the Oakland central business district and other downtown commercial areas, clusters of neighborhood retail shops as well as larger malls, mixed and single-use zoning, various street patterns, bus and rail transit systems, and a population with a wide range of socioeconomic characteristics. According to Census 2000, approximately 51 percent of residents referred to themselves as White, 27 percent Asian, 21 percent Hispanic or Latino, and 14 percent Black. Twenty-four percent of residents are under age 18, 11 percent are over age 64, and 13 percent have some type of disability (*21*).

Intersection Selection

The selection of intersection sites for pedestrian volume counts is critical for developing an unbiased model. Previous modeling efforts that have been based on existing counts may reflect the bias in how those locations were chosen (e.g., communities often take counts at locations with the highest pedestrian volumes or locations of interest to residents or advocacy groups, so a model based on these locations may not represent other types of locations very well). In contrast, this study used a deliberate process to select sites with a wide range of pedestrian volumes, as well as locations surrounded by diverse land use, transportation system, and neighborhood socioeconomic characteristics.

A strategic sampling process was used to select the 50 intersections for this study. First, 30 intersections were selected from all 528 intersections along state-maintained arterial roadways. These 528 intersections were divided into high (highest third), moderate (middle third), and low (lowest third) categories for three variables: population density, median income, and proximity to commercial properties. This resulted in 27 different strata (e.g., Population Density = High, Median Income = High, Commercial Retail = High; Population Density = High, Median Income = Medium, and Commercial Retail = Low; etc.). One intersection was to be chosen from each of these strata. Since two of the strata did not contain any intersections

(Population Density = High, Median Income = Low, Commercial Retail = Low and Population Density = Medium, Median Income = Low, Commercial Retail = Low), one intersection was chosen from each of the 25 strata that were represented. Five additional intersections were chosen randomly from five different strata to complete the initial sample of 30 state-maintained roadway intersections. Counts at these intersections were funded by the state department of transportation.

The 20 remaining intersections for the study were selected from a total of 6,938 intersections (6,902 roadway intersections and 36 major roadway/multi-use trail intersections) along other (non-state-maintained) arterial and collector roadways in Alameda County. Several constraints were placed on the selection of these 20 intersections to ensure variation in land use and transportation system characteristics surrounding the selected points:

- At least four intersections needed to be in the Oakland, Fremont, Hayward, or Berkeley central business districts.
- At least two intersections needed to be where major multi-use trails crossed roadways.
- At least three intersections needed to be in each of the four county planning areas (North, Central, South, and East).

Counts at these 20 intersections were funded by the county transportation authority.

Additionally, the following rules were used to select all 50 intersection points:

- No intersection could be located within 0.25-mile (402 m) of any other selected intersection. This was done to limit spatial autocorrelation (observations at adjacent intersections may not be independent because the same people have a high likelihood of crossing both intersections).
- Intersections were required to have a population density of at least 50 residents per square mile within a 0.25-mile (402 m) buffer to be considered for selection. Low-density areas are likely to have very sparse, variable pedestrian activity, which is difficult to model. This ruled out 485 intersections.
- Intersections needed to be at least 0.25-mile (402 m) from an adjacent county border in order to reduce the amount of data needed from surrounding counties. This ruled out 104 intersections.
- Offset intersections were considered to be a single intersection if the centerline of one intersection was within 20 feet (6.10 m) of the center of the other intersection. Otherwise, they were counted as two separate intersections.
- Intersections undergoing construction were not considered.
- Grade-separated intersections were not considered.

The 50 selected intersections had a wide variety of characteristics and were spread throughout the county (FIGURE 1). While there was significant variation between sites, the average values were similar to the county as a whole (descriptive statistics are provided in TABLE 2). The selected intersections included:

- 9 intersections within 0.5-miles (805 m) of a Bay Area Rapid Transit (BART) station
- 20 intersections within 0.25-miles (402 m) of a elementary, middle, or high school
- 33 intersections with sidewalks on both sides of all roadways within 0.25-miles (402 m)
- 4 trail/roadway intersections

