Pedestrian Volume Modeling: A Case Study of San Francisco

XiaoHang Liu* and Julia Griswold
San Francisco State University

ABSTRACT

Pedestrian volume information is critical to study traffic safety as well as to plan for pedestrian friendly design. We present a model used to estimate the pedestrian volumes for street intersections in the city of San Francisco, California. Through regression analysis at multiple geographical scales, a set of socioeconomic variables and built-environment characteristics were examined. Three factors emerged as having strong explanatory power on the variances of pedestrian volume: population and job density, local transit access, and land use mix. It was found that the strongest area of influence on pedestrian traffic is around a one-block radius of an intersection. Multiple-scale analysis reveals that not all variables are significant at the same scale. In fact, the best model was obtained when a mix of scales was used. Because the analysis in this paper utilizes easy-to-access data and routine statistical analysis, it is easy to apply it in other cities, hence providing a valuable tool for geographers, public health professionals, urban planners, and transportation engineers.

Introduction

In recent years, researchers in the fields of urban planning and public health have come together in a new area of study known as active living research, quantifying the relationship between the built environment and the health of the population. These researchers aim to improve public health through finding ways for people to incorporate physical activities into their daily lives. Walking is the original form of transportation. By taking a trip on foot instead of by car, a pedestrian avoids contributing to the negative impacts of driving, the most prominent of which are air pollution and traffic-related injuries. Walking can also help build informal social networks within a neighborhood that keep areas safer by creating trust in the system of "eyes on the street" (Jacobs 1961). Additionally, walking serves as a connector between other transportation modes, a generator of business through window shopping, and an informal guard of public space.

Despite these advantages, pedestrians and their interests have largely been invisible in the urban and transportation planning process, due to the lack of data about them (Leydon 2003). While substantial data and models are available on vehicular traffic volume and parking need, few cities collect data on pedestrian flow and pedestrian behavior. Consequently, pedestrian advocates can only resort to planning theory and empirical evidences to argue in front of developers and decision-makers when quantitative evidence is much preferred.

The lack of pedestrian data also makes it difficult to study pedestrian safety comprehensively. Fear of accidents is one of the major barriers of walking. In fact, the large number of pedestrian deaths and injuries in the U.S. has generated significant attention on pedestrian safety (Campbell et al. 2001) and led several cities to develop plans to improve their walkability. One important measurement of pedestrian safety is pedestrian risk, which is the number of collisions normalized by pedestrian exposure. In the context of transportation planning, "pedestrian exposure refers to the pedestrian's rate of contact with potentially harmful vehicular traffic. It is measured by pedestrian volume and expressed in units of pedestrians per hour" (Raford and Ragland 2004). While most cities have access to the number and location of pedestrian crashes from the police reports, pedestrian volume or exposure data is rarely available. In fact, the Federal Highway Administration (FHWA) and the National Highway Traffic Safety Administration (NHTSA) listed pedestrian exposure as one of the major areas in need of research for planning and decision-making (NHTSA/FHWA 2000). Without pedestrian volume data, it is difficult to identify areas of greatest risk or evaluate the efficacy of the efforts to improve pedestrian safety.

The aim of our research is to develop a model to estimate the pedestrian volume in San Francisco, using environmental characteristics as the explanatory variables. Although substantial research has been conducted to examine the impact of social and built environment on travel behavior, including walking and biking, few models have related pedestrian volume to the built environment. This paper presents such a model based on regression analysis and the physical and social variables available to most cities. The method is different from previous studies in that it examines the built environment at multiple geographic scales and included pedestrian activities of all potential trip purposes. Such a model can serve several functions, including understanding the association between built environment and pedestrian activity, estimating the impact of development scenarios on pedestrian volume, identifying priority areas for investment in pedestrian facilities, and attracting public and policy-maker attention to pedestrian issues. More importantly, the volume data estimated by the model can be used by decision-makers to identify the street intersections where pedestrian safety is at the highest risk.

Environmental Determinants of Walking and Their Measurement

Built-environment characteristics correlate with the use of nonmotorized transportation. These characteristics include street network, street design, transit access, density, land use mix, safety, etc.

Street Network Configuration / Connectivity

Grid street networks are found more conducive to walking than hierarchical, curvilinear street networks, because trip distances are shorter and there are more route choices (Southworth and Owens 1993). While these distinctions are relatively easy to judge visually, it is not as clear how best to quantify street connectivity. Moudon and Hess (1997) found that neighborhoods with greater street connectivity, measured by mean block length and street system length (the total length of all streets in the network), and continuous sidewalks averaged three times greater pedestrian activity than neighborhoods without such facilities but with comparable population density, land use mix, and income. Cervero and Duncan (2003) used number of three-, four-, and five-or-more-way intersections and dead ends as proportions of total intersection, and found the variables to have a significant impact on choice to walk or bicycle. Proportion of intersections that are four-way is a proxy for grid network.

