WEIGHING INTEGRATION BY BLOCK HETEROGENEITY TO EVALUATE PEDESTRIAN ACTIVITY

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ABSTRACT

Pedestrian exposure is a necessary component for a meaningful evaluation of pedestrian safety. The Space Syntax approach has a track record of accurate prediction of pedestrian activity by estimating the physical street connectivity in urban environments. However, for some environments, the performance of Space Syntax is limited and cannot be used as a reliable estimate of exposure. This paper makes use of the interdependency between: (i) street connectivity - estimated here using *integration*; and (ii) land-use characteristics; to propose a mechanism to adjust *integration* by land-use features at the block level. Different levels of *integration* for each street-block, which hold the same mean values along the same street, are weighted based on dominant land-use features. The *weighted integration* value for a street-block dominated by commercial property is higher than the mean *integration* value for that street. Conversely, the *weighted integration* value for a residential street-block is lower than the mean *integration* value for that street. The proposed approach captures the heterogeneity of street-blocks, which is not always captured by Space Syntax. Applying this method to the northern periphery of the University of California, Berkeley, has produced promising preliminary results. It was shown that the *weighted integration* values (at the street-block level) are better correlated with pedestrian volumes than mean *integration* values (street scale). Further research efforts are required to develop this simplified approach into a pedestrian exposure prediction model.

Key words: pedestrian volumes, weighted integration, street-block, land-use.

BACKGROUND

The interpretation of crash statistics should be accompanied by concepts of *exposure* and *risk* (*1*). Where *exposure* is defined as the number of opportunities for a crash of some type to happen at a specific time-space region, and *risk* is defined as the probability for a crash of some type to occur in a specific time-space region. In light of this, to estimate the *risk* for pedestrians it is necessary to control the absolute number of crashes by pedestrian *exposure* using pedestrian prediction models. Since urban streets are not homogenous it is important to study how different designs affect safety and therefore necessary to obtain *exposure* data at the block level.

Space Syntax theory (*2, 3*) uses spatial and structural descriptions to simplify the complexities of cities, and has played a central role in providing insights regarding pedestrian movement dynamics. Space Syntax also has a track record of high accuracy predicting pedestrian activity within streets in urban environments. It uses *integration* as a measure of accessibility, based on the spatial configuration of urban spaces (*4, 5*).

Predicting pedestrian activity using land-use data has also been shown to produce reliable results (*6, 7*). The assumption here is that land-use features serve as pedestrian attractors and can predict pedestrian activity. In situations where the spatial configuration is not sufficient to predict pedestrian activity, a range of land-use characteristics are used to complement integration by applying a multivariate regression analysis (*8, 9, 10, 11*). This association is necessary because the urban morphology creates a "natural" first movement of pedestrians (*5*), which in turn, attracts more activities and transit opportunities along the main arterials. In turn, the presence of activities and the accessibility to transit amplify the pedestrian traffic. Therefore, integration and land-use rely on each other and describe complementary parts of the complexities of a city. Based on these observations, it seems that incorporating Space Syntax and land-use in a complementary manner would be beneficial.

It is important to emphasize that this manuscript describes preliminary work towards developing a weighting mechanism for Space Syntax using land-use variables, and does not claim a prediction model. It therefore serves the purpose of demonstrating the potential of such an approach.

In the subsequent section the proposed weighting mechanism is introduced, and the collected data is describe to demonstrate its potential. The results are presented next, followed by a discussion of the implications of the findings and future research goals.

METHOD

The proposed approach assumes that *integration* estimates an initial average for pedestrian activity at the street level, for a modeled region. Land-use variables, at the block level, are then used as simple weights to increase or decrease the initial value of integration. This way the *integration* determined initially for a street can vary from one block to another depending on its land use.

