Assessing the Impact of Weather and Season on Pedestrian Traffic Volumes

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ABSTRACT

Twelve months of automated hourly pedestrian counts in downtown Montpelier, Vermont (pop. 8,035) were analyzed along with weather data (temperature, relative humidity, precipitation, and wind) to determine the factors affecting count variability. The study is unique in that a large amount of data in a single location was collected in a locale with an extreme range of weather conditions. Results indicate consistent patterns in relative volumes by hour of the day and month of year that show that good adjustment factors can be developed to use with time-limited counts to estimate usage and pedestrian exposure to accidents. Some predictive relationships were found between weather variables, season and pedestrian volumes (no more than 30% of variation and 20% of volume are affected). Precipitation and season do impact pedestrian levels even when time of day and day of week are controlled, but other larger unmeasured factors are at play. The impact of weather on walking levels in a business and commercial downtown is large enough to consider programs and counter measures that might increase walking in adverse weather.

INTRODUCTION

This paper analyzes a one-year time series of pedestrian traffic volumes on a single downtown sidewalk location and seeks to evaluate the impact of weather on volume levels while controlling for time and day. Most previous pedestrian counts datasets have been collected in locales with less severe weather than this site in Vermont.

We have two broad research goals. First, it is our intention to contribute to a small but growing base of data on temporal variation in pedestrian traffic volumes that might allow a weekly count to be corrected for any week of the year based on standard factors such as those in the Highway Capacity Manual for vehicular traffic. Second, as part of coordinated efforts at the University of Vermont Transportation Research Center, we are seeking to understand seasonal and especially winter weather impacts on travel decisions including pedestrian travel decisions. Ultimately, a better understanding of the factors affecting the choice to use non-motorized transportation will assist 1) policy makers to establish programs that increase walking levels, 2) transportation engineers to address operations and capacity issues, and 3) demand modelers to include walking as a mode in regional models to more accurately forecast non-motorized trips. Increasing non-motorized transportation will in turn reduce energy use, improve the transportation system, and benefit public health through more active living.

BACKGROUND

There is insufficient data for bicycle and pedestrian professionals to adequately forecast demand, adjust short term counts to other times of year, or quantify the benefit of improvements. Specific research on the factors influencing non-motorized travel behavior has been called for by the Federal Highway Administration *(1)*. The general lack of data has recently been affirmed by a private sector company stepping forward and proposing a national documentation project *(2)* including counting standards. Such a task is daunting, as pedestrian volumes have been found to vary by location, street and path type and days of the week *(3)*. While some have demonstrated relatively stable daily patterns in hourly pedestrian volumes even when overall total volume differs, the difference by land use type and surroundings are still noted *(4)*. When researchers consider forecasting pedestrian travel, the large number of factors affecting levels becomes the challenge *(5)*. Moreover, automated methods to count pedestrians can be prone to errors and simply cannot capture the complex factors affecting pedestrian volumes including behavioral aspects *(6)*.

Previous studies have addressed the impacts of climate and season to some extent. Clifton et al. *(7)* found in their Maryland studies that slightly more than 40% of both males and females reported reducing walking in bad weather and that 12-15% stopped walking due to season. In a survey of Tennessee university students, 24% of respondents cited weather as a factor for driving instead of biking or walking *(8)*. In Australia, weather and season were found to have only slight effects on bicycle commuters *(9)*. The authors of this study argue that the perception of weather rather than the weather itself might be more of a deterrent *(9)*.

Several studies find that weather and season affect walking speed *(10,11,12)* although results vary. Some have found winter increases walking speed while others find the opposite. Muraleetharan et al. *(13)* suggest that walking may increase in winter in their Japan study because cyclists are walking not biking. They also suggest weather may impact route choice. Guo et al. *(14)* have found that season affects transit ridership.

In summary, levels of pedestrian activity are found to be affected by numerous complex factors. More pedestrian data are needed in order to address a range of important transportation planning questions. Others have obtained results that suggest weather and season are factors that affect pedestrian levels to some degree. This study has the advantage of a long time period of data collection (hourly observations for a full year) in a location with a significant range of weather conditions. However, data are only collected in one location.

Measuring the impact of weather will allow planners and program managers to consider weather as a factor to lengthen the pedestrian transportation season in northern climates or to take steps to encourage walking during bad weather such as snow, ice or rain. Furthermore, seasonal adjustments for pedestrian accident exposure have been suggested *(15)* and the complete data to obtain such factors which will vary spatially and temporarily have not been collected. This suggests pedestrian travel data are important for planning purposes as well as safety analyses. Collecting data for a long period at one site provides a means to assess whether relative patterns by hour of day and consistency throughout the week allow for correction factor development.

DATA

In this project we make use of two merged hourly datasets: automated pedestrian counts and weather reports from the National Climatic Data Center. Pedestrian counts were recorded at a single downtown location in Montpelier Vermont (population 8,035) for one year from November 2, 2006 to November 1, 2007. Montpelier is the state capital and in addition to retail and commercial businesses, the downtown is home to numerous state government office complexes. The counter is the grey box attached to the pole with a parking meter (mounted 113 cm above the ground and 328 cm from the buildings). It is located on the west side of Main

Street between on street parking and commercial store fronts. Figure 1 is the view south. A bridge before the hill in the distance concentrates pedestrian traffic to this street within this corridor. The town's main intersection is to the north.