Other quantitative measures of street connectivity include block density (census blocks per square mile), street network density (miles per square mile), cul-de-sacs per road mile, intersection density (intersections per square mile), connected node ratio (ratio of street intersections to number of intersections plus cul-de-sacs), and link-node ratio (ratio of street segments to intersections) (Cervero and Kockelman 1997; Handy 1992; Dill 2004). Measures that do not include a distance or area in their calculation can be problematic, because they do not account for scale. For example, a grid neighborhood with 800-foot blocks will have the same link-node ratio as one with 300-foot blocks, while the neighborhood with smaller blocks would produce more route choices and shorter trip distances. It is found that values for street network density, intersection density, and connected node ratio are highly correlated with each other but only weakly correlated with link-node ratio values (Dill 2004).

Street Design

Street design has been shown to have an effect on non-personal vehicle trips and pedestrian volume (Moudon and Hess 1997; Cervero and Kockelman 1997). It is difficult to quantify, however, because there are many relevant factors. Cervero and Kockelman (1997) used factor analysis to reduce several measures—sidewalk provisions, street light provisions, block length, planted strips, lighting distance, and flat terrain—into a walking quality factor. Pikora and Giles-Corti (2003) found the recreational walking in a local neighborhood depends on four aspects: functional aspects, which include surface types, street widths, and street network permeability; safety aspects, such as lighting and street crossings; aesthetic aspects, like trees and street cleanliness; and destination aspects, such as parks and shops. Recently, Ewing et al. (2006) designed a set of factors related to streetscape and provided their functional definitions and measurement protocols.

Quantifying street design can be difficult because the data may not be readily available. Moudon and Hess (1997) determined width and network characteristics of streets, pedestrian facilities by type and extent, the relative safety and completeness of pedestrian facilities, and directness of pedestrian routes using examination of aerial photography and extensive field work. The Making the Land Use, Transportation and Air Quality Connection Project (LUTRAQ) incorporated two aspects of street design—ease of street crossings and sidewalk continuity—in their Pedestrian Environment Factor (PEF). Ease of street crossings was evaluated based on street width, signalization, and traffic volume. Sidewalk continuity was judged subjectively on major arterials within a zone. The subjectivity of many of these measures makes them unreliable to compare across studies.

Transit System Access

Access to transit is an important element of pedestrian friendliness because, in most areas, it is not possible to take care of all of one's needs on foot. Walking serves as the connection to local transit. A higher proportion of non-motorized trips occur in neighborhoods with local access to transit, measured by number of bus routes and distance to regional rail. Along the same lines, streets connecting to transit nodes have more pedestrians in dense urban areas (Kitamura and Mokhtarian 1997).

Population and Employment Density

Population and employment density are some of the easiest to calculate and most commonly used variables in travel behavior research. Higher population density and employment density are associated with more pedestrian activity, but the relationship between population and employment densities and mode choice may not be linear (Frank and Pivo 1994). In their effort to model pedestrian volume in Oakland, California, Raford and Ragland (2004) found that the addition of employment density to their linear regression model increased the regression coefficient from 0.56 to 0.77, indicating the significant influence of the location of employment. It has been suggested, however, that these variables do not have meaning in themselves but serve as proxies for other variables such as land use mix and level of transit service (Kockelman 1997).

Land Use Mix

Trip distance is a potential barrier to walking (Cervero and Duncan 2003). Mixing land uses is thought to bring origins and destinations closer to each other and make trip distances short enough for walking. Euclidean zoning practices in the second half of the 20th century, which kept different land uses separate, have made this impossible to implement in many places. The intermixing of retail and commercial uses within residential areas has been found to increase walking for work travel (Frank and Pivo 1994). Land use mix is often measured by entropy (Cervero and Duncan 2003; Frank and Pivo 1994; Kockelman 1997), which describes the uniformity of distribution of areas of land uses. Hess, Moudon, and Logsdon (2001) highlight the weakness of the entropy measure because it does not distinguish between a Census Tract with large zones of the same use and intermixing of those same uses. Cervero and Kockelman (1997) developed a land use dissimilarity index which examined each hectare for the proportion of neighboring hectares with different land uses and calculated the average for the area. This measure was less successful than entropy. Less sophisticated analysis has used the area devoted to different land uses as separate variables. For accurate measurement, it is desirable to have parcel-level data (Frank 2000).

