SafeTREC Safe Transportation Research & Education Center

Effects of Weather Variables on Pedestrian Volumes in Alameda County, California

Vanvisa Attaset, Robert J. Schneider,
Lindsay S. Arnold and David R. Ragland,
SafeTREC

2010
RR-2010-7
http://www.safetrec.berkeley.edu

ABSTRACT

Accurate estimates of pedestrian volume are important for analyzing pedestrian movement and safety; methods to estimate these volumes are continuously evolving and being improved. However, relatively little is known about the impact of weather conditions on pedestrian activity. This paper evaluates the effect of weather by including temperature, cloud cover, wind, and precipitation variables in a linear regression model of pedestrian volumes. Pedestrian volumes were collected over approximately one year using automated counters at 13 different locations in Alameda County, California. These volumes were compared with weather data available from nearby weather stations. Results show that several weather variables had a significant influence on pedestrian volumes during certain time periods. Rain had the largest effect on pedestrian volumes at a given location, though clouds, wind, and both hot and cold temperatures were also shown to decrease volumes. This study demonstrates the importance of accounting for weather when analyzing pedestrian volumes. Future research should attempt to understand how the effect of weather conditions on pedestrian volumes varies by geographic region, time period, and local land use and site characteristics.

INTRODUCTION

Reliable, cost-effective methods of counting pedestrians are needed for transportation planning, engineering, design, and evaluation. Accurate pedestrian volumes can be used to:

- quantify pedestrian exposure in safety analyses (express pedestrian risk as the rate of reported pedestrian crashes per pedestrian crossing),
- set priorities for pedestrian engineering, education, enforcement, and encouragement projects (in conjunction with public input, safety data, and other inputs),
- provide valid data for estimating pedestrian volume models,
- determine whether or not a particular crossing location will meet an engineering warrant for a pedestrian crossing signal or other crossing treatment,
- document the benefits of specific pedestrian projects by comparing volumes before and after implementation, and
- track changes in pedestrian activity in different parts of a community over time.

There are many challenges to estimating pedestrian volumes. Pedestrian movements are much less predictable and are more likely to be influenced by immediate surroundings and environmental factors than automobile movements. Pedestrians do not follow fixed paths in the same manner as automobiles and are thus more difficult to count. In addition, pedestrians are often acutely aware of temperature, wind, direct sunshine, and precipitation, all of which may affect behavior. Pedestrian trips can be both positively and negatively affected by weather factors, but few studies have tried to measure and quantify what these effects may be. Work being done to estimate pedestrian volumes in different locations is still in progress and is being improved continuously in order to incorporate these environmental factors.

Purpose

The purpose of this paper is to identify weather conditions that have a significant impact on pedestrian volumes. This paper uses data and findings from a previous study conducted through the UC Berkeley Traffic Safety Center (1) as a basis for analyzing approximately one year of data from automated pedestrian counters at 13 sidewalk locations located in Alameda County, California. That study developed a regression model to estimate pedestrian intersection crossing volumes using known characteristics of each intersection. The previous model accounted for the effects of weather on pedestrian volumes, but based its analysis on only three months of weather and volume data. This study uses weather and automated counter data from an entire year to capture the effect of a range of weather characteristics on pedestrian volumes.

PREVIOUS RESEARCH

Previous studies have examined the effects of weather on travel behavior. There are accepted adjustments recommended for seasonal effects on auto volume (2). Though fewer studies have focused on pedestrians, there has been evidence to indicate that weather has an impact on walking trips. Surveys have found that extreme weather is considered an impediment to walking (3). Cervero and Duncan (4), using a discrete choice model, found that rainfall lowered the probability that a trip would be made by walking. In a study that focused only on short trips made to access public transit, weather was found to be influential in two ways: nice days promote walking trips and rainy days hamper them. Wind and cold were also studied in that case but found to have no relationship to the choice to walk (5). The consensus tends toward the intuitive conclusion that unpleasant weather may have a negative effect on walking. However, few studies have been able to identify the specific weather factors that influence pedestrians and to quantify those impacts.