Figure 1: Pedestrian Counter on Signpost in Montpelier Vermont

The device is an Eco-counter Pyro Double Middle Range and is owned by the Vermont Agency of Transportation (VTrans). It was installed by VTrans and data have been downloaded and managed by their project team. The infrared sensor can distinguish direction of travel but cannot distinguish between cyclists and pedestrians. In this location cyclists are expected to be minimal.

While 46.5% of the total pedestrian volume was southbound (the direction of vehicular traffic on this side of the road) and 53.5% was northbound over the one year, total aggregate pedestrian volume in both directions is used in this study. Others have conducted a comparison of this type of counter with video data at three locations and found 9% to 19% undercounting *(16)*. VTrans performed a 2-hour manual check of the counter in 2006 and determined 98% accuracy *(17)*. We conducted a comparison with a manual count in this location in 2008 for a six hour period on one day and found the Eco-counter undercounting by 5%. In this particular location, counters noticed that people putting coins in the parking meter were blocking the counter while pedestrians walked by. We also noted a large difference between the errors in one direction and the other but with this limited observation time no reasons for this difference were evident.

Weather data were downloaded from the National Climatic Data Center for the Edward F Knapp State Airport approximately 3 miles from the counting site. Hourly data were used to link to count information. In most cases, the hourly weather observation was recorded at 51 minutes after the hour which was mapped to the pedestrian count from the 51 minutes before until 7 minutes after the weather observation. When more frequent precipitation observations were recorded (about 65.8% of the hours had extra observations called special reports) the observations were aggregated to hourly totals. The following information was recorded and linked to the pedestrian counts based on time of day: temperature, relative humidity, depth of precipitation, and wind speed.

Overall, the database is very complete and few missing values were present. A total of 21 hours of data during the year were missing relative humidity, while 4 were missing wind speed. Flags indicating trace precipitation were converted to zeros. The large number of blank precipitation records were converted to zero. Four days of data were missing data during a unusually large snow storm in February 2007; the counter data was otherwise unedited. The range, mean and standard deviation for temperature, relative humidity, precipitation and wind speed are shown in

Table 1. As the table illustrates, Montpelier experiences a wide range of temperatures and humidity. It would not be considered windy although it is important to note a reasonable proportion of the precipitation falls as snow or ice and wind is reasonably associated with these winter storms.

Table 1: Summary of Hourly Weather Data

	N	Minimum	Maximum	Mean	Std. Deviation
Dry Bulb Air Temperature (degrees C)	8664	-26.7	32.8	7.47	11.5
Relative Humidity (%)	8643	11.0	96.0	68.63	17.8
Wind Speed (mph)	8660	0.0	29.0	5.24	5.0
Hourly Precipitation (inches)	8664	0.00	0.82	0.0045	0.029

Several variables were created for use in the analysis. A dummy variable for both precipitation, and precipitation when the temperature was below freezing, were created. This corresponds to 9% and 2% respectively of hours when data were recorded. The day of the week record was categorized to dummy variables indicating weekday, weekend and holiday. A total of 11 holidays which fell on weekdays such as the Fourth of July were recorded. The pedestrian volume mean is shown by day and day type in Table 2. As one would expect much of the variation indicated by the standard deviation in Table 2 is due to the differences in pedestrian volume by time of the day as shown in Figure 2. Based on these results, holidays and Sundays were categorized together as were weekdays and Saturdays for a portion of the analysis where volumes were normalized for hour of the day.

The daily pattern in Figure 2 is considered a location-specific attribute. Although there are many workplaces nearby, there is not an AM or PM peak as one might expect if most of the pedestrians were commuting. Rather the pedestrian volume peak at noon and in the afternoon suggests workers eating out, running errands and other shoppers in a commercial district. The total pedestrian volume for each day was calculated and for each hour the percent of the day was calculated. This may be thought of as the hourly share of the given day's pedestrian traffic volume. Figure 3 shows the mean hourly share by hour of the day for the whole year. The error bars correspond to the 95% confidence interval on the mean. The intervals are very small and support the findings of others that the relative levels of pedestrian hourly volumes at a given location are constant throughout the week and year.

Table 2: Mean Hourly Pedestrian Volume by Day and Day Type

Day Type	Mean	N	Std. Deviation
Holiday	56.8	264	69.2
Weekday	104.1	5952	99.9
Weekend	81.7	2448	78.8
Monday	94.4	1248	97.6
Tuesday	101.8	1248	101.3
Wednesday	98.8	1248	95.7
Thursday	100.5	1248	98.4
Friday	115.2	1224	102.0
Saturday	100.2	1224	89.2
Sunday	63.1	1224	61.5
Total	96.32	8664	94.3