Urban Morphology

To characterize the street distribution, Space Syntax defines open spaces that are blocks bounded by the streets surrounding them. Lines that are an axial representation of the space cross these spaces. A simple representation consisting of plotting the lines corresponding to the streets was applied using the AGRAPH software (*12*). The axial representation is then converted into a graph where each line (street) is depicted as a "node" and each intersection between the lines is represented by a "link." Manum provides a detailed description of the mathematical formulas used to calculate indicators of Space Syntax characterizing the arrangement of streets, specifically *integration* (*13*):

1. The *Total Depth* (TD_i) of node *i* expresses the number of links between node *i* and all other network nodes. When the total number of nodes, *n*, is high, as is for cities, TD_i increases quickly and using the "Mean Depth" (MD_i) of node *i* is preferred:

$$MD_i = \frac{TD_i}{n-1}$$

   MD_i is then normalized to be between 0 and 1, where higher values represent a more integrated node.
2. The *Relative Asymmetry* (RA_i) of node *i* is express as:

$$RA_i = 2\left(\frac{MD_i - 1}{n-2}\right)$$

3. The *integration* parameter (*Int*) is the inverse of RA_i:

$$Int = \frac{1}{RA_i}$$

It has been shown that the best correlation between Space Syntax parameters and pedestrian volume were obtained with *integration* radius 3, denoted *Int[3]* (*14*). The term "radius" is not related to a distance but rather to the number of links, this means that for a given node, we take into account in the calculations nodes accessible in less than three (≤ 3) links.

Weighted Integration

The method presented hereafter is designed to locally modify the *Int[3]* of a street to reflect block heterogeneity with respect to activities that influence pedestrian movement. In this study, for each observation point, the value of the *Int[3]* is multiplied by five factors noted λ_i ($i = 1,..,5$):

- λ_1 - the influence of residential areas.
  Pedestrian traffic in residential areas has been shown to be lower than expected from integration value (*14*).
- λ_2 - the influence of activities (stores, movies, offices, schools, etc.).
  These activities have been shown to generate pedestrian traffic (*8,15,16*). However, there is no differentiation between the different activity types because there are not enough results in the literature indicating the weight of each activity type on pedestrian movement.
- λ_3 - the influence of public transportation.
  Access to transit is associated with travel by foot (*10*).
- λ_4 - the influence of sidewalks on pedestrian traffic.
  The absence of sidewalk can reduce the pedestrian traffic (*17*).
- λ_5 - the influence of active frontage.

Blank wall locations that have either very few or no retail active frontages should have their Footway Accessibility (i.e., *integration*) values reduced by a constant factor (*10*).

To a large extent, these factors are independent and therefore the assumption that these factors have a multiplicative effect on *Int[3]* is reasonable. For example, if an observation point is located in a shopping area with numerous public transportation stops, the weighted value, *WInt[3]*, would be: $\lambda_3\ \lambda_2\ Int[3]$. When the five land-use features do not dominate, the corresponding weighting factor takes the value of 1 (no modification of *Int[3]*). Land use data are used to evaluate the dominant features of each block in a study area.

TABLE 1 below describes the criteria and the values assigned for each of the factors.

TABLE 1. Criteria for Assigning the Integration Weights

Factor	Value	Criteria	Effect
λ_1	0.5	Street block population density > 10,000 / m^2	Reduction effect
λ_2	2	# of stores > 10	Attraction effect
λ_3	2	# of operational transit stops > 20/day	Attraction effect
λ_4	0.5	incomplete sidewalk	Reduction effect
λ_5	0.5	Predominantly “blank” (parking lot, wall, etc.)	Reduction effect
λ_5	2	Heavily occupied by activities	Attraction effect

Study Area

The study area is the northern periphery of the University of California at Berkeley. The area is bounded on the north by Virginia Street, south by Hearst Avenue, east by La Loma Avenue and west by Oxford Street as shown in Figure **1**. This area was chosen since it has moderate pedestrian activity and consists of many different land-use types such as residential, commercial, academic, etc.