Schneider, Arnold, and Ragland (6) developed a method to extrapolate two-hour manual pedestrian counts to estimate weekly pedestrian volumes. They recognized the need to adjust manual counts for weather conditions and calculated adjustment factors for rain, temperature, and cloudy days. An even more extensive attempt to quantify weather effects on pedestrian volume was undertaken in Montpelier, Vermont (7). That study made use of an entire year of pedestrian counts at one location and sought to quantify the amount of variation in pedestrian volume at one site that can be attributed to weather factors. The authors found that a combination of weather variables could explain some of the variation in pedestrian volumes and that the effect of individual weather conditions on average hourly volumes could be quantified. That study not only showed that pedestrian volume can increase and decrease with varying weather conditions, but attempted to define by how much.

METHODOLOGY

This study was conducted in Alameda County, California, part of the San Francisco Bay Area Metropolitan Region. Alameda County is home to approximately 1.46 million residents (Census Bureau 2007). Oakland is the largest city in the county with a population of 401,000 (Census Bureau 2007).

The two primary sets of data used for this study were pedestrian counts gathered from automated sensors and weather data gathered from weather stations. Both data sources provided data at one-hour intervals over an entire year (April 2008 to April 2009). The study also incorporates land use data collected through the U.S. Census, Alameda County Assessor's Office, and the San Francisco Bay Area Metropolitan Transportation Commission.

Pedestrian Count Data

EcoCounter Dual Infrared Pyroelectric sensors were used to collect continuous pedestrian counts and document fluctuations in pedestrian activity over time. Four sensors were rotated among 12 locations in Alameda County, so each location has three to four months of total data. A fifth counter was installed permanently near one intersection in Downtown Oakland. Each sensor was mounted at waist height on a sign or parking meter within 100 feet (30.5 meters) of an intersection and pointed across a sidewalk. Pedestrians were counted each time they crossed the sensor beam as they walked along the sidewalk. The research team tested the accuracy of the sensors and found that they typically undercounted pedestrians by approximately 10 to 20 percent (likely due to pedestrians walking side-by-side or crossing in front of the sensor at the same time), which was consistent with previous studies (6, 8). Since the undercount was similar during low-volume and high-volume periods, the sensor data was determined to be a good representation of the overall pattern of pedestrian activity at each location. Raw data were downloaded from the sensor using a portable digital assistant. These data were corrected for obvious anomalies, such as bicycles parked in front of the sensor, a single person walking back and forth in front of the sensor, etc. If any particular hourly measurement looked to be unusually low or high, it was replaced with the average hourly count during that hour and day of the week for that location. Measurements made on holidays were not included in the analysis.

Weather Data

Weather data were obtained from three different Alameda County weather stations. Air temperature, precipitation, solar radiation, wind speed, relative humidity, and dew point data were downloaded from the weather station closest to each of the pedestrian counter locations. Hours that had incomplete weather data were not included in the analysis. Ten of the 13 sidewalk locations were in proximity to the Oakland Foothills weather station, two to the Union City station, and one to the Pleasanton station. The locations studied and the corresponding weather stations are listed in TABLE 1.

TABLE 1 Automated Counter and Weather Station Locations

Counter Location (nearby intersection)	Weather Station
Broadway & 12th Street	Oakland Foothills
MLK Jr. Way & 17th Street	Oakland Foothills
Amador Valley Blvd. & Stagecoach Rd.	Pleasanton
Mission Blvd. & Jefferson St.	Union City
University Avenue & Bonar Street	Oakland Foothills
Ashby Avenue & Benvenue Avenue	Oakland Foothills
Ashby Avenue & Acton Street	Oakland Foothills
Davis Dr. & Warden St.	Oakland Foothills
San Pablo Avenue & Ward Street	Oakland Foothills
Foothill Boulevard & 15th Avenue	Oakland Foothills
Broadway & Calhoun Street	Oakland Foothills
Foothill Boulevard & D Street	Union City
Ashby Avenue & Telegraph Avenue	Oakland Foothills

Several weather variables were derived from these direct measurements for analysis. This allowed the data to be simplified, rescaled, and adjusted for non-linear effects. These are the last six variables listed in TABLE 2.

Combined Pedestrian Count and Weather Condition Database

The pedestrian count and weather datasets were merged together seamlessly. The counts recorded by the automatic sensors refer to the total count for the hour following the recorded time. The weather data gives the measurement (or average) for the hour preceding the recorded time. Hours referenced in this paper follow the convention of the pedestrian counters (i.e. 12 AM will refer to the time period from 12 – 1 AM). In total, there were 29,680 hourly records available for analysis among the thirteen locations.