Safety

Safety includes two main aspects: crime safety and traffic safety. Although crime has been acknowledged as a factor influencing the decision to walk (Sallis, Mauman, and Pratt 1998), few researchers to date have directly incorporated crime data into a model of pedestrian volume or mode choice. The model presented in our paper used crime data at police-lot level and examined its relationship with pedestrian count and other environmental variables. Compared to crime safety, traffic safety is affected by many more factors. Landis et al. (2001) identified three factors that are statistically significant in their effects on sense of safety: presence of sidewalk and lateral separation, which refers to the distance between a pedestrian and moving traffic; automobile traffic volume; and traffic speed. Other factors, such as presence and condition of pedestrian facilities, pedestrian-scale lighting, and "eyes on the street," are also relevant (Dixon 1996). Interestingly, Gallin (2001) rated low pedestrian volumes favorably in her Pedestrian LOS.

Existing Methods for Estimating Pedestrian Volume

Pedestrian volume data is a vital part of traffic safety analysis, allowing researchers to determine exposure to and risk of traffic injuries. To date, methods that can derive quantitative estimates of pedestrian volume have been developed mainly in the context of pedestrian travel demand. The utility of these methods to estimate the pedestrian volume data needed by pedestrian safety research varies, depending on whether the estimation is made at facility- or area-level (FHWA 1999). Methods such as aggregate behavior studies, regional travel models, and discrete choice models are not very useful, because their spatial unit of analysis is too big—usually census tracts or transportation analysis zones. These models also study walking as a primarily utilitarian behavior, leaving out recreational walking and visitors from outside the region.

For the purpose of pedestrian volume estimate, comparison studies and pedestrian sketch plan methods can be used. Comparison studies use the observed pedestrian count of an intersection to estimate the intersections with similar characteristics; the challenge is how to compare intersections. Sketch plan methods are simple calculations based on travel behavior and/or land use characteristics (FHWA 1999). Many of the existing models of pedestrian volume fall into this category. For example, Pushkarev and Zupan (1971) counted the numbers of pedestrians at different times of day using aerial photography, then used regression analysis to estimate pedestrian volume by block based on land use intensity, distance to transit, and amount of sidewalk and plaza space. Behnam and Patel (1976) used building use and/or walking space to estimate the instantaneous and hourly pedestrian volumes, respectively, in a central business district. Ercalano, Olson, and Spring (1997) made more-complicated models by including trip generation potential and vehicle data.

Despite these efforts, there remains a shortage of pedestrian volume models in the U.S. cities. Recent work in the UK have developed several pedestrian flow models, notably Space Syntax and Visibility Graph Analysis (VGA), which have been applied in many European and Asian cities (Hillier 1996; Penn and Hiller 1998; Desyllas et al. 2003). Both methods are based on routine regression analysis between pedestrian count and the built environment, but the methods to model the built environment are rather unique. Space syntax represents a pedestrian network as a graph of the minimum number of sight lines. It produces variables such as connectivity, the number of nodes that are directly connected to a given node; mean depth, the mean number of segments between any node and any other node; and relative asymmetry or integration, which determines a measure of accessibility by comparing the graph in question with an ideally connected graph (Raford and Ragland 2004). Penn and Hiller (1998) explained nearly all the variation in pedestrian flow in a London neighborhood using this method. Raford and Ragford (2004) also applied the model to estimate the pedestrian volume in Oakland, California, and obtained a regression coefficient of 0.77. The other method, VGA, is also built on graph theory but looks at the extent to which a point can be viewed from any other point and the number of intervening points necessary to view that point. VGA is reportedly more effective than Space Syntax at capturing steep changes in pedestrian volume between large streets and adjacent small streets (Desyllas and Duxbury 2001). In spite of the good potential of these methods, they rely on special softwares to perform the complicated analysis. This disadvantage restrained their utility for practitioners with limited technical resources.

Pedestrian Volume Modeling in San Francisco

The goal of this project is to estimate the impact of the built environment on pedestrian volume at a given point in the street network of San Francisco, California. The model used ordinary linear regression to predict pedestrian volume at intersection level, as a function of environmental factors that affect walking activity. The fine scale of analysis allowed for a more detailed understanding of pedestrian flow on a block-by-block basis. The approach used is unique in that it examines the built environment at multiple geographic scales and included pedestrian activities of all potential trip purposes.