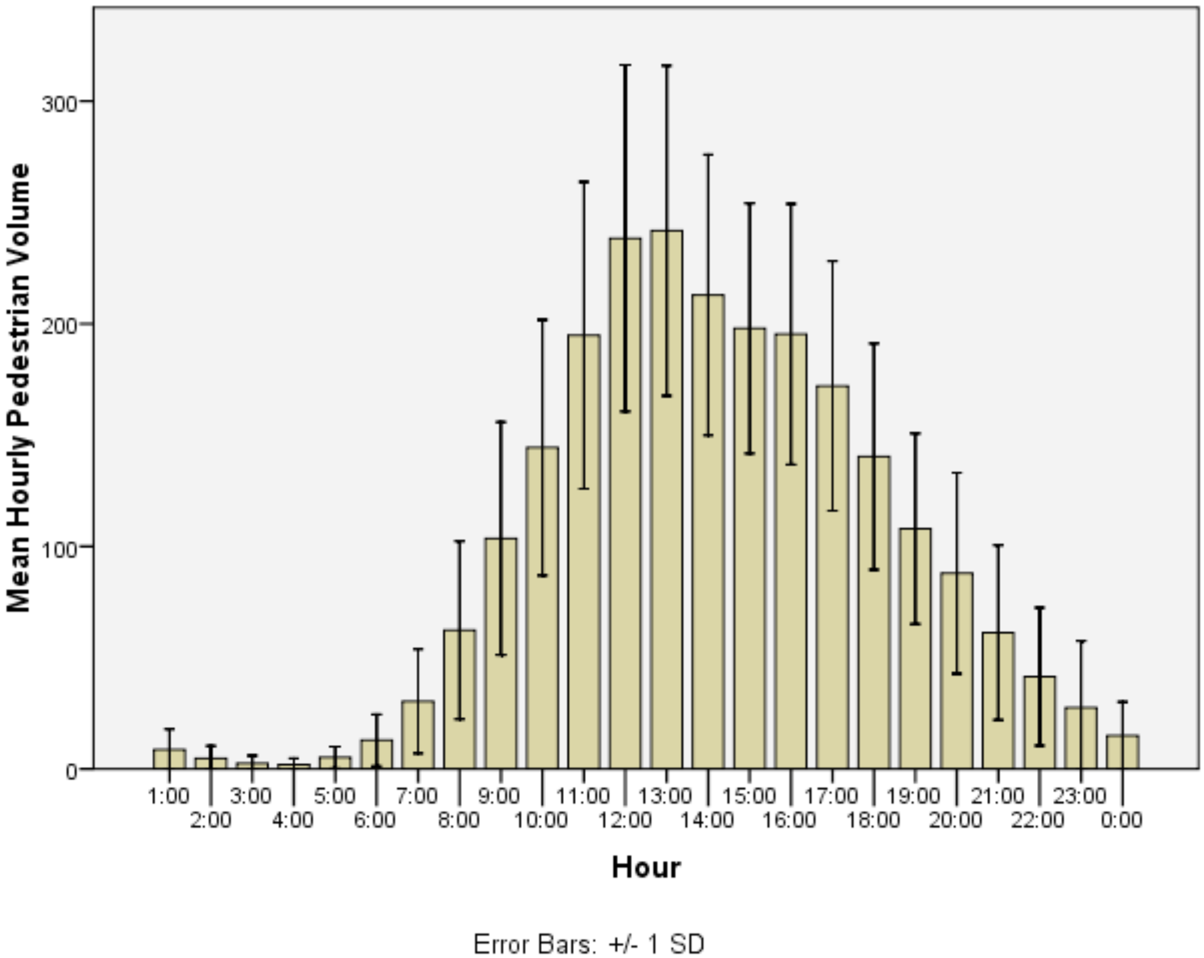

Figure 2: Mean Pedestrian Volume by Hour of the Day

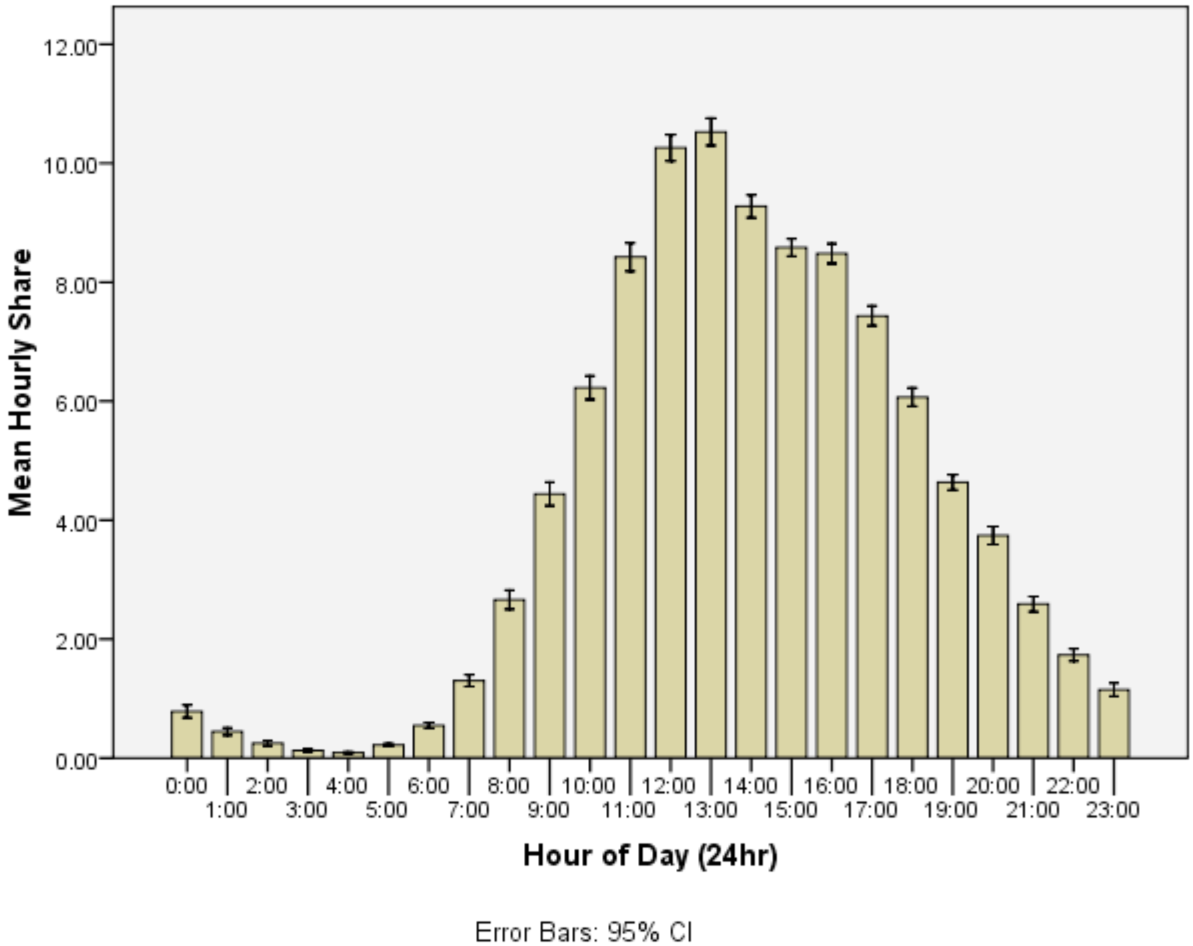

Figure 3: Mean Share of Daily Pedestrian Volume by Hour of the Day

As shown in Table 3, the variation by month is not as large as that throughout the day. It was initially assumed that monthly pedestrian volumes would be correlated with the weather variables of interest in the study. One-way Analysis of Variance (ANOVA) confirms that between month differences in pedestrian volume are significant ($p < 0.0005$). Other factors beyond weather such as festivals, state legislative sessions or seasonal businesses are assumed to impact these monthly differences but are not measured here. The winter months of January through April are lower but December is not, presumably due to Christmas holiday shopping in this downtown location. Note that winter daylight hours are short in Vermont but that if this alone was a factor in pedestrian volumes we would expect December to also be low. The months of January through April might reasonably be associated with times when snow is present on the ground. Therefore a dummy variable for winter was created corresponding to the months of January through April.

Table 3: Hourly Pedestrian Volume by Month

Month	Mean	N	Std. Deviation
JAN	85.89	744	89.80
FEB	76.23	576	83.86
MAR	91.87	744	92.16
APR	88.32	720	86.13
MAY	99.85	744	93.51
JUN	102.38	720	89.56
JUL	104.06	744	94.29
AUG	102.86	744	91.69
SEP	95.17	720	87.43
OCT	100.54	744	96.86
NOV	94.46	720	96.16
DEC	109.51	744	119.24
Total	96.32	8664	94.34

Because one main objective of the analysis is to measure the impact of weather on pedestrian volume, the volumes needed to be normalized for day of the week and hour of the day. A factor of the mean was calculated using the following equation:

Factor of Mean = Hourly Total / Hourly Mean for Day Type

where the hourly mean for day type was calculated for the given hour of the day for either weekday/Saturday or holiday/Sunday. The result is a variable distributed around 1.0 where a value above 1.0 indicates the pedestrian volume for that hour was higher than the mean for that hour and day type. Similarly, a value below 1.0 indicates the given hour is lower than the mean for the particular hour and day type. A histogram of the factor of the mean is provided in Figure 4. Note the distribution is not completely normal.