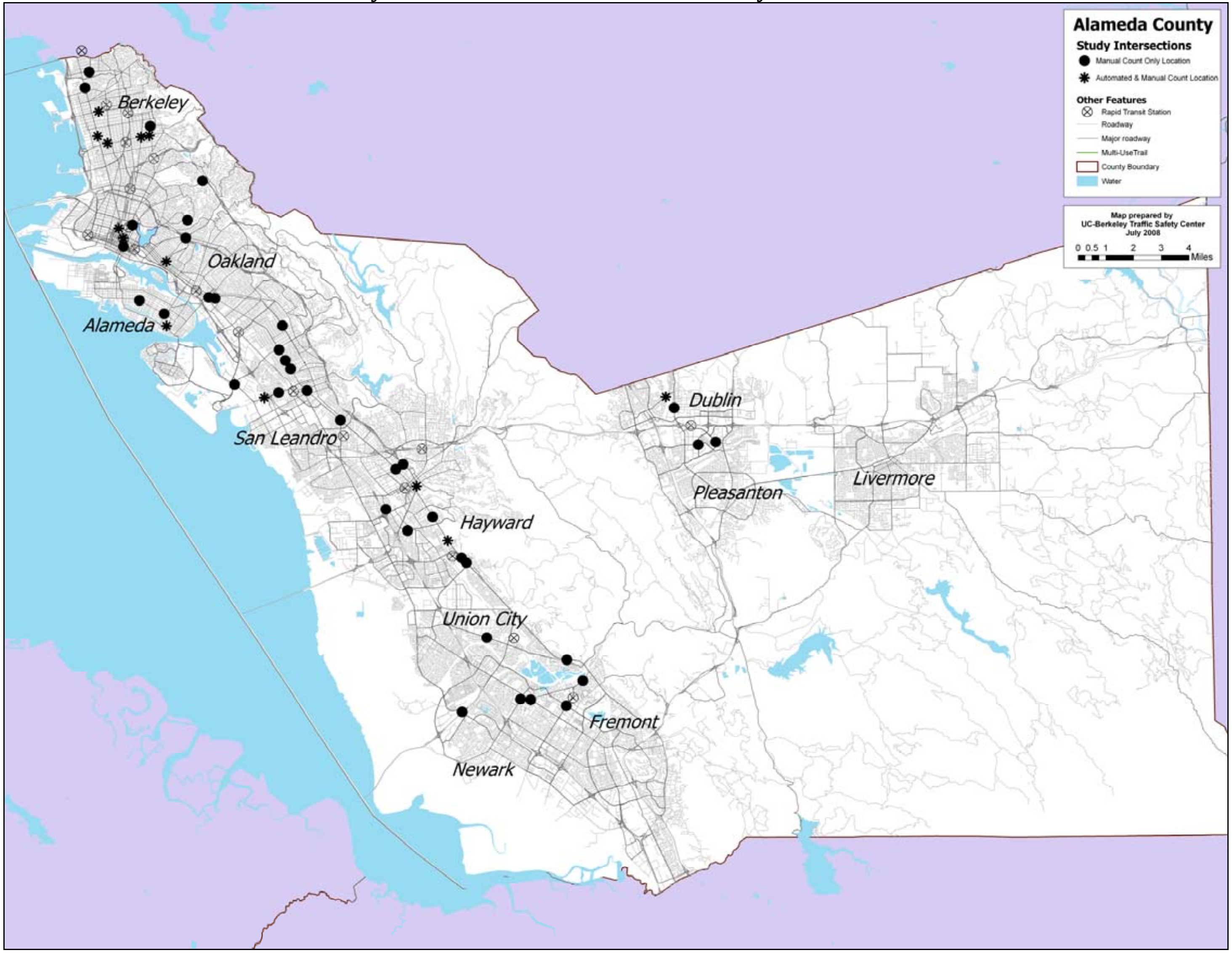
- 6 central business district intersections
    - Oakland (4)
    - Hayward
    - Fremont
- Intersections in neighborhoods with a wide range of socioeconomic characteristics (within 0.25-miles (402 m))
    - Between 45.5 and 56.0 percent male
    - Between 7.42 and 36.4 percent under age 18
    - Between 5.55 percent and 91.2 percent rental housing
    - Median incomes between $14,600 and $114,000 per year (1999 dollars)
- A variety of site characteristics, including number of travel lanes, traffic volumes, speed limits, median islands, curb radii, and types of traffic control.

Pedestrian Crossing Counts

One of the overall goals of the study was to evaluate intersection exposure to vehicle-pedestrian collisions. Therefore, pedestrian counts were taken at intersection pedestrian crossings. While pedestrian counts along sidewalk segments are important for planning and prioritization, pedestrians are typically exposed to the risk of collision and injury when crossing the street. Further, the study focused on pedestrians crossing arterial and collector roadway intersections because these roadways often have the most activity destinations for pedestrians, highest motor vehicle volumes, most popular bus lines, and most challenging pedestrian crossings. Intersections of two local streets were not evaluated.

Any pedestrian who crossed within a crosswalk or within 50 feet (15.2 m) of either side of any marked or unmarked crosswalk was counted (this included people walking their bicycle across the street, babies being carried, and individual pedestrians crossing each intersection leg multiple times, but it did not include skateboarders, in-line skaters, or people riding bicycles). Each leg of the intersection was counted separately and summed to derive the total pedestrian volume. Midblock crossings (more than 50 feet (15.2 m) from the intersection crosswalk) were not observed during this analysis. Midblock counts require data collectors to focus simultaneously at the intersection and further down all approaching roadways. This is difficult to do accurately without additional data collectors at midblock locations.

FIGURE 1 Locations of 50 Study Intersections in Alameda County



A single pedestrian was counted multiple times at the same intersection if he or she crossed more than one leg. Right-turning pedestrians on the sidewalk were not counted because they did not cross the roadway. At "T-intersections" there are only three roadway crossings. However, pedestrians using the sidewalk on the fourth side of the intersection were counted as long as they walked at least half of the "crossing" distance on that leg. This made it possible to make direct comparisons between the total intersection volumes at 3- and 4-way intersections.

Two separate manual counts were taken at each study intersection between April and June 2008. One was a weekday count (Tuesday, Wednesday, or Thursday) and the other was a Saturday count. All manual count periods were two hours long, from 9:00 a.m. to 11:00 a.m., 12:00 p.m. to 2:00 p.m., or 3:00 p.m. to 5:00 p.m. These time periods were chosen because they were expected to have the most consistent pedestrian travel patterns from week to week.

Daily, Weekly, and Seasonal Pedestrian Volume Patterns

It is critical to understand hourly, daily, weekly, and seasonal variations in pedestrian and bicycle activity at different sites in order to interpret count data correctly (*21,22,23,24*). The peak hour period for pedestrian travel may not be the same at all locations, even within the same neighborhood. Near a school, the peak hour may be from 3:00 p.m. to 4:00 p.m.; in a restaurant district, the peak hour may be from 7:00 p.m. to 8:00 p.m. Several studies have classified daily distributions of pedestrian volumes into different categories based on land use type. Classifications have been based on the type of pedestrian activity near a count location, including shopper, employee, visitor, commuter, mixed, or special (*21*) and on the location of a count site within a region, including central business district, residential, or fringe area (*23*). A study of 14 count sites in Washington, DC found six distinct pedestrian volume distribution patterns (*22*).