Study Area

San Francisco is a city of approximately 750,000 population, located at the tip of a peninsula in the San Francisco Bay. It is densely populated and walkable, compared to other cities in the Western U.S. that were built after the advent of the automobile. Most of the city was built around a grid street pattern, except for the neighborhoods around Twin Peaks, two large hills near the center of the city. Downtown, with the largest concentration of jobs in the city, is in the northeast and has a large financial district with skyscrapers. The major corridor in Downtown is Market Street, under which there are tunnels for the local light-rail systems (BART and MUNI). This is the most transit-rich area of the city, although most places throughout the city are within a few blocks of a bus line. San Francisco has peculiar topography for a large city, with several steep hills located within the areas of grid street network. Higher-density housing is concentrated in the eastern neighborhoods, where most of the multi-unit residential buildings are located. The western portion of the city has mostly medium-density, single-unit residences.

Environmental Variables

Based on the previous review of environmental determinants of walking and their measurements, the variables in Table 1 were examined. Measures of most of the environmental variables were calculated for the areas within a radius distance of each street intersection. Each measure was calculated for multiple buffer sizes, between 1/2 and 1/16 mile, for testing during model calibration. Shapiro-Wilk's test showed that only three variables were normally distributed. Each variable was transformed using one of the three methods: square root, inverse, and natural logarithm. For each variable, the method producing the highest significance value was chosen to be included in the regression analysis.

Most of the variables in Table 1 are self-explanatory, except for the two metrics describing land use mix: Patch Richness Density (PRD) and Shannon's Diversity Index (SHDI). These metrics were originally developed to measure landscape diversity. In the context of land use, a patch is defined as a contiguous area with the same land use. For example, parcels with the same land use that are adjacent or directly across the street from each other belong to the same patch. PRD finds the areal density of patches using the following equation:

$$PRD = \frac{m}{A}(10,000)(100)$$

where m is the number of patches in the buffer around an intersection and A is the total area of the buffer in square meters. PRD always produces a value greater than zero and has no upper limit; larger values represent higher diversity. The other metric to describe land use mix is SHDI, which is defined as:

$$SHDI = -\sum_{i=1}^{m} (P_i \ln P_i)$$

where P_i is the proportion of the buffer area occupied by land use type i. SHDI always produces a value greater than zero and has no upper limit; higher values suggest higher diversity. The land use types in this study include residential, commercial, retail, and the others. The value of PRD and SHDI are calculated using Fragstats (McGarigal et al. 2002), a public-domain software compatible with Geographical Information Systems (GIS), based on parcel-level data.

Data Sources

Demographic data were retrieved from the U.S. Census Bureau for the year 2000. Data on employment came from the Association of Bay Area Governments' (ABAG) Projections 2003 disc (ABAG 2003). GIS data for census blocks, block groups, tracts, street and transportation network, and land use were retrieved from the Department of Telecommunication and Information Services (DTIS) server, a repository for GIS data created by city agencies that is run by the DTIS of the City of San Francisco. Liquor store locations were provided by the Department of Public Health. Crime data came from the San Francisco Police Department. Slope was derived from the 10-meter digital elevation model of San Francisco from the USGS.

Pedestrian count data were provided by the San Francisco Department of Public Health Pedestrian Safety Project, which had commissioned the counts from a professional firm. Counts were observed from 2:30 to 6:30 p.m. in the afternoon at each of 63 intersections in the City of San Francisco during 12 days in May, June, August, and September 2002. Counts were observed once per intersection, and all counts were collected on weekdays.

Two observers were positioned kitty corner at each intersection, and they counted pedestrian crossings in the two adjacent crosswalks using digital counters. Observation points were chosen for the sample in an attempt to cover as much of the city as possible, while including only intersections with an assumed base level of pedestrian activity. The count total for one intersection was an outlier and was removed from the samples used for modeling.

Regression Analysis

Moran's I analysis of the pedestrian counts collected at the sample intersections showed there is no spatial autocorrelation. The variances in pedestrian counts were then examined using the variables in Table 1. The values of the variables were calculated using different buffers around the intersections. To examine the impact of geographic scale, the buffer distances ranged from 1/2 mile, 3/8 mile, 1/4 mile, 1/8 mile, and 1/16 mile. At each scale, a set of variables with no strong correlations were created and included in the regression analysis to avoid multi-collinearity. Additionally, backward elimination was run to further identify the significant variables. Table 1 provides the details on the inclusion and significance of variables at each scale.

To examine the extent to which different scales affect different variables, one final model was created using a mix of variables calculated at different scales. The scale for each variable was chosen according to the strongest Pearson's Correlation Coefficients with the Pedestrian Counts. In an ideal study, regression analysis would be run on each variable at each scale with all the other variables at each scale. With 18 variables and 5 geographic scales, there would be nearly 4 trillion possible combinations. Clearly, the necessary processing power is beyond the scope of this study. Backward regression was run on a set of built-environment variables that did not strongly correlate with each other. Table 2 shows the model results. Surprisingly, the only variables removed during analysis were three of the ones that were not scale-dependant: Distance to BART, Presence of Retail, and Arterial Street. However, access to transit was still accounted for with the MUNI variable—the MUNI network has much greater coverage than BART. The regression coefficient of 0.743 implies that measuring each variable at the same scale is not the most effective approach. Factors such as street design may impact volume between parallel streets at a very small scale, while the presence of potential destinations may matter at the scale of several blocks. The final model was nearly identical to the 1/16-mile model, but the regression coefficient is higher.