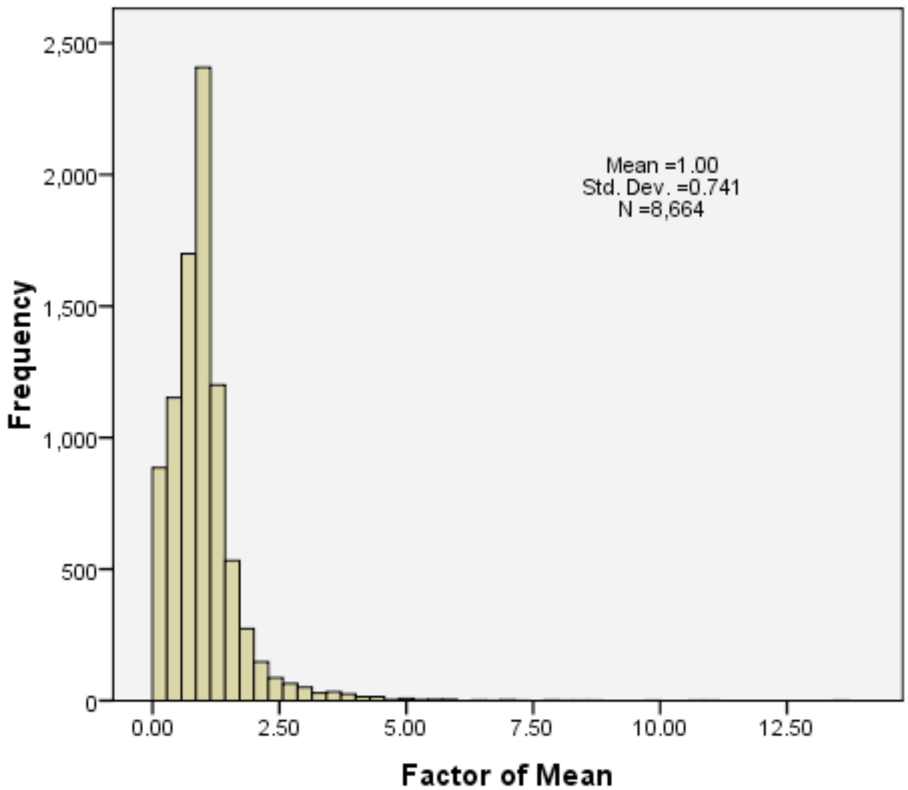

Figure 4: Factor of Mean (normalized for hour and day type) Frequency

Using the factor of the mean it is possible to consider whether a HCM-style correction for time of year or month of year might be feasible for this location. Figure 5 illustrates the confidence interval of the monthly means for the factor of the mean pedestrian volume. The relatively small confidence intervals suggest some feasibility but the causal impacts by month of the year remain unclear. February is a busy month for the adjacent legislature, but it includes a school vacation week when many families travel. It could be perceived as having bad winter weather, and along with November, could be affected by limited daylight. August may be a popular vacation month and could be too hot for the northern pedestrians.

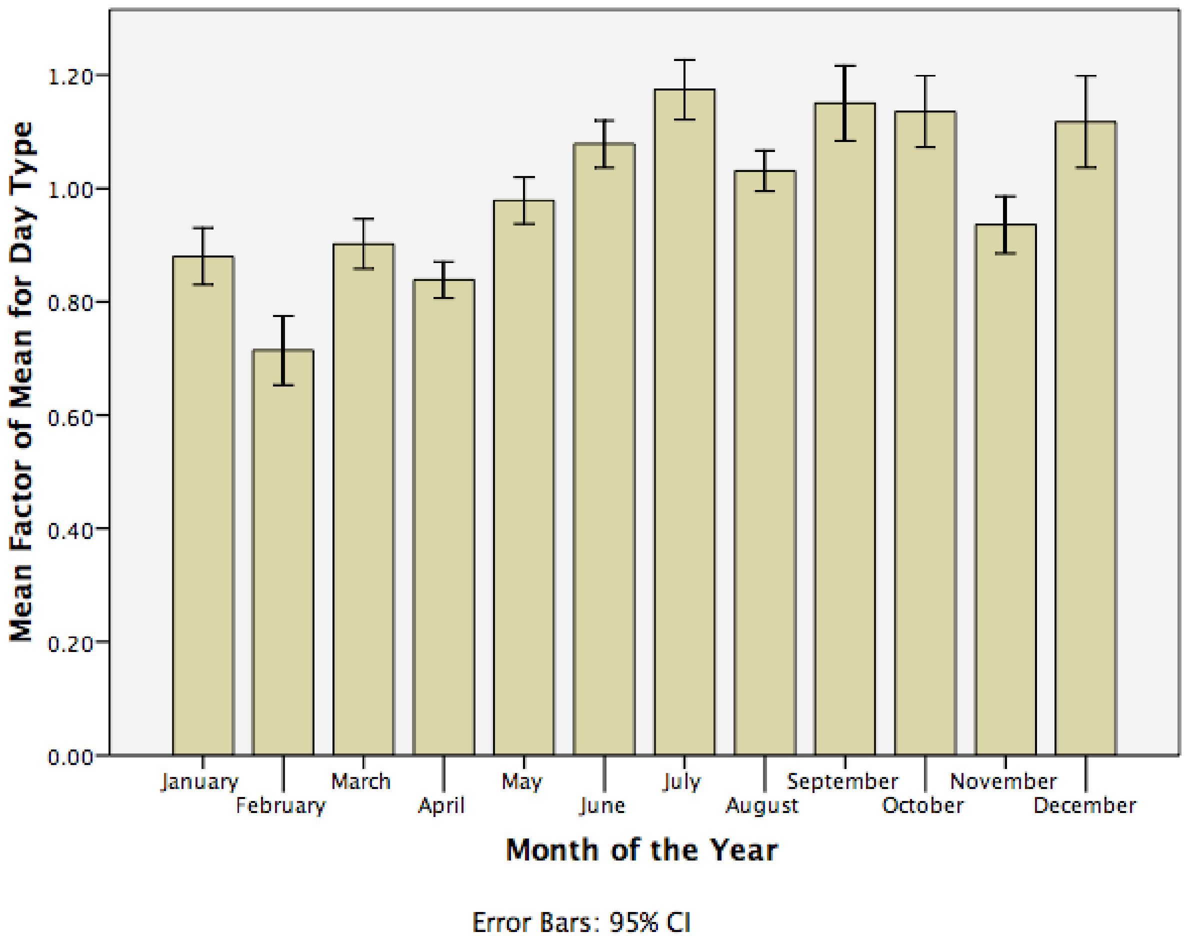

Figure 5: Mean Pedestrian Volume by Month

RESULTS ON WEATHER AND SEASON

In order to evaluate the impacts of weather conditions on pedestrian volume linear regression models were initially pursued. In the first model estimations, the modeled output variables were weekday/Saturday factor of the mean and holiday/Sunday factor of the mean. In the second set of model estimations, only the noon hour (the peak time for most days) or the 8 hours from 10AM to 6PM were used.