EcoCounter Dual Infrared Pyroelectric pedestrian sensors were used to extrapolate the two-hour weekday and Saturday manual counts to average daily, weekly, and annual pedestrian volumes. Between April and June 2008, these devices were rotated among a set of 13 of the 50 locations to identify different patterns of pedestrian activity (FIGURE 1).

The infrared counters were installed to count pedestrians on the sidewalk near the intersection (i.e., within approximately 100 feet of the intersection). This is because the technology is not suitable for counting pedestrians crossing the street. Therefore, it was assumed that the daily pattern of sidewalk activity was nearly identical to the daily pattern of pedestrian activity in the crosswalks. The infrared sensors tend to undercount pedestrians slightly, most likely because they do not detect pedestrians walking exactly side-by-side.

To address undercounting, the sensor counts were tested against manual counts during several different time periods. This comparison revealed undercounting between one and 20 percent, similar to a previous evaluation of the same technology (*25*). There was no evidence that rate of undercounting was related to pedestrian volume. Therefore, undercounting was assumed to have no effect on the daily pedestrian volume distributions used in the analysis (e.g., a given time period represents the same percentage of the total daily volume, regardless of how much each hour is undercounted, since the rate of undercounting is the same throughout the day).

Reliable counts were gathered at 11 of the 13 infrared sensor locations. The analysis identified differences in pedestrian volume patterns near employment centers, residential areas, neighborhood commercial areas, and multi-use trails. Adjustments were made to account for these differences at all 50 study intersections. The two-hour manual counts were also adjusted to account for differences in time (e.g., time of day, day of week) and weather (e.g., cloud cover, temperature).

Extrapolated weekly pedestrian crossing volume at each intersection was the dependent variable used in the pilot model. Weekly pedestrian volumes ranged from 323 at an intersection surrounded by open space, hotel, and industrial land uses near Oakland International Airport to 113,000 at an intersection in the Oakland central business district. For all 50 intersections, the average weekly pedestrian volume was 9,260 (standard deviation = 18,000).

A more extensive description of the pedestrian counting methodology used for this study is provided in the paper, "A Methodology for Counting Pedestrians at Intersections: Using Automated Counters to Extrapolate Weekly Volumes from Short Manual Counts" (*26*).

ANALYSIS

This section describes the data analysis process used to estimate regression models and recommend one of the alternatives as the final pilot model. After the pedestrian count data were extrapolated to weekly volume estimates (described above), four main steps were followed: 1) screen all of the potential explanatory variables and do not consider any variables that do not have a relatively high correlation with pedestrian volume, 2) screen the remaining explanatory variables for collinearity and avoid including highly-correlated variables in the same model, 3) choose three alternative model structures that had a good overall fit and statistically-significant explanatory variables to compare, and 4) examine the three alternatives and recommend one preferred pilot model.

Regression Modeling

Ordinary least squares (OLS) regression was used to develop the pedestrian crossing volume model. The modeling process tested the statistical relationship between weekly pedestrian crossings at each intersection and a range of land use, transportation system, socioeconomic, and intersection site characteristics. More than 50 variables were reviewed for inclusion in the model (TABLE 2). The land use factors, transportation system attributes, and socioeconomic characteristics were gathered from the area surrounding each intersection. Three different buffer radii were used: 0.1 miles (161 m), 0.25 miles (402 m), and 0.5 miles (805 m) (most of the 0.5-mile variables are omitted from Table 2). Few previous studies have examined the distances at which specific variables influence pedestrian volumes. Using several different radii for each variable makes it possible to explore this issue.

TABLE 2 (Part 1) Land Use and Transportation System Variables Considered for the Pedestrian Volume Model