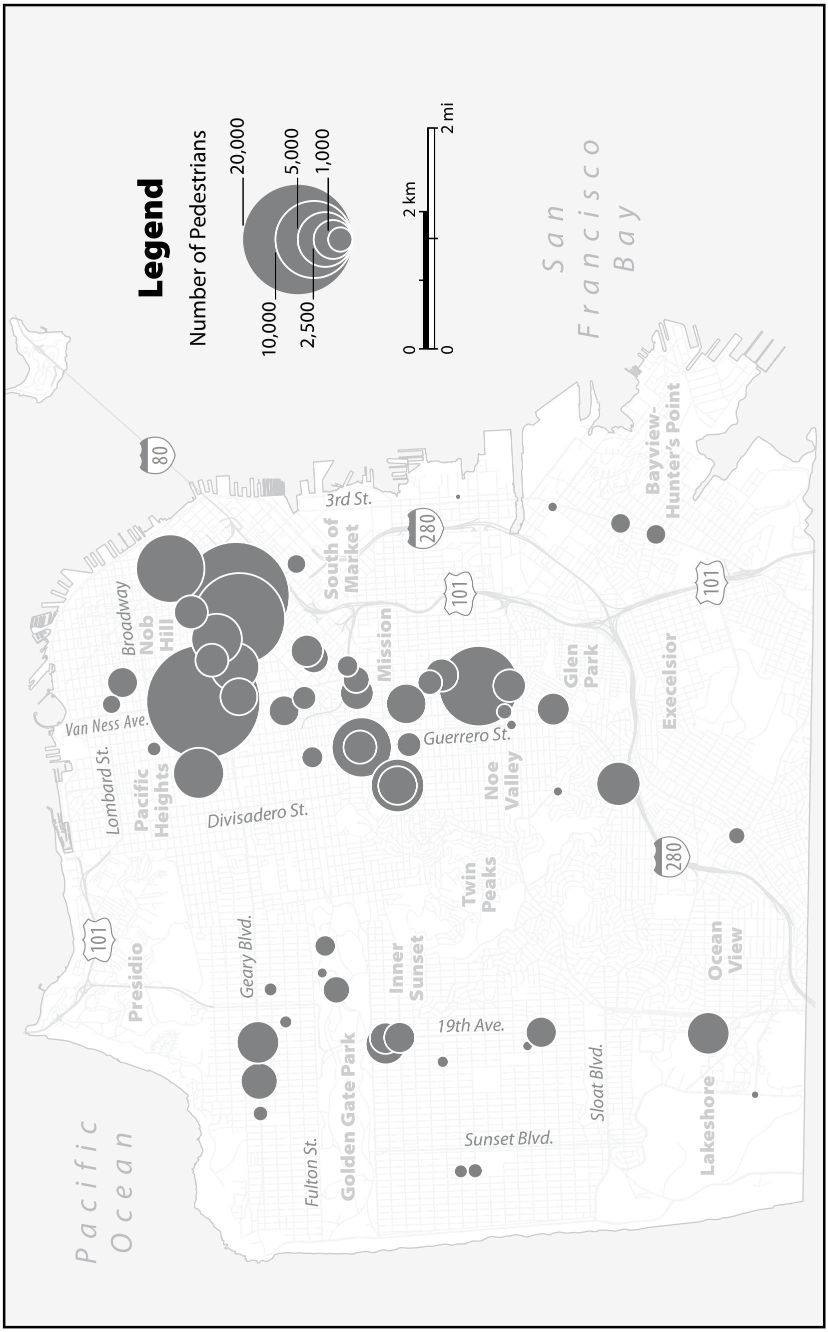

Figure 1. Study area and pedestrian count locations.