As a first step, linear correlations between the continuous predictor variables temperature, wind speed, relative humidity and precipitation were calculated. Although statistically significant correlations were found, all absolute values of the Pearson's Correlation Coefficient were below 0.20 except for a -0.4 correlation between relative humidity and wind speed.

A Student's t-test was used to evaluate the difference in mean between hours with and without precipitation or frozen precipitation (there was not a way to distinguish between ice and snow). For weekdays/Saturday the levels of hourly pedestrian volume were significantly lower (factor of the mean 0.87 and 0.86) for hours with precipitation and frozen precipitation than for days without (1.01 and 1.00). However, for holidays/Sundays, the hourly pedestrian volumes were not statistically different for days with and without precipitation or frozen precipitation. This may be due to the low pedestrian volume those days, either as a statistical power effect or because there may be a certain number of pedestrians who must travel regardless of the weather. The difference between the hourly factor of the mean for winter (January through April) and the other months was statistically significant (0.84 versus 1.08 $p < 0.0005$). One might interpret these mean differences by saying precipitation reduces average pedestrian volume by 13% on weekdays and Saturdays but not on Sundays or holidays. And "winter" reduces average pedestrian levels by 24%.

Scatterplots such as those shown in Figure 6 reveal large scatter in the factor of the mean for pedestrian volume with all continuous predictor variables for both weekdays/Saturdays and holidays/Sunday. Similar scatterplots were created by month and season and also only noon in the summer months of June, July and August as shown in Figure 7. No strong relationships were noted. A small quadratic relationship was found between pedestrian factor of the mean and temperature with very cold and very hot temperatures reducing pedestrian volume levels slightly. Whether this is due to fewer pedestrians, or poor counter performance in extreme conditions requires additional checks to determine.

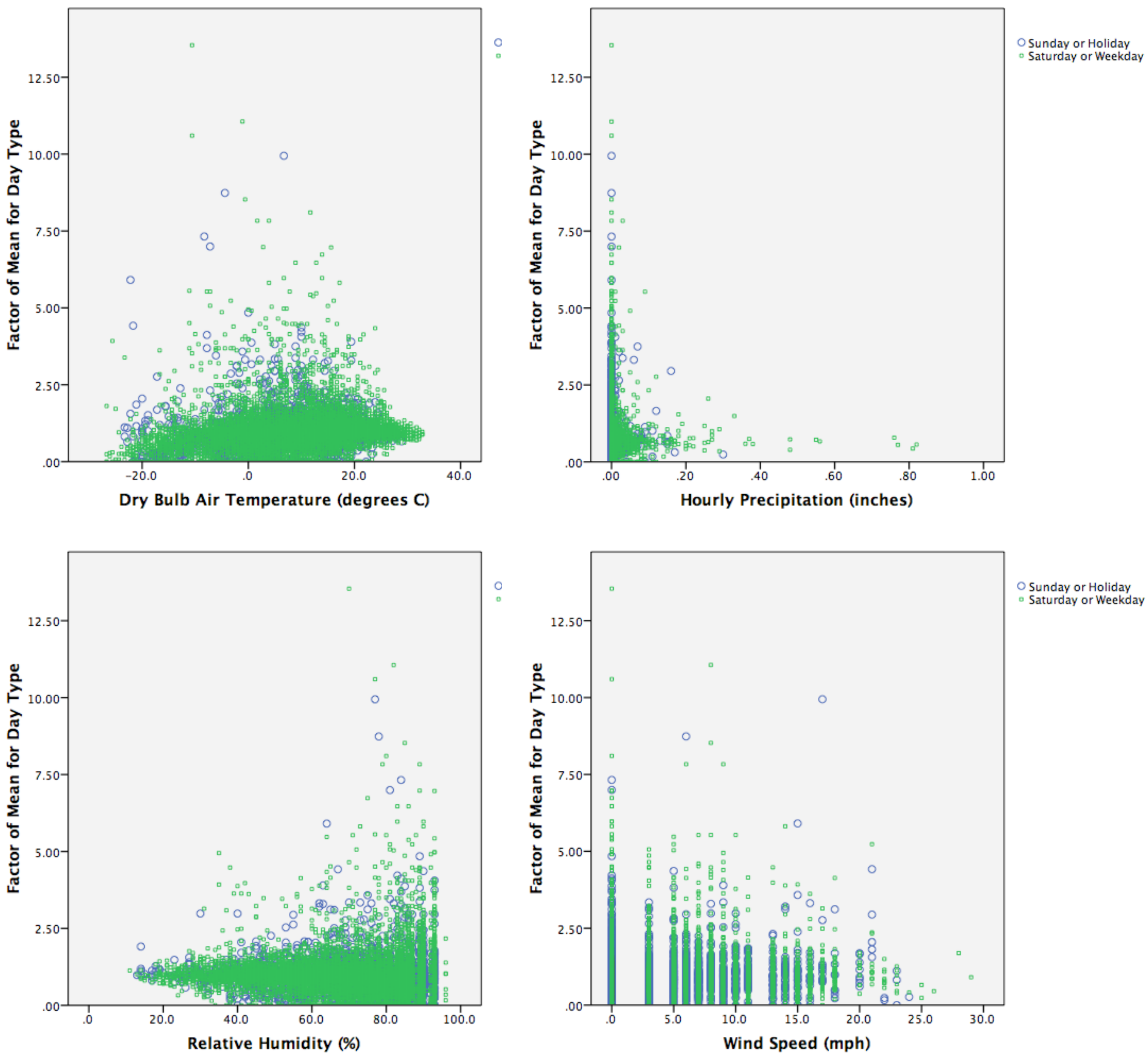

Figure 6: Pedestrian Volume and Weather Factors (all hours)