LAND USE VARIABLES

		50 Study Intersections (N = 50)				All Major Street Intersections (N = 8055)				
Variable Name	**Description**	**Mean**	**Std. Dev.**	**Min.**	**Max.**	**Mean**	**Std. Dev.**	**Min.**	**Max.**	**Data Source (Year)**
TOTPOP_T	Total population within 1/10-mile (161 m)	291	156	7.03	614	265	208	0.0658	1700	U.S. Census (2000)
TOTPOP_Q	Total population within 1/4-mile (402 m)	1880	869	254	3670	1640	1180	0.390	7430	U.S. Census (2000)
TOTPOP_H	Total population within 1/2-mile (805 m)	7500	3290	798	15100	6410	4140	1.96	21700	U.S. Census (2000)
TOTEMP_T	Total employment within 1/10-mile (161 m)	315	764	1.54	4170	151	350	0.896	4190	SF MTC[6](2005)
TOTEMP_Q	Total employment within 1/4-mile (402 m)	1660	3510	9.60	18900	930	1930	5.60	19600	SF MTC[6](2005)
PCTVAC_T	Proportion of housing units within 1/10-mile (161 m) that are vacant	0.0398	0.028	0.00673	0.122	0.0373	0.0349	0.00	0.371	U.S. Census (2000)
PCTVAC_Q	Proportion of housing units within 1/4-mile (402 m) that are vacant	0.0385	0.026	0.00849	0.106	0.0366	0.0325	0.00	0.290	U.S. Census (2000)
TOTVAC_T	Number of housing units within 1/10-mile (161 m) that are vacant	5.22	5.66	0.127	29.7	4.13	5.51	0.00	75.9	U.S. Census (2000)
TOTVAC_Q	Number of housing units within 1/4-mile (402 m) that are vacant	32.1	28.5	1.58	124	25.4	30.2	0.00	316	U.S. Census (2000)
PCTRENT_T	Proportion of housing units within 1/10-mile (161 m) that are rented	0.549	0.198	0.0560	0.923	0.449	0.254	0.00	1.00	U.S. Census (2000)
PCTRENT_Q	Proportion of housing units within 1/4-mile (402 m) that are rented	0.544	0.186	0.0555	0.912	0.45	0.244	0.00	1.00	U.S. Census (2000)
TOTRENT_T	Number of housing units within 1/10-mile (161 m) that are rented	69.4	52.1	3.39	230	60.0	76.8	0.00	970	U.S. Census (2000)
TOTRENT_Q	Number of housing units within 1/4-mile (402 m) that are rented	453	310	22.0	1240	369	427	0.00	2850	U.S. Census (2000)
NCOMPROP_T	Number of commercial properties within 1/10-mile (161 m)	6.66	8.11	0.00	40.0	3.48	6.04	0.00	48.0	Alameda Co. Assessor (2007)
NCOMPROP_Q	Number of commercial properties within 1/4-mile (402 m)	25.3	26.5	0.00	50.0	15.3	20.6	0.00	134	Alameda Co. Assessor (2007)
NESCH_T	Number of elementary schools within 1/10-mile (161 m)	0.0400	0.196	0.00	1.00	0.049	0.22	0.00	2.00	Alameda Co. Assessor (2007)
NESCH_Q	Number of elementary schools within 1/4-mile (402 m)	0.320	0.508	0.00	2.00	0.307	0.53	0.00	3.00	Alameda Co. Assessor (2007)
NMSCH_T	Number of middle schools within 1/10-mile (161 m)	0.00	0.00	0.00	0.00	0.00857	0.0922	0.00	1.00	Alameda Co. Assessor (2007)
NMSCH_Q	Number of middle schools within 1/4-mile (402 m)	0.08	0.337	0.00	2.00	0.0567	0.233	0.00	2.00	Alameda Co. Assessor (2007)
NHSCH_T	Number of high schools within 1/10-mile (161 m)	0.00	0.00	0.00	0.00	0.00372	0.0609	0.00	1.00	Alameda Co. Assessor (2007)
NHSCH_Q	Number of high schools within 1/4-mile (402 m)	0.0400	0.196	0.00	1.00	0.0539	0.232	0.00	2.00	Alameda Co. Assessor (2007)
NTSCH_T	Number of elem., middle, high, and other schools within 1/10-mile (161 m) [1]	0.060	0.237	0.00	1.00	0.0683	0.260	0.00	2.00	Alameda Co. Assessor (2007)
NTSCH_Q	Number of elem., middle, high, and other schools within 1/4-mile (402 m)[1]	0.480	0.700	0.00	3.00	0.458	0.669	0.00	4.00	Alameda Co. Assessor (2007)
COLDUM_T	Presence of college campus within 1/10-mile (161 m) (Yes=1, No=0)	0.00	0.00	0.00	0.00	0.0283	0.166	0.00	1.00	Alameda Co. Assessor (2007)
COLDUM_Q	Presence of college campus within 1/4-mile (402 m) (Yes=1, No=0)	0.00	0.00	0.00	0.00	0.0622	0.242	0.00	1.00	Alameda Co. Assessor (2007)

TRANSPORTATION SYSTEM VARIABLES

		50 Study Intersections (N = 50)				All Major Street Intersections (N = 8055)				
Variable Name	**Description**	**Mean**	**Std. Dev.**	**Min.**	**Max.**	**Mean**	**Std. Dev.**	**Min.**	**Max.**	**Data Source (Year)**
NBARTSTA_T	Number of regional rail transit stations within 1/10-mile (161 m)	0.0200	0.140	0.00	1.00	0.00993	0.0992	0.00	1.00	SF MTC[6](2007)
NBARTSTA_Q	Number of regional rail transit stations within 1/4-mile (402 m)	0.0400	0.196	0.00	1.00	0.0467	0.212	0.00	2.00	SF MTC[6](2007)
NBUSSTOP_T	Number of bus route stops within 1/10-mile (161 m)[2]	12.9	17.1	0.00	118	8.64	11.4	0.00	135	SF MTC[6](2007)
NBUSSTOP_Q	Number of bus route stops within 1/4-mile (402 m)[2]	47.4	55.9	2.00	335	36.1	39.8	0.00	337	SF MTC[6](2007)
TRAILMI_T	Total multi-use trail centerline distance (miles) within 1/10-mile (161 m)	0.0258	0.0765	0.00	0.365	0.014	0.0558	0.00	0.609	SF MTC[6](2007)
TRAILMI_Q	Total multi-use trail centerline distance (miles) within 1/4-mile (402 m)	0.0916	0.262	0.00	1.32	0.0719	0.207	0.00	1.78	SF MTC[6](2007)
STREETMI_T	Total street centerline distance (miles) within 1/10-mile (161 m)	0.939	0.287	0.227	1.53	0.758	0.254	0.00	2.34	SF MTC[6](2007)
STREETMI_Q	Total street centerline distance (miles) within 1/4-mile (402 m)	5.64	1.43	2.23	9.40	4.70	1.57	0.278	10.5	SF MTC[6](2007)
BL_MI_T	Total centerline (miles) of streets with bicycle lanes within 1/10-mile (161 m)	0.101	0.157	0.00	0.471	0.086	0.153	0.00	0.936	SF MTC[6](2007)
BL_MI_Q	Total centerline (miles) of streets with bicycle lanes within 1/4-mile (402 m)	0.321	0.365	0.00	1.10	0.327	0.443	0.00	2.20	SF MTC[6](2007)
FWY_DUM_T	Freeway presence within 1/10-mile (161 m) (Yes = 1, No = 0)	0.120	0.325	0.00	1.00	0.168	0.374	0.00	1.00	SF MTC[6](2007)
FWY_DUM_Q	Freeway presence within 1/4-mile (402 m) (Yes = 1, No = 0)	0.180	0.384	0.00	1.00	0.302	0.459	0.00	1.00	SF MTC[6](2007)
SWCOV_Q	Est. sidewalk coverage (0.00,0.25,0.50,0.75,1.00) within 1/4-mile (402 m)[3]	0.875	0.195	0.25	1.00	Not calculated[5]				Google Earth® (2008)
SWBUF_Q	Est. prop. of sidewalks with buffer (0.00,0.25,0.50,0.75,1.00) within 1/4-mile[4]	0.525	0.288	0.00	1.00	Not calculated[5]				Google Earth® (2008)