Table 1. Environmental Variables and Their Inclusion in Regression Analysis

	buffer distance around an intersection (miles)									
	1/2		3/8		1/4		1/8		1/16	
	reg	bwd	reg	bwd	reg	bwd	reg	bwd	reg	bwd
regression coefficient R^2	**0.72**	**0.71**	**0.56**	**0.54**	**0.68**	**0.64**	**0.80**	**0.78**	**0.73**	**0.71**
variable inclusion										
demographics										
mean income (at block group level)	●		●		■	■		■		
job density (at census tract level)	■	■	●				■	■	■	■
population density (at census block level)	■	■	●				■	■	■	■
household density (at census block level)					●					
unemployment rate (at block group level)			●		●			■		
percentage of commuters who walk or take transit (at block group level)								■		
transportation and street network										
mean block length	■	■			●		●		●	
presence of arterial street*	■	■			●		■	■		
presence of bike lane*	■	■			■	■	■	■	■	■
MUNI stop density: number of MUNI bus or light rail stops			■	■	■	■	■	■	■	■
distance to BART stations*	■		●		■		●		●	
land use										
presence of retail*	■	■			■	■		■	●	
percentage of residential land use	●		●		●		●			
percentage of commercial land use							■	■	■	■
percentage of retail land use							■		●	
patch richness density (see section 4.2)			■	■	●		■		■	■
Shannon's diversity index (see section 4.2)	■	■			■	■				
liquor store density					■	■	●		●	
number of property and violent crimes										
topography										
mean slope	●		■	■	●		●	■	■	■

reg: regular linear regression model • **bwd:** backward elimination model

* scale-independent variables

● variables not significant at 0.05 level but included in the regression model

■ variables significant at 0.05 level hence included in the regression model

Findings and Discussion

The results in Table 1 and Table 2 suggest that 70 to 80 percent of the variation in pedestrian count can be explained by environmental variables if appropriate scale and measurement are used. Three built-environment

Table 2. Relationship Between Pedestrian Counts and Built Environment Variables At a Mix of Scales

	Scale (miles)	Regression Model (R^2=0.754) Coefficients	Backward Elimination (R^2=0.743) Coefficients
presence of bike lane	n/a	.792	.707
job density	1/4	-.230	-.275
residential land use	1/16	-1.107	-1.061
MUNI stop density	3/8	1.508	1.507
population density	1/2	.013	.012
mean slope	1/16	-.262	-.254
patch richness density	1/16	.047	.060
(constant)	n/a	.144	.999

factors emerge as having a strong effect on pedestrian volume: population and job density, local transit access, and land use mix. Greater population density would mean greater land use intensity and wold justify improved transit access and service. Improved transit service would make transit a more attractive alternative to the automobile. Transit riders probably make up a large portion of pedestrians on the street. Increasing land use mix in residential neighborhoods involves bringing retail and other services within walking distance of potential users. All these factors intuitively would increase pedestrian volume in San Francisco. These factors also concur with the findings by Raford and Ragland, who modeled pedestrian volume in Oakland, another city in the San Francisco Bay area (2004). Raford and Ragland's analysis is also based on linear regression ($R^2 = 0.77$); however, their measurement of street network involves complex topological analysis using the U.K. software Space Syntax. In contrast, the measurements of all the variables in this research are straightforward, using GIS and a public-domain software. The fact that only three factors emerged as the strongest inducers of pedestrian volume does not mean that the other factors do not make a difference. Slope was also a strong performer at the smaller scales.

The varying results among the different models confirm that geographic scale is an important consideration when examining the pedestrian environment. Although the model with half-mile scale produced a strong statistical result, 10 of the 18 scale-dependant variables correlated most strongly with pedestrian volume when they were calculated using the smallest scale (1/16 mile), indicating that the immediate surroundings of a pedestrian have the greatest effect on levels of pedestrian traffic. Since the mean block length for San Francisco is 412 feet (125 meters), this means that the strongest area of influence is within a one-block radius. The pedestrian environment is clearly much smaller than that of the automobile, which is normally analyzed using larger units such as Census Tracts and traffic/transportation analysis zones. At the same time, some built-environment variables, such as MUNI Stop Density and Mean Block Length, were more significant when measured at a larger scale. A mix of scales seems necessary to produce more meaningful answers about pedestrian volume.

During the analysis, the crime variables were found to have positive strong correlations with pedestrian count and many of the built-environment variables. This is counterintuitive, as high levels of crime were expected to scare people away from exposing themselves to danger. A possible reason is that the raw measure of crimes is inappropriate for this study. The Downtown area had the most crime incidents, but it also has the greatest number of people exposed to crime, so the actual crime rate may be lower. Considering this outcome, perception of crime safety may be a better measure for modeling pedestrian flow. And, along the same line, pedestrian level-of-service (LOS) could have contributed strongly to this study, as it captures perception of safety. Data limitations precluded inclusion of qualitative street-design variables. These factors, such as street trees and furniture, traffic calming, and sidewalk width, examine the smallest scale of the pedestrian environment and address the aesthetic pedestrian experience more than the study variables, which mostly addressed functionality. These factors are usually considered in pedestrian LOS. A survey is currently under coordination to collect these qualitative data.