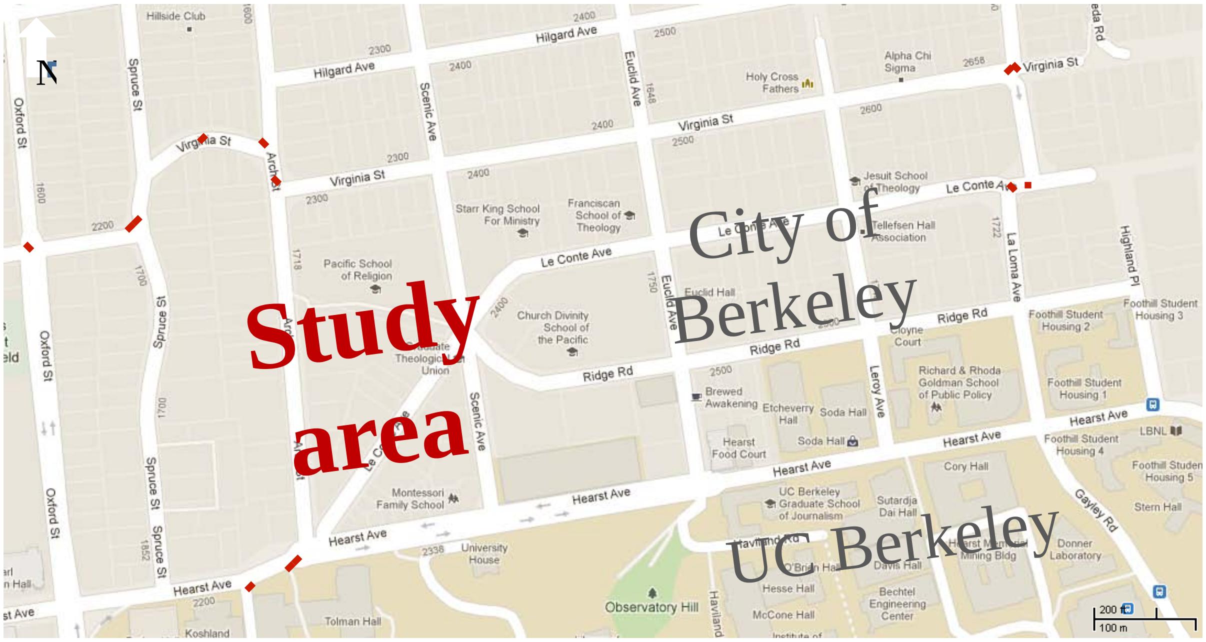


FIGURE 1. Study Area Map

Pedestrian Counts

The counting method is derived from that recommended for Space Syntax analysis by Desyllas and Duxbury (*17*). It consists of midblock counting pedestrians crossing a virtual line in front of the observer (**FIGURE 2**) for 5-minute intervals. The observations were made on two different days: May 3, 2011 and May 19, 2011, which are both after the Spring 2011 semester has ended, and don't represent a typical week. However, since the purpose of this experiment is not a prediction it was not necessary to select a typical week.