1) Total schools does not include colleges. Colleges are included in a separate variable.
2) The number of "bus route stops" is the sum of the number of different bus routes servicing each bus stop within a given distance of the intersection (e.g., if 4 routes service a single bus stop, that particular bus stop will be counted 4 times).
3) Sidewalk coverage is estimated from aerial photography. 100% coverage (1.00) is sidewalks on both sides of all surface streets within 1/4-mile of the intersection. Sidewalks on only one side of all streets would be considered 50% coverage (0.50).
4) Sidewalk buffer is estimated from aerial photography. 100% buffer (1.00) indicates that the sidewalks on both sides of all surface streets are separated from the edge of the roadway by a grass, tree, shrub, or other type of buffer. If
5) Detailed intersection characteristics were not gathered for all roadways in Alameda County. Because of cost, these characteristics would only be collected if they were significant in the final regression model.
6) SF MTC = San Francisco Bay Area Metropolitan Transportation Commission.

TABLE 2 (Part 2) Neighborhood Socioeconomic and Intersection Site Variables Considered for the Pedestrian Volume Model

NEIGHBORHOOD SOCIOECONOMIC VARIABLES

		50 Study Intersections (N = 50)				All Major Street Intersections (N = 8055)				
Variable Name	**Description**	**Mean**	**Std. Dev.**	**Min.**	**Max.**	**Mean**	**Std. Dev.**	**Min.**	**Max.**	**Data Source (Year)**
PCTWHITE_T	Proportion of population within 1/10-mile (161 m) that is white	0.461	0.202	0.0401	0.822	0.495	0.234	0.0233	1.00	U.S. Census (2000)
PCTWHITE_Q	Proportion of population within 1/4-mile (402 m) that is white	0.463	0.196	0.0655	0.822	0.492	0.232	0.0364	0.920	U.S. Census (2000)
PCTMALE_T	Proportion of population within 1/10-mile (161 m) that is male	0.489	0.0286	0.421	0.556	0.492	0.0319	0.231	0.742	U.S. Census (2000)
PCTMALE_Q	Proportion of population within 1/4-mile (402 m) that is male	0.492	0.0222	0.455	0.560	0.491	0.0271	0.356	0.679	U.S. Census (2000)
PCT0VEH_T	Proportion of households within 1/10-mile (161 m) that have no automobile	0.168	0.168	0.0138	0.769	0.124	0.13	0.00	0.802	U.S. Census (2000)
PCT0VEH_Q	Proportion of households within 1/4-mile (402 m) that have no automobile	0.159	0.150	0.0150	0.638	0.126	0.127	0.00	0.738	U.S. Census (2000)
TOT0VEH_T	Total households within 1/10-mile (161 m) that have no automobile	23.2	36.2	0.299	182	18.3	31.3	0.00	483	U.S. Census (2000)
TOT0VEH_Q	Total households within 1/4-mile (402 m) that have no automobile	148	200	2.06	964	112	172	0.00	1600	U.S. Census (2000)
MEDINC_T	Median income (1999 dollars) of households within 1/10-mile (161 m)[1,2]	47800	21000	122	107500	59700	27900	122	167000	U.S. Census (2000)
MEDINC_Q	Median income (1999 dollars) of households within 1/4-mile (402 m)[1,2]	49400	20300	14600	114000	59600	27200	1051	169400	U.S. Census (2000)
PCTU18_T	Proportion of population within 1/10-mile (161 m) that is under 18 years old	0.223	0.0675	0.0563	0.372	0.234	0.0728	0.00872	0.626	U.S. Census (2000)
PCTU18_Q	Proportion of population within 1/4-mile (402 m) that is under 18 years old	0.223	0.0633	0.0742	0.364	0.236	0.0694	0.0112	0.625	U.S. Census (2000)
PCTO64_T	Proportion of population within 1/10-mile (161 m) that is over 64 years old	0.117	0.0776	0.0245	0.423	0.108	0.0573	0.00	0.502	U.S. Census (2000)
PCTO64_Q	Proportion of population within 1/4-mile (402 m) that is over 64 years old	0.114	0.0631	0.0245	0.340	0.108	0.0508	0.00	0.394	U.S. Census (2000)