Ideally, pedestrian counts would have been collected for more intersections throughout the city for a multiple-hour period on the same day. However, this would have required significant funding to hire a firm to perform the counts or a major effort to organize volunteers, both of which were beyond the means of this study at this stage. As a result, the findings may not be generalizable to some neighborhoods with steep terrain and curvilinear street patterns, such as Twin Peaks, that were underrepresented in the sample. Considering that every city is different in terms of population density, transit access, street network etc., one cannot expect the built-environment factors to affect pedestrian volume at exactly the same magnitude as in San Francisco. However, the study does provide a guide on selection of the environmental variables and the method to effectively measure them.

Conclusion

Walking is an important component of a healthy lifestyle. To encourage people to incorporate walking into their everyday lives, planners and engineers need to study pedestrians from various aspects, including pedestrian safety and the impact of environmental characteristics. Our paper presents an easy-to-use approach that can be applied to model the pedestrian volume at street intersection level. The fine grain of the estimate makes it especially useful to study pedestrian safety. As discussed previously, pedestrian risk, the number of pedestrian crashes normalized by the pedestrian volume, is an important indicator of pedestrian safety. While most cities have access to pedestrian collision data, detailed and accurate pedestrian volume data is rarely available. The model presented in this paper filled such a gap by providing a tool that allows planners and engineers to obtain reasonably accurate estimates with limited technical resources. Unlike pedestrian travel demand models that use Census Tracts or transportation analysis zones as the spatial unit and consider utilitarian walking only, our model makes estimates at the street-intersection level and includes pedestrian trips of all purposes. On the other hand, our model is significantly less complicated than other advanced pedestrian models, such as Paramics and Space Syntax. Paramics is based on agent-based modeling and requires customization through programming, whereas Space Syntax requires special softwares not readily available. In contrast, our model uses routine statistical and GIS functions, and the key data required is available in most U.S. cities.

The research identified three built-environment factors with a strong effect on pedestrian volume: population and job density, local transit access, and land use mix. It also illustrates the importance of scale when quantifying the pedestrian environment. The strongest area of influence on pedestrians is within a one-block radius of a street intersection, which is significantly smaller than that of the automobile. To date, most research uses a uniform scale to measure all environmental variables. Our research shows that different variables have the most-significant impact at different scales, suggesting that geographic scale is an important factor to consider when modeling pedestrian activity.

Walking is the original form of traveling. For years, planning decisions have favored the automobile, in part because of the availability of vehicle traffic models that can be utilized to show the need for more car space. However, the importance of pedestrian safety and pedestrian-friendly design are also gaining attention among health and urban planners, transportation engineers, and government agencies. The research presented here demonstrates that pedestrian volume can be reasonably estimated using environmental variables, if appropriate measurement and geographical scale are utilized, thus helping professionals, communities, and walking advocates to raise the priority of pedestrian issues in the planning process.

Literature Cited

Association of Bay Area Governments (ABAG). "ABAG projections 2003 bay area air quality management district (BAAQMD)." *Bay Area 2000 Clean Air Plan: A Triennial Assessment*, 2003.

Behnam, J. and B. G. Patel. "A method for estimating pedestrian volume in a central business district." 1976. *Transportation Research Record: Journal of the Transportation Research Board* 629:22–26.

Campbell, B., C. Zegeer, H. Huang, and M. Cynecki. 2001. *Pedestrian Safety Research in the U.S.,* FHWA.

Cervero, Rovert and Kara Kockelman. 1997. "Travel demand and the 3Ds: Density, diversity, and design." *Transportation Research Part D* 2 (3):199–219.

Cervero, Robert and Michael Duncan. 2003. "Walking, bicycling, and urban landscapes: Evidence from the San Francisco Bay Area." *American Journal of Public Health* 93 (9):1478–1483.

Desyllas, Jake and Elspeth Duxbury. 2001. "Axial maps and visibility graph analysis: A comparison of their methodology and use in models of urban pedestrian movement." *Proceedings of the Space Syntax Third International Symposium*. Atlanta, GA, May 7–11.

Desyllas, Jake, Elspeth Duxbury, John Ward, and Andrew Smith. 2003. "Pedestrian demand modeling of large cities: An applied example from London." *Centre for Advanced Spatial Analysis Working Paper*, 62, University College London.

Dill, Jennifer. 2004. "Measuring network connectivity for bicycling and walking." *Proceedings of the 83rd Annual Meeting of the Transportation Research Board*, Washington, D.C., January 11–15.