Land Use Data

In addition to the hourly datasets, land use data were included in the analysis. The following four significant land use factors found by Schneider et al. (1) were included for each of these locations:

- total population within half a mile,
- total jobs within a quarter mile,
- number of commercial properties within a quarter mile, and
- number of BART (regional rail) stations within a tenth of a mile.

All of the count, weather, and land use variables used in this study are listed and described in TABLE 2.

TABLE 2 Variables and Descriptive Statistics

			13 Study Locations			
Variable Name	**Units**	**Description**	Mean	Std Dev	Max	Min
Automated Pedestrian Count	Persons	Number of pedestrians counted by sensor in one hour	46	102	688	0
		Land Use				
TotPop_H	Persons	Total population within 1/2-mile	8579	3297	14078	3798
TotEmp_Q	Jobs	Total employment within 1/4-mile	2706	5089	18877	220
NBARTSta_T	Stations	Number of BART stations within 1/10-mile	0.08	0.28	1	0
NCOMPROP_Q	Properties	Number of commercial properties within 1/4-mile	34	32	112	0
		Weather	All recorded hours for 13 study locations			
Sol Rad (Ly/day)	Ly/day	Average hourly solar radiation 2 meters above ground	389.92	589.99	2154	-1
Air Temp (°F)	°F	Average hourly air temperature 1.5 meters above ground	57.21	11.00	99.6	26.3
Wind Speed (MPH)	MPH	Average hourly wind speed 2 meters above ground	2.47	1.52	14.6	0.9
Precip (in)	Inches	Total hourly precipitation	0.0019	0.02	1.81	0
Rel Hum (%)	%	Average hourly relative humidity at 1.5 meters above ground	70.59	20.62	100	7
Dew Point (°F)	°F	Hourly dew point temperature	46.06	7.32	61.6	14.1
CloudRatio		Ratio of average hourly solar radiation to 10-year average solar radiation for same day and hour	0.75	1.88	30	-20
Cloudy	Binary (0/1)	1 if cloud ratio is < 0.6 (cloudy) 0 if cloud ratio is ≥ 0.6 (clear) Only for daytime hours	0.08	0.27	1	0
TempU50	Binary (0/1)	1 if air temp is < 50 °F (10 °C) 0 if air temp is ≥ 50 °F (10 °C)	0.25	0.43	1	0
TempO80	Binary (0/1)	1 if air temp is ≥ 80 °F (27 °C) 0 if air temp is < 80 °F (27 °C)	0.04	0.20	1	0
WindO5	Binary (0/1)	1 if wind speed is ≥ 5 mph (8 kph) 0 if wind speed is < 5 mph (8 kph)	0.06	0.24	1	0
Rain	Binary (0/1)	1 if precip is > 0 inches 0 if precip = 0 inches	0.03	0.18	1	0

ANALYSIS

Time Periods

Five different time periods were chosen to analyze the influence of weather conditions on pedestrian counts. These time periods represent a range of weekday and weekend times, including peak commuting periods. The hours chosen were:

- Saturday 12-1 PM
- Sunday 12-1 PM
- Weekday 8-9 AM
- Weekday 12-1 PM
- Weekday 5-6 PM.

For the weekday hours, Tuesday, Wednesday, and Thursday were treated in the same manner, so a combination of data from all three days was used.

Initial Separate Models for Land Use and Weather

First, two linear regression models were run for each of the time periods; one with only land use variables and one with only continuous weather variables. The land use model was run using the recorded pedestrian volumes during that hour as the dependent variable. These models demonstrated that the four land use variables converged upon by Schneider et al. (1) were still effective in this case. The high R^2 values (between 0.87 and 0.97, depending on the hour of the week being modeled) indicate that the four land use variables explain much of the variation in pedestrian volumes among the various measurement locations.

The models with only continuous weather variables were run with pedestrian volume variation as the dependent variable instead of the recorded pedestrian volumes. Pedestrian volume variation was calculated by finding the average volume for each location during each hour, then calculating the deviation from this average (as a percent of the average) for each measurement. The R^2 values for the weather only models tended to be much lower than for the land use models (between 0.02 and 0.11). The largest R^2 value for the weather only model occurs during the Saturday 12 PM time period and reached 0.1064. This suggests that taken as a group these weather variables may explain only about 10% of the total annual variation in pedestrian volume at any given location in Alameda County.