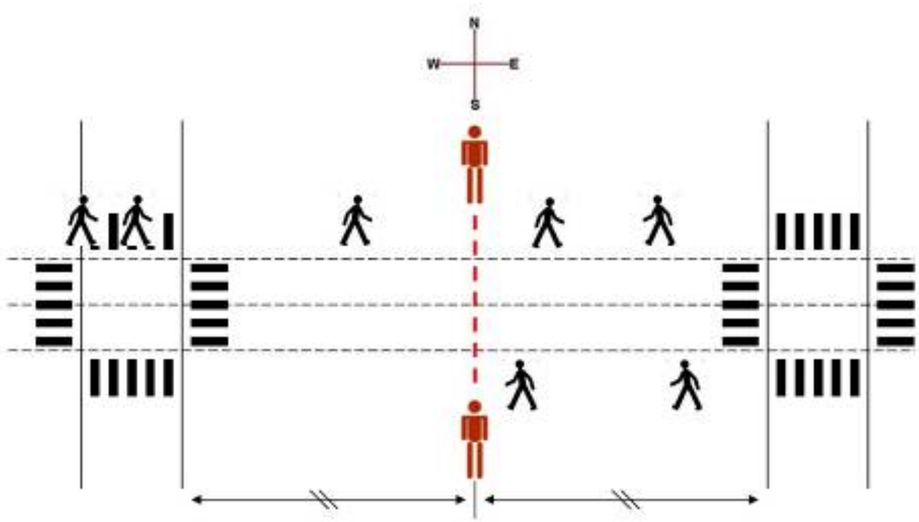
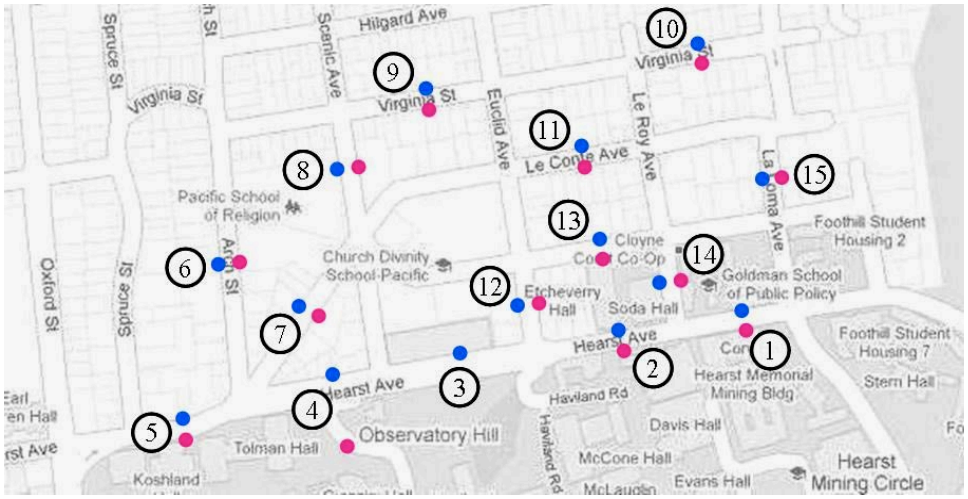


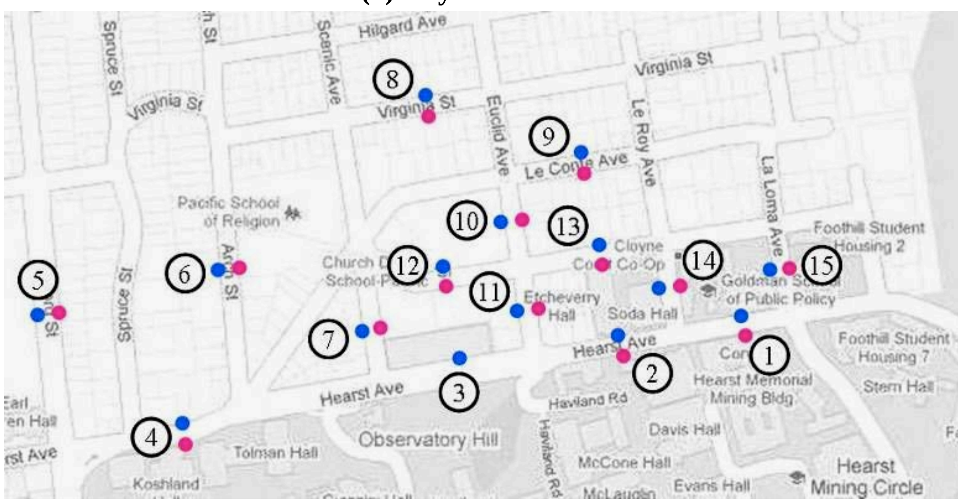
FIGURE 2. Location of a Stationary Observer and Virtual Gate