Dixon, Linda. 1996. "Bicycling and pedestrian level-of-service performance measures and standards for congestion management systems." *Transportation Research Record: Journal of the Transportation Research Board* 153:1–9.

Ercolano, J. M., J. S. Olson, and D. M. Spring. 1997. "Sketch-plan method for estimating pedestrian traffic for central business districts and suburban growth corridors." *Transportation Research Record: Journal of the Transportation Research Board* 1578:38–47.

Ewing, Reid, Otto Clemente, Susan Handy, Ross Brownson, and Emily Winston. 2006. "Identifying and measuring urban design qualities related to walkability." *Journal of Physical Activity and Health* 3:S223–S240.

FHWA. 1998. *Guidebook on Methods to Estimate Non-motorized Travel: Supporting Documentation*. Publication FHWA-RD-98-166, U.S. Department of Transportation.

Frank, Lawrence. 2000. "Land use and transportation interaction: Implications on public health and quality of life." *Journal of Planning Education and Research* 20 (1):16–22.

Frank, Lawrence and Gary Pivo. 1994. "Impacts of mixed use and density on utilization of three modes of travel: Single-occupant vehicle, transit, and walking." *Transportation Research Record: Journal of the Transportation Research Board* 1466:44–52.

Gallin, Nichole. 2001. "Quantifying pedestrian friendliness—Guidelines for assessing pedestrian level of service." *Proceedings of Australia: Walking the 21st Century*. Perth, Australia, February 20–22, pp. 119–128.

Handy, Susan. 1992. "Regional versus local accessibility: Neo-traditional development and its implications for non-work travel." *Built Environment* 18 (4):253–267.

Hess, Paul, Anne Moudon, and Miles Logsdon. 2001. "Measuring land use patterns for transportation research." *Transportation Research Record: Journal of the Transportation Research Board* 1780:17–24.

Hillier, Bill. 1996. *Space is the Machine*. Cambridge, MA: Cambridge University Press.

Jacobs, Jane. 1961. *The Death and Life of Great American Cities*. New York, NY: Vintage Books.

Kitamura, Ryuichi, Patricia Mokhtarian, and Laura Laidet. 1997. "A micro-analysis of land use and travel in five neighborhoods in the San Francisco Bay Area." *Transportation* 24:125–158.

Kockelman, Kara. 1997. "Travel behavior as a function of accessibility, land use mixing, and land use balance: Evidence from San Francisco Bay Area." *Transportation Research Record: Journal of the Transportation Research Board* 1607:116–125.

Landis, Bruce, Venkat Vattikuti, Russell Ottenberg, Douglas Mcleod, and Martin Guttenplan. 2001. *Modeling the Roadside Walking Environment: A Pedestrian Level of Service*. Paper 00-0511, Transportation Research Board, National Research Council, Washington, D.C.

Leydon, Kevin. 2003. "Social capital and the built environment: The importance of walkable neighborhoods." *American Journal of Public Health* 93:1546–1551.

McGarigal, K., S. A. Cushman, M. C. Neel, and E. Ene. 2002. *FRAGSTATS: Spatial Pattern Analysis Program for Categorical Maps*. Computer software program produced by the authors at the University of Massachusetts, Amherst. Available at the following Web site: www.umass.edu/landeco/research/fragstats/fragstats.html [Accessed June 27, 2008].

Moudon, A. and P. Hess. 1997. "Effects of site design on pedestrian travel in mixed-use, medium-density environments." *Transportation Research Record: Journal of the Transportation Research Board* 1578:48–55.

NHTSA/FHWA. 2000. *Pedestrian and Bicycle Strategic Planning Research Workshops*, Final Report, April.

Penn, A. and B. Hiller. 1998. "Configurational modeling of urban movement networks." *Environment and Planning B—Planning & Design* 25:59–84.

Pikora, Terri, Bille Giles-corti, Fiona Bull, Konrad Jamrozik, and Rob Donovan. 2003. "Developing a framework for assessment of the environmental determinants of walking and cycling." *Social Science &* Medicine 56:1693–1703.

Pushkarev, B. and J. Zupan. 1971. "Pedestrian travel demand." *Highway Research Record* 355:37–53.

Raford, Noah and David Ragland. 2004. "Space syntax: An innovative pedestrian volume modeling tool for pedestrian safety." *Transportation Research Record: Journal of the Transportation Research Board* 1878:66–74.

Sallis, J., A. Bauman, and M.Pratt. 1998. "Environmental and policy interventions to promote physical activity." *American Journal of Preventive Medicine* 15 (4):379–397.

Southworth, Michael and Peter Owens. 1993. "The evolving metropolis: Studies of community, neighborhood, and street form at the urban edge." *Journal of the American Planning Association* 59:271–287.