This preliminary analysis also found that weekday time periods have consistently higher R^2 values for the land use only model, but consistently lower R^2 values for the weather only model. This may reflect the fact that weekday trips are less discretionary than weekend trips and are thus much less affected by weather. The raw data support this hypothesis when used to compare the effect of rain on pedestrian trips during the Sunday 12-1 PM and weekday 8-9 AM time periods. One would expect that weekday commute hour trips should be less affected by rain than weekend midday trips. The data show that the presence of rain decreases Sunday 12-1 PM trips by 61%, but only decreases weekday 8-9 AM trips by 24%. This comparison is shown graphically in FIGURE 1.

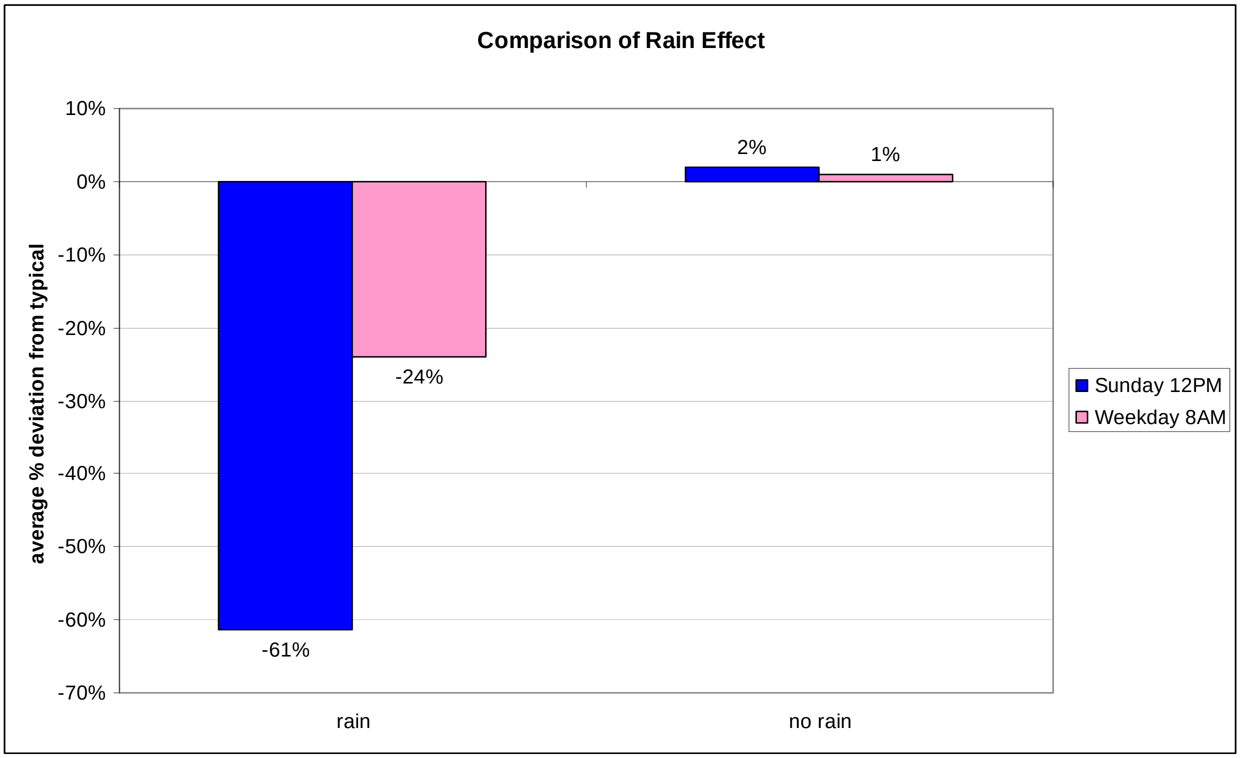

FIGURE 1 Comparison of Rain Effect on Sunday 12-1 PM and Weekday 8-9 AM Pedestrian Volumes

While the effects of weather may be relatively small, specific weather variables have statistically significant effects on pedestrian activity. These initial models indicate that air temperature and precipitation may be significant during several of the time periods. In addition, weather effects may vary by geographic region. The study done in Montpelier, VT found that during a peak hour in one particular location, weather could account for up to 30% of the overall variation in pedestrian volume (7). This disparity could be due to more extreme weather fluctuations in VT compared to CA, in addition to other geographic differences.

