Looking both ways:

Space Syntax for pedestrian exposure forecasting and collision risk analysis

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Abstract
This project used Space Syntax to create a Pedestrian Risk Index for the city of Oakland, California. The Index helped planners identify high risk intersections for the first time, using predicted pedestrian volumes and existing pedestrian - vehicle collision data. A major challenge facing pedestrian safety advocates and urban planners at this time is the availability of detailed, high quality pedestrian exposure data. Exposure is defined as the rate of contact with a potentially harmful agent or event. Pedestrian exposure is therefore defined as the rate of contact with potentially harmfully situations involving moving vehicles (i.e., crossing intersections). Pedestrian risk is defined as the probability that a pedestrian - vehicle collision will occur, based on the rate of exposure. To estimate exposure, pedestrian volume measurements must be made, but such measurements are often unavailable or too expensive. In the absence of accurate exposure data, pedestrian safety decisions are often made by estimation, rules of thumb, or political influence, resulting in mixed and potentially less effective outcomes. This paper explores the value of Space Syntax in generating volume estimations for pedestrian exposure measurement, discusses a novel approach for utilising a “volume co-efficient” to extrapolate volume based on Integration, population density, and a limited set of pedestrian counts, and explores issues associated with applying Space Syntax research in a “real world”, resource-constrained planning environment within the United States.

Keywords
modelling, pedestrian volume, pedestrian safety, pedestrian exposure

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1. Introduction

There has been a significant increase in pedestrian research in the United States during recent years. This interest is the result of a growing awareness among urban planners and public officials that walking is vital to the health of cities and their residents, and that in general, Americans walk far too little. According to the United States Department of Health and Human Services, at least 60% of American adults do not meet the recommendations of the United States Surgeon General for accumulating 30 minutes of moderate-to-vigorous activity most days of the week, and over 25% of American children are clinically obese (USDHHS, 1996a). Physical inactivity is estimated to be responsible for more than 200,000 deaths annually and over $77 billion dollars in direct health care costs each year (USDHHS, 1996b).

While it is known that the majority of Americans are insufficiently active, it is not fully understood why this is the case. Much of the literature has focused on pedestrian safety as a major barrier to walking in American cities. In 1999, approximately 4,906 pedestrians were reported to have been killed in motor vehicle crashes in the United States. An additional 80,000 pedestrians were injured in motor vehicle collisions, and it is likely that this figure is much higher due to unreported incidents (NHTSA, 1999). A significant amount of attention has therefore been given to making America's streets safer for pedestrian travel (Zweig, et al., 2002; Camprell, et al., 1999; ITE, 1998). Several American cities have drafted their first Pedestrian Master Plan in efforts to improve walkability and pedestrian safety, including the cities of Portland, Oregon, Cambridge, Massachusetts, and now Oakland, California.

A smaller body of literature has focused on exploring the aspects of the physical and social environment that encourage or stimulate walking (Frank and Engele, 2001). Physical factors such as residential population density, mixed land use, street connectivity, and adequate pedestrian facilities have been found to be key physical variables that influence the number and types of walking trips. Frank and Pivo (1994) found that increased vehicle transportation is associated with decreased levels of walking and biking and that walking is positively associated with land use measures such as residential density, proximity of services, and high street connectivity. Moudon et al. (1997) found that neighbourhoods with higher street connectivity, continuous sidewalk conditions, and small block size experienced an average of three times higher pedestrian travel than other neighbourhood with similar population density, land use mix, and income, but lacking these facilities. Physical design also affects the type and kind of walking trip in addition to the overall amount. Shriver (1997) found that three times more respondents walked to work in higher density, mixed use, "traditional neighbourhoods," and walked to errands with 65% greater frequency than those in lower density neighbourhoods with poor pedestrian facilities. Many other researchers have found similar connections between the built environment and pedestrian activity.