On May 3, 2011, counts are made over three periods: 8:30 a.m. –10:30 a.m., 11a.m. –1 p m , and 4 p.m. – 6 p.m. The aggregate observation duration (six hours) is shorter than what is usually seen in the literature (ten hours). Nevertheless, the chosen periods are representative of pedestrian traffic (office hours, classes, lunch break, etc.). Fifteen observation points (gates) were selected and their location is shown in **FIGURE 3**. On the second counting day (May 19, 2011), some observation points of the previous day—mostly those located in residential areas—were moved to more crowded places like Euclid avenue to study the block variation of pedestrian traffic.

At each gate, counting is done simultaneously on opposite sidewalks of the street by two observers (points • and • in **FIGURE 3**). Each observer counts passing pedestrians for 5 minutes (red line in **FIGURE 2**) and specifies the direction of movement relative to the four cardinal directions (North, South, East, and West). Observers then move to the next gate in the direction indicated by the route numbers of the gates (1 to 15, Figure 3). The number of gates (15 in total) enables to complete all gates within two hours. The numbering of gates gives the sense of journey made by observers and aims to minimize the walking time from one gate to another.



(a) Day 1 - 3/5/2011



(b) Day 2 - 3/5/2011

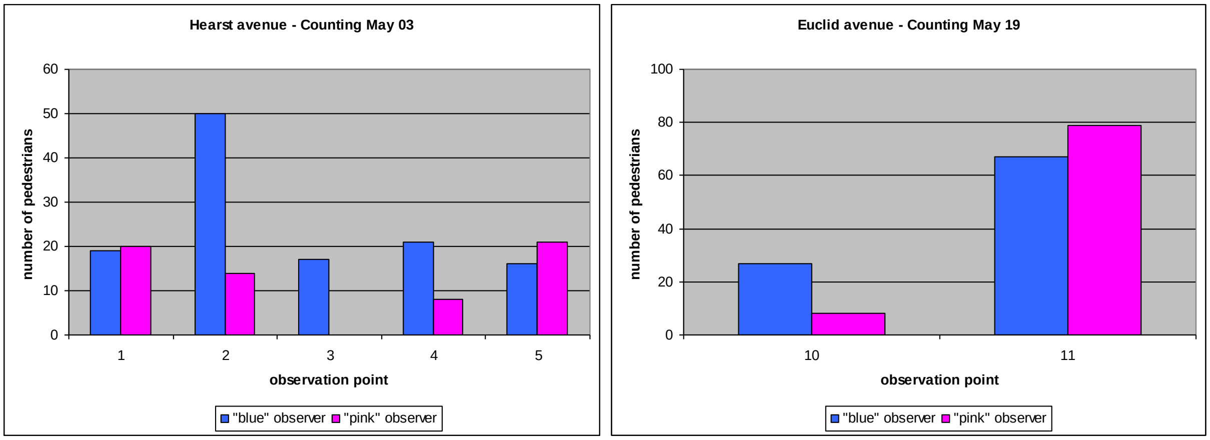
FIGURE 3. Location of Pedestrian Counts

RESULTS

Pedestrian Counts

For streets that have more than one observation point (gate), the number of pedestrians crossing for the different gates were plotted (**FIGURE 4**). Note that since counts can not be made concurrently, the comparison assumes that pedestrian volumes are stationary and do not fluctuate significantly during the counting period of that street. Since the time between two successive gates, is about 8 minutes (5 min. count and ~3 min. to transfer), this comparison is reasonable.

FIGURE 4 shows that the pedestrian volumes may also vary from one side of the block to another (gate 2, and to a lesser degree gate 4, on Hearst Avenue, **FIGURE 4**a) and from one observation point to another (gates 1 and 2 on Hearst, **FIGURE 4**a; gates 10 and 11, **FIGURE 4**b).