Weather Models with Continuous and Binary Variables

Next, linear regression models were run separately with continuous weather variables and binary weather variables. The dependent variable for both models was the deviation of the recorded pedestrian volume from the average volume at a specific location during the specified hour.

Linear Regression Model with Continuous Weather Variables

The first set of models used only continuous weather variables. These models included all of the downloaded hourly weather variables. A correlation test was run on the continuous weather variables since correlation among the independent variables could be a statistical problem and lead to insignificant parameters. There were only three pairs of variables with a magnitude of correlation that was greater than 0.5. Air temperature and solar radiation had a correlation coefficient of 0.64; relative humidity and solar radiation were correlated with a coefficient of -0.60; relative humidity and air temperature were correlated with a coefficient of -0.74. These variables were not included together in the same model.

Parameter results for the continuous weather variable models are shown in TABLE 3. Though several variables were significant during one or more time periods, there were no weather variables that were consistently significant across all time periods. This is possibly due to lack of data, or potentially non-linear effects of some of the continuous variables. For example, air temperature is likely to have a non-linear effect on pedestrian volumes because walking may be less appealing when it is very warm or very cold. Therefore, a second set of models was developed with binary variables.

Linear Regression Model with Binary Weather Variables

Binary dummy variables were used to capture possible non-linear effects of temperature, wind speed, solar radiation, and rainfall on pedestrian volumes. These dummy variables represented temperatures cooler than 50 degrees Fahrenheit (10 degrees Celsius), temperatures warmer than 80 degrees Fahrenheit (27 degrees Celsius), wind speeds greater than 5 m.p.h. (8 k.p.h), cloudy days, and measurable rainfall. In general, the binary variables were more likely to have lower p-values, which indicate greater statistical significance. Parameter results for the binary weather variable models are shown in TABLE 4.

Final Linear Regression Model

Using the results from these models and systematically eliminating the least significant variables yielded the best models for each of the time periods. The final results are presented in TABLE 5.

TABLE 3 Model Parameters for Continuous Weather Variables

	Saturday 12 PM			Sunday 12 PM		
Adjusted R^2	0.075			0.054		
	Coefficients	*Standard Error*	*P-value*	*Coefficients*	*Standard Error*	*P-value*
Intercept	1.560	0.425	0.000	0.112	1.057	0.916
Air Temp (°F)	-0.026	0.008	0.001	0.002	0.021	0.934
Wind Speed (MPH)	0.007	0.023	0.768	-0.010	0.024	0.672
Precip (in)	-31.514	18.500	0.090	-3.501	1.649	0.035
Rel. Humidity (%)	-0.016	0.006	0.006	-0.002	0.012	0.874
Dew Point (°F)	0.023	0.009	0.018	-0.004	0.022	0.867
Solar Rad. (Ly/day)	0.000	0.000	0.585	0.000	0.000	0.426

	Weekday 8 AM			Weekday 12 PM			Weekday 5 PM		
Adjusted R^2	0.013			0.032			0.010		
	Coefficients	*Standard Error*	*P-value*	*Coefficients*	*Standard Error*	*P-value*	*Coefficients*	*Standard Error*	*P-value*
Intercept	-0.166	0.436	0.704	0.650	0.277	0.019	0.731	0.291	0.012
Air Temp (°F)	0.008	0.010	0.408	-0.013	0.005	0.005	-0.015	0.005	0.005
Wind Speed (MPH)	-0.007	0.019	0.710	-0.016	0.014	0.231	0.002	0.012	0.851
Precip (in)	-10.463	3.854	0.007	0.129	0.187	0.491	-6.700	6.773	0.323
Rel. Humidity (%)	0.002	0.005	0.697	-0.009	0.003	0.007	-0.009	0.003	0.009
Dew Point (°F)	-0.008	0.010	0.416	0.013	0.005	0.012	0.016	0.006	0.012
Solar Rad. (Ly/day)	0.000	0.000	0.732	0.000	0.000	0.012	0.000	0.000	0.455