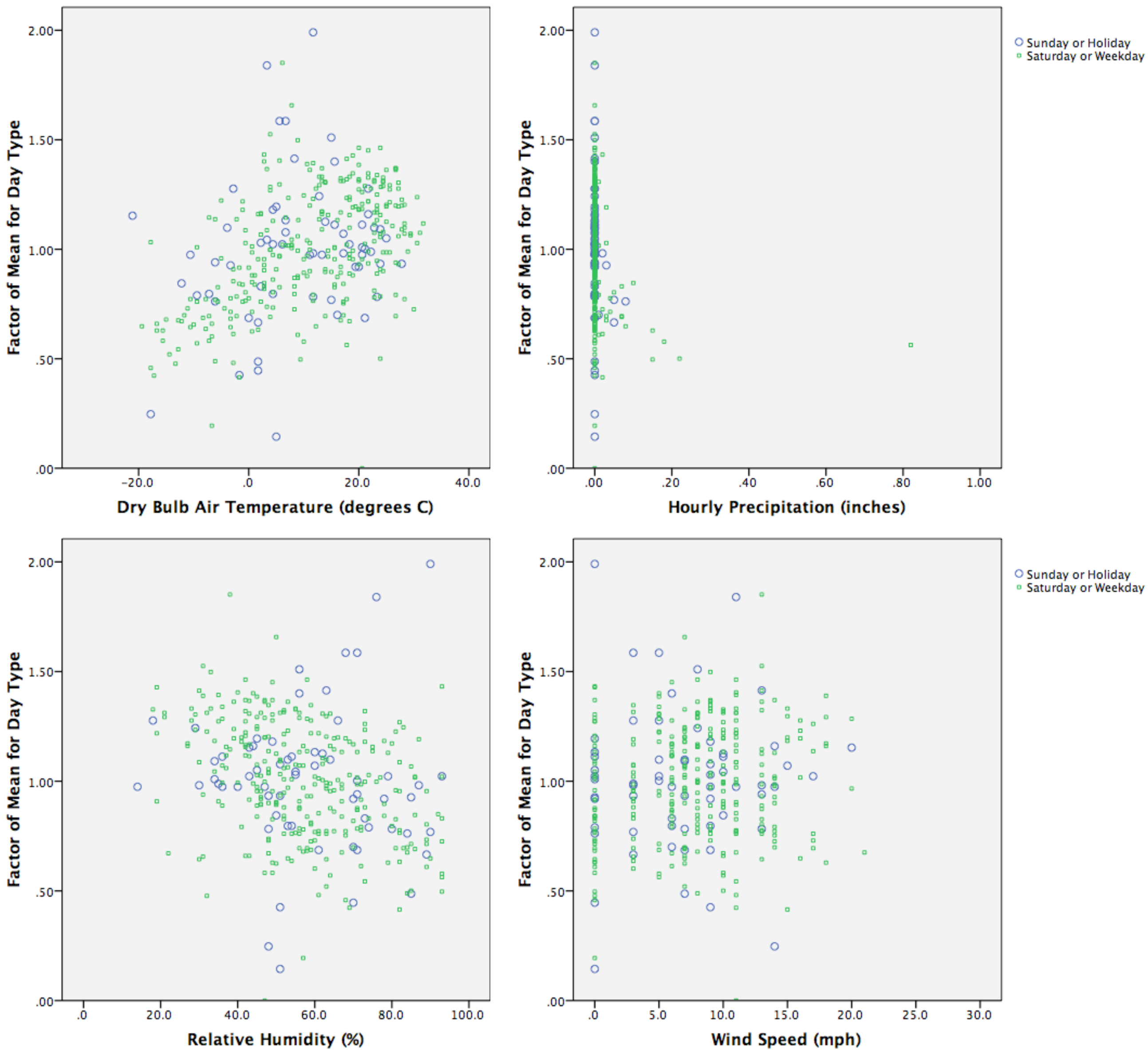

Figure 7: Pedestrian Volume and Weather Factor (noon only)