(a) Hearst Avenue **(b) Euclid Avenue**

FIGURE 4. Variation in Pedestrian Volumes

For the variation of traffic at gate 2 (**FIGURE 4**a), the explanation comes from the presence of two buildings Soda Hall (Electrical and Computer Engineering) and Etcheverry Hall (Mechanical Engineering) on the North side ("blue" observer) that allow more student to leave classes than all other buildings on the South side ("pink" observer). For the traffic variation between gates 10 and 11 of Euclid (**FIGURE 4**b), the explanation comes from the difference of space occupation between gate 11's block (restaurants, shops) and gate 10's block (virtually no land use) (**FIGURE 5**). The influence of the land use is evident here as the block length is relatively short (about 70m), and one would assume that traffic is the same between gates 10 and 11.

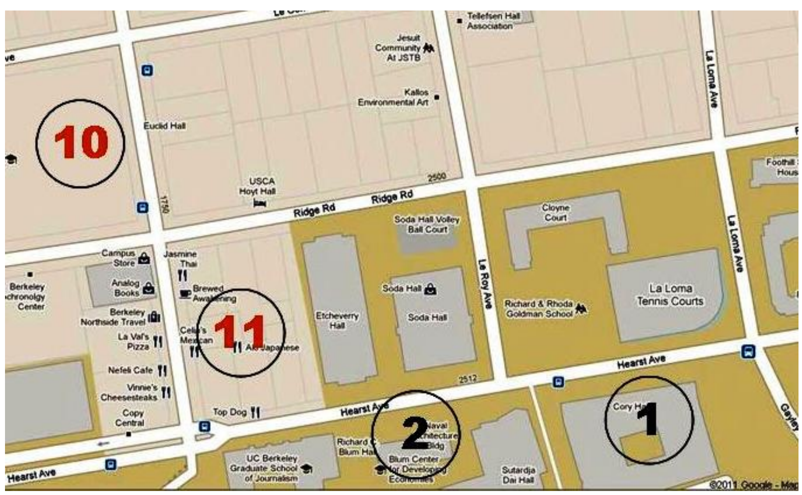


FIGURE 5. Land Use on Hearst and Euclid Avenues

Integration

The results of the Space Syntax analysis are summarized in **TABLE 2** and **FIGURE 6**. The rows of the table are color coded to the same color of the lines in **FIGURE 6**. It shows that all the streets which are horizontal to campus are well integrated. Note that the size of the study area limits the number of links (intersections) between nodes (streets) to 3 at most. The calculate *integration* parameter is therefore automatically of radius 3.

TABLE 2. Space Syntax Parameters for the North Periphery of UC Berkeley

Street	Total Depth	Mean Depth	Relative Asymmetry	Int[3]
Hearst	**12**	**1.200**	**0.044**	22.5
Ridge	**17**	**1.700**	**0.156**	6.4
Le Conte	**13**	**1.300**	**0.067**	15.0
Virginia	**13**	**1.300**	**0.067**	15.0
Oxford	**19**	**1.900**	**0.200**	5.0
Spruce	**19**	**1.900**	**0.200**	5.0
Arch	**17**	**1.700**	**0.156**	6.4
Scenic	**16**	**1.600**	**0.133**	7.5
Euclid	**16**	**1.600**	**0.133**	7.5
Le Roy	**16**	**1.600**	**0.133**	7.5
La Loma	**16**	**1.600**	**0.133**	7.5

FIGURE 6. *Integration* (*Int[3]*) for the North Periphery of UC Berkeley

FIGURE 7 shows the relationship between integration and pedestrian volumes. Each point represents a single observation. There are roughly three levels of *Int[3]* while pedestrian traffic varies much more. **FIGURE 7** does not demonstrate any pattern that defines a relationship between *Int[3]* and pedestrian volumes. This result is not surprising and compares to those found in the literature (*8*). This strengthens the notion that predicating pedestrian activity based on *integration* is limited for certain locations.