TABLE 4 Model Parameters for Binary Weather Variables

	Saturday 12 PM			Sunday 12 PM		
Adjusted R^2	0.029			0.076		
	Coefficients	*Standard Error*	*P-value*	*Coefficients*	*Standard Error*	*P-value*
Intercept	0.049	0.033	0.142	0.028	0.041	0.493
Cloudy	-0.152	0.085	0.076	-0.190	0.123	0.124
TempU50	---	---	---	0.128	0.162	0.431
TempO80	-0.142	0.074	0.057	0.098	0.132	0.456
WindO5	-0.057	0.090	0.530	0.001	0.095	0.990
Rain	-0.567	0.378	0.136	-0.558	0.164	0.001

	Weekday 8 AM			Weekday 12 PM			Weekday 5 PM		
Adjusted R^2	0.013			0.034			0.007		
	Coefficients	*Standard Error*	*P-value*	*Coefficients*	*Standard Error*	*P-value*	*Coefficients*	*Standard Error*	*P-value*
Intercept	0.031	0.020	0.111	0.037	0.018	0.040	0.026	0.017	0.137
Cloudy	-0.054	0.039	0.169	-0.115	0.058	0.047	0.006	0.083	0.943
TempU50	-0.044	0.037	0.237	-0.143	0.140	0.308	-0.112	0.052	0.031
TempO80	---	---	---	-0.056	0.041	0.176	-0.083	0.047	0.077
WindO5	-0.001	0.115	0.992	-0.075	0.047	0.107	-0.031	0.048	0.526
Rain	-0.232	0.087	0.008	-0.333	0.117	0.005	-0.444	0.347	0.201

TABLE 5 Final Models for All Time Periods

	Saturday 12 PM			Sunday 12 PM		
Adjusted R^2	0.087			0.085		
# Observations	180			183		
	Coefficients	*Standard Error*	*P-value*	*Coefficients*	*Standard Error*	*P-value*
Intercept	0.671	0.180	0.000	0.038	0.036	0.302
Air Temp (°F)	-0.010	0.003	0.000			
Precip (in)						
Cloudy	-0.240	0.087	0.007	-0.140	0.098	0.155
TempU50						
TempO80						
WindO5						
Rain	-0.562	0.358	0.118	-0.558	0.163	0.001

	Weekday 8 AM			Weekday 12 PM			Weekday 5 PM		
Adjusted R^2	0.017			0.034			0.010		
# Observations	531			531			530		
	Coefficients	*Standard Error*	*P-value*	*Coefficients*	*Standard Error*	*P-value*	*Coefficients*	*Standard Error*	*P-value*
Intercept	0.020	0.018	0.262	0.035	0.018	0.051	0.023	0.016	0.165
Air Temp (°F)									
Precip (in)	-10.937	3.679	0.003						
Cloudy	-0.052	0.039	0.181	-0.110	0.058	0.057			
TempU50							-0.111	0.052	0.033
TempO80				-0.054	0.041	0.192	-0.082	0.046	0.078
WindO5				-0.076	0.047	0.106			
Rain				-0.349	0.116	0.003	-0.435	0.337	0.198

RESULTS

A model using the hourly weather variables was developed for each of the time periods considered. Weather variables were included in the final model if they were significant at a 90% significance level (p-value ≤ 0.10). Parameters with p-values between 0.10 and 0.20 were also included if their inclusion improved the explanatory power of the model compared to other model specifications (by increasing the model's adjusted-R^2 value). Constants were included in all models. Models were often run once with a significant continuous variable and then again, replacing the continuous variable with the corresponding binary variable. The form of the variable with the lower p-value or that which most improved the overall quality of the model was chosen for inclusion in the final model. The final models all have adjusted- R^2 values greater than the adjusted- R^2 value of the initial models with only continuous or binary variables. In general, the parameters affect the estimates of pedestrian volumes in an expected manner.

Saturday Midday Hour: 12 – 1 PM

The model for the midday hour on Saturday shows that pedestrian volumes tend to be lower than the average at a location as air temperature increases and when clouds or precipitation are present. This model has the highest adjusted R^2 value, 0.087, (best overall model fit) among all the time periods.

Sunday Midday Hour: 12 – 1 PM

The model for the midday hour on Sunday includes rain and cloud cover as significant variables. Pedestrian volumes are lower than average under these weather conditions.

Weekday Morning Hour: 8 – 9 AM

The model for the weekday morning hour also includes precipitation and cloudiness as significant variables and shows that pedestrian volumes have a negative association with inches of precipitation and the presence of cloud cover.