2. The Role of Exposure in Pedestrian Planning

Despite an increased understanding and interest, most urban planners and policymakers tasked with making American cities safer and more walkable are forced to do so with limited tools and resources. The Federal Highway Administration (FHWA) and the National Highway Traffic Safety Administration (NHTSA) recently identified four major areas of need in pedestrian planning (FHWA, 2000). Among these, accurate pedestrian exposure data was determined to be the least understood and most important area of research for pedestrian planners and decision-makers. In public health terms, exposure is defined as the rate of contact with a dangerous or potentially harmful agent or event. Exposure is distinct from risk, which is defined as the probability of a dangerous event occurring. Clearly exposure and risk are related. High exposure to a low risk situation may not result in a situation occurring, such as high pedestrian volumes at a busy but safe and well-designed intersection. Conversely, low exposure to high risk situations may result in greater likelihood of a harmful event occurring. This could be the case when fewer pedestrians cross a busy or dangerous highway intersection where the chance of being hit is higher. When applied to pedestrian safety, exposure is defined as the ratio of pedestrian accidents to pedestrian volume.

Many American cities have access to pedestrian crash data through police reports, which give planners a detailed picture of the amount and location of pedestrian – vehicle collisions occurring each year. But without pedestrian volume counts to determine walking rates, this information paints an incomplete picture of actual pedestrian risk. High volume intersections may experience a large number of collisions per year, but may be relatively safer than intersections that experience less annual collisions, but also receive less usage. This mismatch often results in funding allocation to pedestrian planning projects based on the "squeaky wheel" principle instead of on objective data analysis (i.e., intersections with the highest rates of collision are given attention instead of those that experience the greatest risk).

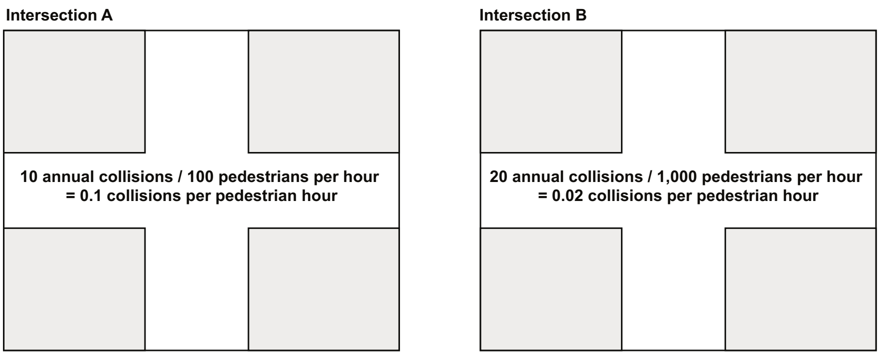

Figure 1. Pedestrian risk is a function of the number of annual pedestrian – vehicle collisions divided by the amount of pedestrian exposure (pedestrians per hour)

Figure 1 demonstrates the concept of exposure as it relates to pedestrian risk. Intersection A experiences 10 collisions per year, with an average peak hour pedestrian rate of 100 pedestrians per hour. Intersection B experiences 20 collisions per year, but has an average peak hour pedestrian rate of 1,000 pedestrians per hour. Which intersection is the most dangerous? At first glance, it would appear that Intersection B is the most dangerous, with 20 collisions per year. However, dividing the annual number of collisions by the pedestrian flow rate (exposure) gives a measurement of actual risk, and reveals that Intersection A experiences 0.1 annual collisions per pedestrian hour while Intersection B experiences 0.02 annual collisions per pedestrian hour. Intersection A is therefore the most dangerous intersection, experiencing five times the likelihood of collision than Intersection B, even though Intersection B experiences more absolute collisions per year. Absolute collision data can therefore provide an inaccurate or misleading picture of pedestrian risk when considered in isolation.

3. Creating a Pedestrian Risk Index for Oakland, California

The city of Oakland, California is located directly across the San Francisco Bay from the city of San Francisco, CA. Oakland has a population of approximately 400,000 people and is approximately 56 square miles in area. From a land use perspective, Oakland is part of a larger urban fabric that stretches uninterrupted to the north to Berkeley, CA, and to the south to San Leandro, CA. Oakland's population is primarily middle and lower income and is extremely racially diverse. Figure 2 displays the City of Oakland's street network.

Figure 2. Study area street network

The City of Oakland recently completed its first Pedestrian Master Plan. As part of this effort, the City sought to identify areas of high pedestrian risk to prioritize spending on streetscape improvement projects. Like many other American cities, Oakland had statistics derived from police reports (known as SWITRS, which stands for Statewide Integrated Traffic Reporting System), that indicated the absolute number of pedestrian – vehicle collisions per year. In Oakland, the majority of collisions occurred within the downtown area.