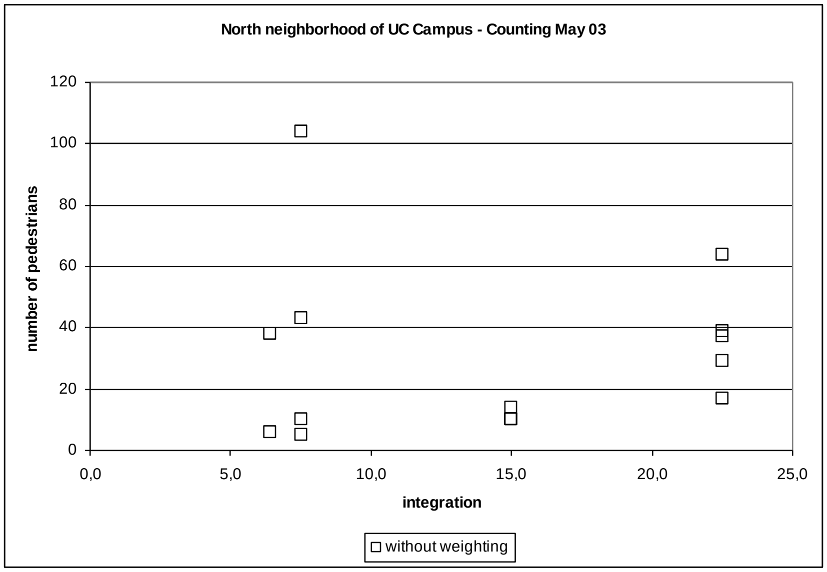


FIGURE 7. Relationship Between *Int[3]* and Pedestrian Volumes

Weighted Integration

TABLE 3 summarizes the assigned weights and the data used to derive them.

TABLE 3. Land-Use Related Weights

Gate	Street	Population	λ_1	Stores	λ_2	Transit	λ_3	λ_4	λ_5
		#/sq mile	habitation	#	activities	#stops/day	Transit	sidewalk	active
1	Hearst	12,616	0.5	0	1	262	2	1	0.5
2	Hearst	5,568	1	0	1	89	2	1	0.5
3	Hearst	7,535	1	3	1	173	2	0.5	0.5
4	Hearst	10,143	0.5	0	1	0	1	0.5	1
5	Hearst	3,940	1	0	1	343	2	1	0.5
6	Arch	16,743	0.5	0	1	0	1	1	1
7	Le Conte	19,885	0.5	0	1	0	1	1	1
8	Scenic	10,638	0.5	0	1	0	1	1	1
9	Virginia	19,518	0.5	0	1	0	1	1	1
10	Virginia	10,281	0.5	0	1	0	1	1	1
11	Le Conte	36,985	0.5	0	1	0	1	1	1
12	Euclid	8,037	1	22	2	30	2	1	2
13	Ridge	25,243	0.5	1	1	0	1	1	1
14	Le Roy	13,470	0.5	0	1	0	1	1	0.5
15	La Loma	14,135	0.5	0	1	0	1	1	1

The relationship between *WInt[3]*, taking into account the influence of land use, and the pedestrian volumes is shown in **FIGURE 8**. The regression line results in a high correlation coefficient of 0.72. Improvement can be seen compared with the **FIGURE 7** even if the sample size (15 points) and the presence of one point at high pedestrian volume and high weighted integration ask for further investigation to confirm this first tendency.