Weekday Midday Hour: 12 – 1 PM

The model for the weekday midday hour shows that cloud cover, temperatures above 80 degrees Fahrenheit (27 degrees Celsius), wind over 5 m.p.h. (8 k.p.h), and rain have a significant association with pedestrian activity. Temperatures above 80 degrees Fahrenheit and winds over 5 m.p.h. both decrease pedestrian volume relative to the average volume for that location, as do the presence of rain or clouds.

Weekday Evening Hour: 5 – 6 PM

The model for the weekday evening hour includes extreme air temperatures and rain as significant factors. As before, pedestrian volumes tend to be lower when it is warmer but also lower when it is colder. The presence of rain again decreases the pedestrian volume at a given location.

Overall Effects of Weather on Pedestrian Volumes

The final models indicate that individual weather conditions have an effect on pedestrian volumes. Overall, the parameters of the different time period models showed consistent results for specific conditions.

- Rain had the largest effect on pedestrian volumes. The parameters show that the presence of rain can reduce the pedestrian volume by between 35 percent and 56 percent of the typical average volume. These results also suggest that rain has a greater effect on pedestrian volumes on weekends, when people may be making more discretionary pedestrian trips.
- Cloud cover was associated with lower pedestrian volumes. The model parameters indicate that pedestrian volumes during a time period with clouds may be between five and 24 percent lower than during an average time period. Cloud cover may also have a larger effect on trips made during the weekend compared to those made on a weekday.
- Warmer air temperatures were associated with lower pedestrian volumes. As temperatures increase, pedestrian activity levels generally decrease. During the Saturday midday period, each additional degree Fahrenheit (0.56 degrees Celsius) is associated with one percent lower than average pedestrian volume at a particular location. Most of the temperature data in this study were between 40 and 80 degrees Fahrenheit (4 to 27 degrees Celsius). During a full year at the Oakland foothills station, there were only 530 total hours with an average temperature over 80 degrees F (27 degrees Celsius) out of 8,792 total hours of observation. The study periods included very few hours with average temperatures below 50 degrees F (10 degrees Celsius). Therefore, the effects of more extreme hot and extreme cold temperatures were difficult to capture.
- Temperatures over 80 degrees Fahrenheit (27 degrees Celsius) were associated with lower pedestrian volumes. Pedestrian volumes may be depressed five to eight percent during hours with warm temperatures, according to the model parameters.
- Temperatures below 50 degrees Fahrenheit (10 degrees Celsius) were associated with lower pedestrian volumes. Due to the time periods chosen, there were few hours included in the analysis during which the average temperature was below 50 degrees F (10 degrees Celsius).
- Higher winds were associated with lower pedestrian volumes.
- Dew point and relative humidity were not shown to have a significant impact on pedestrian volumes. However, Alameda County tends to have dew points and relative humidity that are in the comfortable range for most humans (9).

FURTHER RESEARCH

There have been very few studies that attempt to quantify weather effects on pedestrian volume. The Aultman-Hall et al. study in Vermont used detailed weather data over the course of a full year in one location. Using a year of weather data and automated pedestrian counts at 13 locations, his paper finds that weather has significant effects on pedestrian volumes, but the effects of temperature and precipitation may be different during different hours of the week.

It is important to recognize that Alameda County has relatively small variations in weather. In comparison with Burlington, VT and other major U.S. cities, such as Phoenix, Miami, and Chicago, Oakland has the smallest variation in average daily temperature, ranging from 40 degrees Fahrenheit (4 degrees Celsius) in winter to 80 degrees Fahrenheit (27 degrees Celsius) in summer. Chicago and Burlington both have ranges that span almost 90 degrees F. Oakland also experiences approximately one-third the annual precipitation of Chicago or Burlington and one-fourth the precipitation of Miami.

These temperature and precipitation data demonstrate that Oakland (and Alameda County in general) has a relatively mild climate. Thus, the total effect of weather variables identified in this Alameda County study may be closer to a lower bound of the potential explanatory power of weather variation. By comparison, Vermont has a harsher climate than Alameda County, and the continuous pedestrian volumes collected in the Aultman-Hall et al. (7) study showed up to 30 percent of the variation in pedestrian volume could be due to weather conditions. Therefore, it is possible that regions with greater weather variation have greater fluctuations in pedestrian volumes due to weather.