INTERSECTION SITE VARIABLES

		50 Study Intersections (N = 50)				All Major Street Intersections (N = 8055)				
Variable Name	**Description**	**Mean**	**Std. Dev.**	**Min.**	**Max.**	**Mean**	**Std. Dev.**	**Min.**	**Max.**	**Data Source (Year)**
CONTROLDUM	Either traffic signal or stop sign controling mainline roadway (Yes=1, No=0)[3]	0.560	0.496	0.00	1.00	Not calculated[7]				Field observation (2008)
MAXADT	Max. average daily traffic volume on a roadway passing through intersection	24000	12200	3000	55000	Not calculated[7]				CA DOT (2007); local municipalities[8]
MAIN_WIDTH	Average curb-to-curb length (feet) of the 2 crosswalks across the mainline ro	79.2	27.8	29.0	163	Not calculated[7]				Field obs., Google Maps® (2008)
MAIN_LANES	Average number of lanes on mainline approaches to the intersection[3,4]	4.44	1.47	2.00	8.50	Not calculated[7]				Field obs., Google Maps® (2008)
MAIN_XW	Number of marked crosswalks across the mainline roadway[3]	1.30	0.755	0.00	2.00	Not calculated[7]				Field obs., Google Maps® (2008)
MAIN_MED	Median refuge area present for at least one mainline roadway crosswalk[3]	0.580	0.494	0.00	1.00	Not calculated[7]				Field obs., Google Maps® (2008)
MAIN_BL	Bicycle lanes on at least one mainline approach to intersection[3]	0.260	0.439	0.00	1.00	Not calculated[7]				Field obs., Google Maps® (2008)
CURBRADCAT	Curb radius category (<15 feet (<4.57 m)=1, 15-25 feet=2, >25 feet (>7.62 m)	1.90	0.806	1.00	3.00	Not calculated[7]				Field obs., Google Maps® (2008)
TINTER	Intersection is a "T" intersection (Yes=1, No=0)[6]	0.240	0.427	0.00	1.00	Not calculated[7]				Field obs., Google Maps® (2008)

1) Median income is calculated as the weighted average of median incomes reported for the census block groups surrounding the intersection. Weights are assigned based on the proportion of the census block group within the specific buffer diatance from the intersection.
2) Several census block groups did not have data for median income. Intersections with a median income of 0 within the given buffer distance considered in this statistical summary.
3) Mainline roadway is the intersecting roadway with the higher traffic volume.
4) Average number of lanes on each mainline approach includes all through-, left-, and right-turn lanes.
5) Curb radius category reflects the average estimated curb radius of all corners at the intersection.
6) "T" intersections are 3-way intersections. Intersections were not considered to be "T" intersections if the fourth approach was a commercial driveway.
7) Detailed intersection characteristics were not gathered for all roadways in Alameda County. Because of cost, these characteristics would only be collected if they were significant in the final regression model.
8) Traffic volume data were gathered from Alameda (2004), Berkeley (2000-2007), Dublin (2000-2007), Fremont (2005), Hayward (2003-2008), Livermore (2007), Pleasanton (2007), and Oakland (2007).

With a sample size of 50 intersections, it is not possible to include all of the potential independent variables in the model. Variables were selected for the model or removed from consideration using several steps. First, variables with a low correlation ($|\rho|<0.4$) with the dependent variable (e.g., number of weekly pedestrian crossings) were removed. Then, correlations between the remaining independent variables were analyzed. Independent variables with high correlation coefficients ($|\rho|>0.7$) were not included in the same model. Finally, several OLS models were estimated. The three models with the best balance of statistically-significant independent variables, overall model fit, and intuitive coefficients were selected as final alternatives.

Model Alternatives

Three alternative model structures were considered when choosing the final recommended model (TABLE 3). All three models have a good overall fit. The adjusted R^2-values are between 0.87 and 0.91, and F-tests show that each model is significant at greater than the 99 percent confidence level. Model A shows that weekly pedestrian volume at an intersection is higher when there is more population within 0.5-miles (805 m), more employment within 0.25-miles (402 m), more commercial properties within 0.25-miles (402 m), a regional transit station within 0.10-miles (161 m), and a lower percentage of the population under age 18 within 0.25-miles (402 m). For example, the NCOMPROP_Q variable coefficient means that for each additional commercial property within 0.25-miles (402 m) of an intersection, it will, on average, have approximately 106 more pedestrian crossings per week. Most of these factors have also been identified in previous studies. Neighborhoods with a greater percentage of children under age 18 may have lower pedestrian volumes at arterial and collector roadway intersections because parents may be cautious about letting their children cross these types of busy streets.

Model B is similar to Model A, but it does not include the variable for percentage of the surrounding population that is under age 18. As a result, Model B may be easier for practitioners to use than Model A since it does not require gathering neighborhood-level age data from census files.

Model C uses many of the same types of variables as the other two models, but the distance thresholds are different. Population and commercial properties are evaluated at a distance of 0.10-miles (161 m), and a 0.25-mile (402 m)-distance is used for proximity to a regional transit station. The total number of bus stops within 0.10-miles is also included in this model. Model C has several disadvantages. While the smaller buffer areas provide more localized population and commercial property information, these variables may not work well in larger-scale suburban areas. For example, commercial retail properties in malls may be more than 0.10 miles (161 m) from adjacent intersections. In addition, data on the total number of bus route stops (each bus line is counted separately) may be difficult to gather.