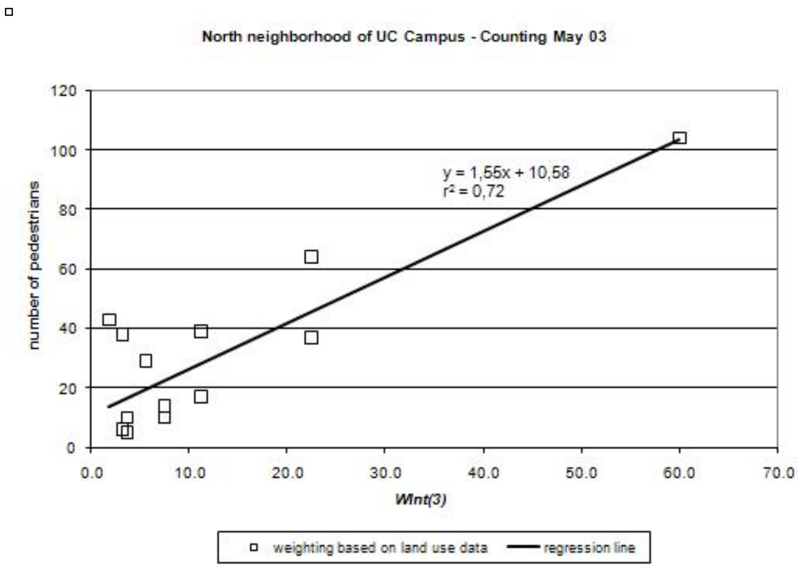


FIGURE 8. Relationship Between *WInt[3]* and Pedestrian Volume – 5/3/2011

The weighting method was also applied to the data from the second counting day of May 9. **FIGURE 9** demonstrates a similar correlation and strengthens the validity of the proposed approach.

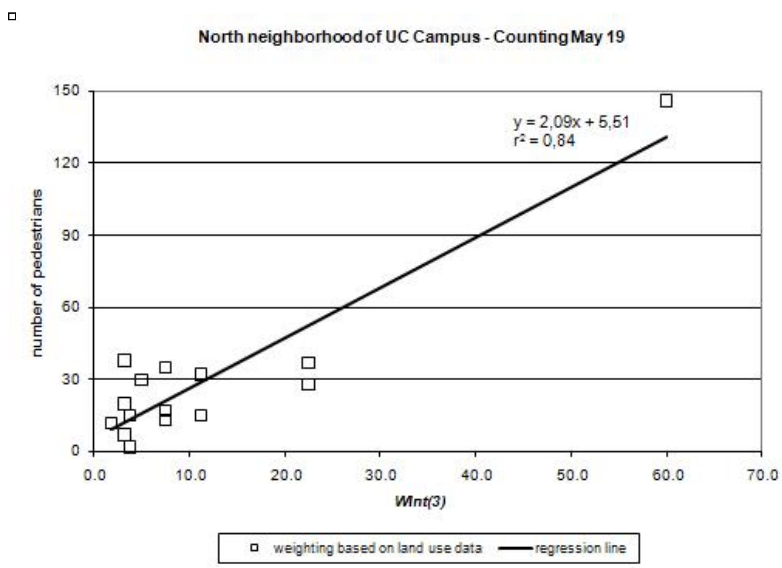


FIGURE 9 Relationship Between *WInt[3]* and Pedestrian Volume - 5/3/2011

SUMMARY AND CONCLUSIONS

Under some scenarios an average *integration* value is not sufficient to describe the movement of pedestrians along a street. This paper describes a relationship between the integration of a street, derived from morphology analysis of an urban space, the land-use features of a street-block, and pedestrian volumes for a street-block. Using Space Syntax to determine the *integration* of urban streets, block-level land-use characteristics were applied as weights to adjust the initial *integration*. A simple weighting mechanism is proposed to modify the value of integration at the block level. Applying the proposed method for a north periphery of UC Berkeley has produced promising results significantly improved the correlation between *integration* and pedestrian volumes. These promising preliminary results have shown that this approach is valid and feasible and warrants further study. Future research should address the weaknesses of the proposed method by identifying more rigorous weighting factors and eliminating subjective elements related to judging the dominance of land use features. The application of the proposed method to a wider urban space should also help refine the choice of land use features. Applying a simple weighting mechanism on *integration* using block-level land-use data can significantly improve the correlation with pedestrian volumes and provide valid estimates of pedestrian exposure for urban environments.

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