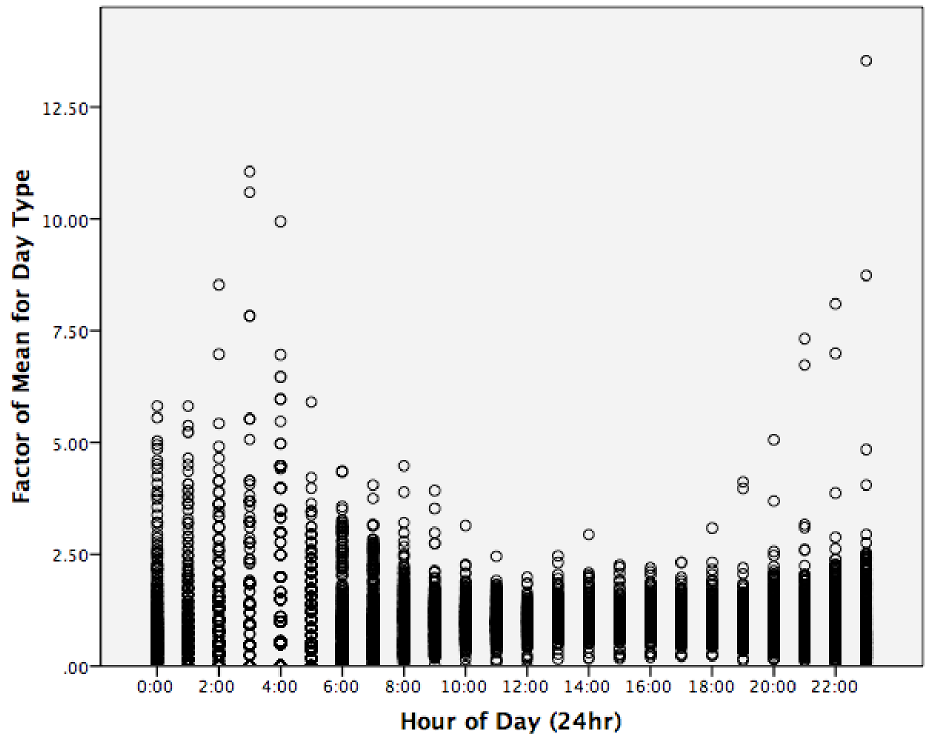

Figure 8: Distribution of Factor of the Mean Pedestrian Volume by Hour of Day

When linear regression models were estimated for all 24 hours of the weekday/Saturday dataset all coefficients for the weather variables were significant. However, the adjusted R^2 of 0.03 confirms that these variables account for little of the variation in the hourly pedestrian volumes. For the holiday/Sunday dataset, none of the precipitation variable coefficients were significant and the R^2 was still 0.03. Recall the factor of the mean already accounts for hour of the day as well as whether the observation was on a weekday/Saturday versus holiday/Sunday.

Because the factor of the mean is skewed by the very low pedestrian volumes in the night (Figure 8) regression models were estimated for only the hours of 10AM through 6PM. But no R^2 above 0.05 was obtained. In all cases, a significance level of 0.05 was used for testing if coefficients were significantly different from zero using a Student's t-test.

For the noon hour regression model development, the predictor variable temperature squared was included. Model parameters are shown in Table 4. Other weather variables did not have significant coefficients. This model had an adjusted R^2 of 0.3. Therefore, even for the peak noon hour, weather only accounts for 30% of the overall variation in volume. Note that the different effect of precipitation on holidays/Sunday versus weekdays/Saturday affected several model specifications and is the reason the output variable of factor of mean is retained in this noon model. The constant of 1.139 indicates the mean pedestrian volume in the noon hour is higher than the rest of the day. On average this model suggests pedestrian volume increase in the noon hour by 1.5% for every degree C. But note the negative coefficient for temperature squared; that is very cold and very hot temperatures reduce volume. Humidity has a limited but statistically significant effect. Any type of precipitation reduces the volume by on average 15%.

Table 4: Linear Regression Model for Noon Hour Pedestrian Volume

Parameter	**Coefficient**	**P value (Student's t-test)**
Constant	1.139	<0.0005
Temperature C	0.015	<0.0005
Relative Humidity (%)	-0.003	<0.0005
Precipitation (yes/no)	-0.152	0.002
Temp * Temp /100	-0.041	<0.0005

CONCLUSIONS

These results are consistent with other studies in establishing that pedestrian volumes are affected by a large number of interrelated factors. While this study was based on counts at only a single location, the wide range of weather conditions provides a robust dataset. The findings suggest that season and weather have an effect on levels of pedestrian volume in downtown Montpelier Vermont. Precipitation reduces the average hourly volume level by approximately 13% and the winter months reduce it by 16%. At best a combination of weather variables account for 30% of the variance measured in hourly volumes. From a predictive power point of view the models are weak. But considered as portion of variability, 30% is high and suggests policies and measures to address weather as a factor in walking levels might be worthwhile.

The year of hourly data clearly suggest that reasonable week of year and hour of day corrections factors can be estimated. But the overall shape of the daily curve for this test location, without AM and PM peaks, reaffirms the assertions made by others that pedestrian volumes are very site specific. This suggests that household travel survey or planning style analysis rather than operational count are best suited for understanding behavioral motivations for pedestrian travel.

For policy makers and transportation planners, these initial findings are useful in several ways. First, the consistent hourly pattern within a day and the consistency of day type (weekday/Saturday versus holiday/Sunday) suggests that correction factors and forecasting methods are feasible. The daily pattern is likely to vary significantly from place to place and an effort to define a number of pedestrian location types might assist with factor development. Second, the results indicate that weather such as cold temperature or precipitation are directly and consistently reducing aggregate levels of walking by only a moderate amount (less than 20%). Programs to alter habits/perceptions and extend the walking season may be viable. But many factors are affecting pedestrian activity clearly suggesting more comprehensive data are needed.

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