TABLE 3 Alternative Pedestrian Volume Model Specifications

Dependent Variable = Total Weekly Pedestrian Intersection Crossings						
	Model A		**Model B**		**Model C**	
Model Variables	**Coeff.**	**(Std. Err.)^1**	**Coeff.**	**(Std. Err.)^1**	**Coeff.**	**(Std. Err.)^1**
CONSTANT	4170	(4270)	-4910	(2050)**	-5790	(1990)***
TOTPOP_T					14.5	(7.19)**
TOTPOP_H	0.884	(0.254)***	0.928	(0.266)***		
TOTEMP_Q	1.72	(0.400)***	2.19	(0.367)***		
NCOMPROP_T					456	(118)***
NCOMPROP_Q	106	(39.0)***	98.4	(40.8)**		
NBARTSTA_T	56,800	(7810)***	54,600	(8160)***		
NBARTSTA_Q					44,800	(6280)***
NBUSSTOP_T					465	(81.4)***
PCTU18_Q	-36,400	(15,200)**				
Overall Model						
Sample Size (N)	50		50		50	
Adjusted R^2	0.907		0.897		0.870	
F-Test	96.6***		108***		83.2***	

1) Significance is indicated by asterisks: *** indicates significant at 99% ($\rho<0.01$), ** indicates significant at 95% ($\rho<0.05$), * indicates significant at 90% ($\rho<0.10$)

The model residuals (difference between predicted volume and observed volume at each intersection) were also graphed for all three models. Differences in predicted and observed values ranged between almost zero to less than 20,000 pedestrian crossings per week (FIGURE 2). None of the three residual patterns suggested that one model was better or worse than the others.

While all three models could be used, Model B was recommended because it is has a good overall model fit, includes statistically significant and logical independent variables, and can be estimated using readily-available data.

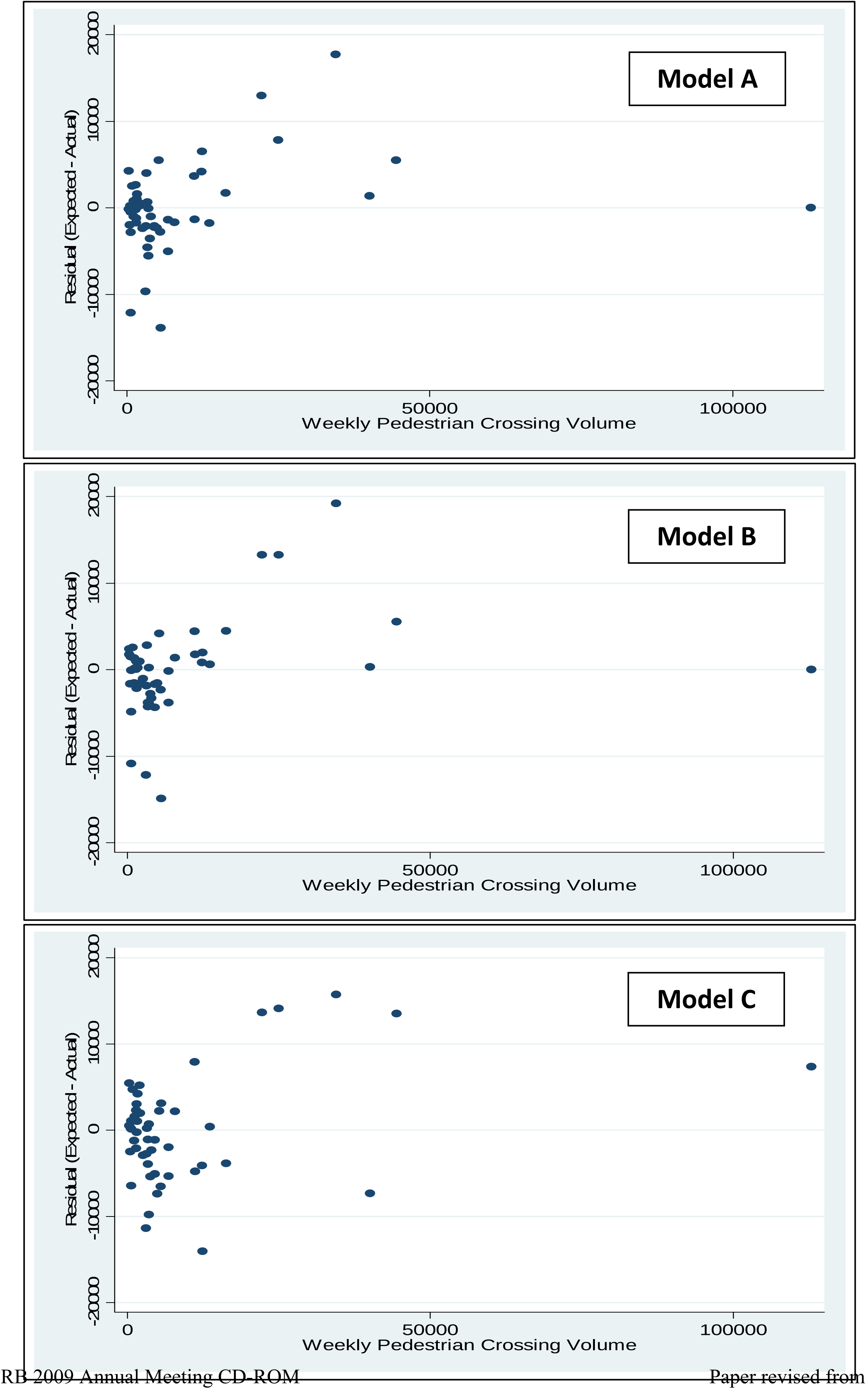
RESULTS

The recommended pilot pedestrian intersection crossing model has the following form:

Total pedestrian intersection crossings per week =
0.928 * Total population within 0.5-miles of the intersection
+ 2.19 * Total employment within 0.25-miles of the intersection
+ 98.4 * Number of commercial retail properties within 0.25-miles of the intersection
+ 54,600 * Number of regional transit stations within 0.10-miles of the intersection
- 4910 (1)

The adjusted R^2-value of the model is 0.897, and the F-test is significant at a 99.9 percent confidence level. All of the independent variables in the recommended model are statistically significant at the 95 percent confidence level and have a logical interpretation.