Differences in pedestrian activity levels in different parts of the country may be due to variations in weather. However, pedestrians in different regions may also have different responses to weather because of the weather to which they have been conditioned. It is also possible that land use and weather-related effects may interact. Therefore, it may be valuable to compare the effect of weather on pedestrian volume patterns at groups of sites with different land use characteristics. In addition to studying differing land use among various locations, it may also be important to account for other factors that may influence pedestrian volumes at a given site. These factors may include measures related to the existence of pedestrian facilities, accessibility, safety, and network connectivity.

Further, the specific weather variables used for this study may not capture all the effects of the weather environment on pedestrian volume. There may be additional interaction effects that were not included in this analysis that better reflect the impact on pedestrians.

Future studies should be conducted that combine the strengths of the previous research. Ideally, detailed weather data for a long, continuous period of time (preferably a year or more) would be available. This could be combined with accurate pedestrian counts for many different locations with different land use and site characteristics. If done in a region with a significant amount of variation in hourly, daily, or seasonal weather, the results may be more dramatic. Regional differences (weather, behavior, urban design) may be strong enough that separate analyses would be required to capture varying weather effects among regions. Addressing these issues in future studies may improve pedestrian volume modeling and pedestrian risk analysis.

CONCLUSION

Weather can influence decisions about which trips to make, where to go, and what mode to choose. This paper identifies specific weather conditions that have a significant impact on pedestrian volumes at 13 sites in Alameda County, CA. It shows the importance of accounting for weather when analyzing pedestrian volumes. However, the sites studied in Alameda County show that weather effects may hold less explanatory power than other determinants of pedestrian volume, such as land use characteristics. During the hours studied, the group of weather variables alone was found to account for at most 10% of the total variation in pedestrian crossings at any specific location. However, individual weather conditions, including rain, clouds, wind, and temperature, can have significant effects on the pedestrian volume during a given hour. Weather variation appears to be more significant during weekend hours and during the midday hour on weekdays. This pattern may be due to more discretionary trips being taken during those times and days. Other geographic regions that have more extreme variation in hourly, daily, and seasonal weather measurements may show that weather variations account for more of the pedestrian volume variation than was found in the relatively mild climate of the San Francisco Bay Area.

REFERENCES

1. Schneider, R.J., L.S. Arnold, and D.R. Ragland. "A Pilot Model for Estimating Pedestrian Intersection Crossing Volumes," UC-Berkeley Traffic Safety Center, Transportation Research Board 2009 Annual Meeting CD-ROM, 2009.
2. FHWA. *Traffic Monitoring Guide,* U. S. Department of Transportation, Washington, D.C., 2001.
3. Clifton, Kelly J. and Andrea D. Livi. "Gender Differences in Walking Behavior, Attitudes About Walking, and Perceptions of the Environment in Three Maryland Communities," Research on Women's Issues in Transportation Vol. 2: Technical Papers, Report of a Conference No. 35, 2005.
4. Cervero, Robert and Michael Duncan. "Walking, Bicycling, and Urban Landscapes: Evidence from the San Francisco Bay Area," American Journal of Public Health Vol. 93, No.9, 2003.
5. Walton, D. and S. Sunseri. Impediments to Walking as a Mode Choice, Land Transport New Zealand Research Report 329, 2007.
6. Schneider, R.J., L.S. Arnold, and D.R. Ragland. "A Methodology for Counting Pedestrians at Intersections: Using Automated Counters to Extrapolate Weekly Volumes from Short Manual Counts," UC-Berkeley Traffic Safety Center, Transportation Research Board 2009 Annual Meeting CD-ROM, 2009.
7. Aultman-Hall, L., D. Lane, and R.R. Lambert. "Assessing the Impact of Weather and Season on Pedestrian Traffic Volumes," University of Vermont Transportation Research Center, Transportation Research Board 2009 Annual Meeting CD-ROM, 2009.
8. Greene-Roesel, Ryan, M. Chagas Diogenes, D.R. Ragland, L.A. Lindau. "Effectiveness of a Commercially Available Automated Pedestrian Counting Device in Urban Environments: Comparison with Manual Counts," Transportation Research Board, 2008.
9. Haby, Jeff. Explaining Dewpoint and Relative Humidity to the Public. http://www.theweatherprediction.com/habyhints/190/. Accessed July 2009.