FIGURE 2 Residual Analysis for Three Alternative Pedestrian Volume Models



Validation

An important next step in the modeling process will be to test the predictive accuracy of the model at other intersections in Alameda County. This will require collecting comparison counts using a methodology identical to the approach used in this study. While new counts are needed, several counts from the past six years were available in different parts of Alameda County. Of hundreds of previous counts, only 46 included a clear description of the number of crossings at each intersection and the time of day and day of week when the count was taken. Important information about the specific data collection methods (e.g., how close to the intersection pedestrians needed to cross to be counted) and data collector accuracy were not available. Nonetheless, the pilot model pedestrian volume estimates were within 50 percent of the historic manual counts at 30 of the 46 comparison intersections. In the future, more consistent counts are needed to compare with the predicted model volumes. However, these historic count comparisons suggest that the pilot model and future refinements will be useful for estimating pedestrian volumes.

CONSIDERATIONS FOR FUTURE RESEARCH

The pilot model described in this paper is based on observations at 50 intersections in Alameda County, CA. The pedestrian volume estimates produced by the model are intended for planning, prioritization, and safety analysis at the community, neighborhood, and corridor levels. Since the model provides rough estimates of pedestrian activity, actual pedestrian counts should be used for site-level safety, design, and engineering analyses.

Although a systematic process was used to select the study intersections and gather count data, there are many variables that cannot be captured in a model with a sample size of 50. Variables that were not included in the model but may have a significant relationship with pedestrian volumes when more counts are taken include:

- Sidewalk coverage and buffer between roadway and sidewalk
- Roadway width and number of motor vehicle lanes
- Street network density
- Percentage of households with no vehicles available

While this pilot study suggests that pedestrian activity levels are influenced more by land use patterns than pedestrian facility and roadway design characteristics, accessible sidewalks and well-designed pedestrian street crossings are critical for pedestrian safety. In addition, many community surveys indicate that a safe and comfortable walking environment will increase pedestrian activity. Future research should continue to examine pedestrian facility quality variables.

Different types of statistical models should also be tested. This may include categorical models, model specifications that constrain predicted values to positive numbers, and models with interaction terms. Testing the predictive ability of the pilot model against future pedestrian counts will help suggest the types of refinements that should be made.

Due to restrictions used in the intersection selection process, the model may not be appropriate for predicting volumes at intersections adjacent to freeways and other grade separated roadways or in rural areas with less than 50 residents per square mile. In addition, the model may not perform well in locations close to special attractors, such as amusement parks, waterfronts, sports arenas, and regional recreation areas. Pedestrian volumes in these areas tend to be highly variable, with high volumes during certain seasons or during nice weather. Bridges and underpasses may also channel pedestrian activity, so more research may be necessary to adjust volume estimates near these features.

Daily, weekly, and seasonal pedestrian volume patterns were captured by infrared sensors at 11 of the 50 locations. While the temporal patterns from these intersections were applied to other locations with similar land use characteristics, they may not be precise matches. For example, a particular attractor, such as a gym or a school with certain hours of operation may exert a significant influence over the distribution of pedestrian activity at nearby intersections. This effect may not be captured in more general daily patterns of activity from other locations.

While people often walk along street segments and other pathways, straight-line distances were used in this study. Therefore, a commercial property that is within a 0.25-mile (402 m) radius of a person's home may actually require walking further than 0.25 miles (402 m). Network distances were not used because micro-scale data on pedestrian-only pathways, internal property circulation patterns, and informal pedestrian cut-throughs were not available.

The study used a stratified random sampling process. This was chosen over other methods in order to provide the greatest variation in the characteristics of study intersections while maintaining random selection for each individual intersection. If a simple random method had been used, intersections in the most common types of areas (such as low-density residential neighborhoods with middle-range incomes) would likely have made up most of the sample. Alternatively, selecting study intersections by convenience (such as locations suggested by local experts or community members) would introduce bias into the method.

Pedestrian trip attractors, such as commercial properties, regional transit stations, and schools were treated with equal weight in the modeling process. Future analyses could be done to incorporate weighting factors based on retail square footage, transit station access/egress counts, or school enrollment to capture these differences. However, an advantage of treating pedestrian attractors equally is that the pilot model remains relatively easy for practitioners to use.

The number of people walking in a particular community may also vary due to the overall condition of pedestrian facilities and attitudes towards walking in the community. These broader characteristics may change over time. Additional analysis in multiple communities is needed to identify these broader geographic and cultural influences on pedestrian volumes.

Further research is needed to increase the number of intersection count locations to increase the predictive capability of the model. These additional counts could be taken in Alameda County as well as other locations throughout the United States and other countries. Communities that are good candidates for refining the model would have a variety of pedestrian environments and have access to all necessary land use, transportation system, and socioeconomic data in GIS. It may also be possible to apply a similar methodology to develop models of midblock pedestrian crossing volumes and pedestrian volumes on sidewalk segments.

Finally, it would be beneficial to do a study to compare this study with other pedestrian models, such as Space Syntax. The models could be compared based on overall predictive ability, applicability to different geographic areas, cost, ease of implementation, and other factors.

CONCLUSION

The recommended pilot model is a simple tool that can be used to develop rough estimates of pedestrian intersection crossing volumes. Additional research and testing is needed to refine the model and determine its applicability in other communities. However, the model has a good overall fit, and the variables are statistically-significant and have a logical relationship with pedestrian volume. Practitioners can use this initial model and future refinements to estimate pedestrian exposure for safety analyses, prioritize locations for pedestrian projects, predict pedestrian volumes at intersections in new developments, and for many other purposes. Better pedestrian volume estimates will help planners, designers, engineers, public health professionals, and others improve the safety and convenience of pedestrian transportation.

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