Although SWITRS data identified where the greatest number of pedestrians had been hit, there was little data available on pedestrian volumes. This made calculation of pedestrian exposure impossible, and hence, an understanding of actual risk. To solve this problem, Space Syntax was used to generate pedestrian volume predictions on a city-wide level. These volumes were then compared to the existing crash data to create a more accurate measure of pedestrian risk.

4. Methodology

4.1 Axial Line Map

The first step in creating the Pedestrian Risk Index was the creation of an axial line map for the entire city of Oakland. This was done by hand, using ArcGIS and TIGER/line street files as a base map. The longest axial lines were drawn first, descending from the longest to the shortest, until all 7,000 street segments were modeled.

In order to process the axial map in Ovation, it was necessary to perform a multi-step conversion from ArcGIS shapefiles to a text file with XY coordinates. This conversion was accomplished by exporting the axial map from ArcGIS as DWG file, then importing the DWG file to MapInfo for conversion to an MIF file. The resulting MIF file was read by the Ovation TalkBack utility and translated into a text file with XY coordinates for each axial line. This file was then ready to be imported into Ovation and processed using standard Space Syntax measures. The resulting axial map and accompanying Space Syntax measures were then re-imported to MapInfo, converted to a shapefile, and read by ArcGIS for further analysis. Figure 3 displays the final axial map with Radius-3 integration values. 51.5

Figure 3. Axial map of the City of Oakland, California (Radius-3)

4.2 Pedestrian Counts

Citywide pedestrian counts from previous planning studies were then added to the GIS as point files. A total of 94 counts from 42 different intersections were utilised. Counts were conducted continuously in two hours segments, during the peak hours of 7 A.M. to 9 A.M. and 4 P.M. to 6 P.M, for a total of four hours per intersection. Both the number of pedestrians as well as the turning direction of each pedestrian were recorded. Counts were then averaged to estimate the pedestrians per hour (PPH) for peak hour periods. A total of 670 intersections were analysed, 42 of which had pedestrian volume counts, resulting in a confidence level of 95% with a confidence interval of 14.7. Initial observations found that observed pedestrian levels followed an exponential distribution curve.

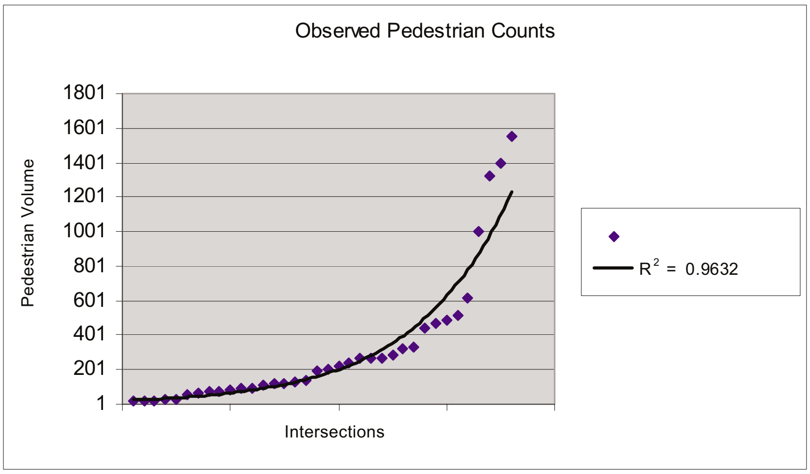

Figure 4. City-wide pedestrian counts displayed an exponential followed an exponential distribution curve

4.3 Axial Line – Intersection Conversion

In order to adapt traditional Space Syntax measurements, which are based on the linear unit of the axial line, to the more commonly used unit of the intersection, two approaches were evaluated. The first approached simply added the Integration value of each axial line crossing the intersection. The second averaged these values. For this project, it was found that averaged values resulted in more accurate correlations, so averaged Integration values were utilised for each intersection.

4.4 Population Density

Population density was added to the axial map in ArcGIS, using Census 2000 data at the block group level. This allowed for basic measurement of the influence of land use on pedestrian levels. These files included population density, median household income, age, race, and other standard demographic characteristics. Population density was chosen as a rough proxy for land use concentration and usage.

4.5 Initial Correlation

Pedestrian volumes for each intersection were then correlated against population density, Radius-3, and Radius-5 Integration values to identify a "best-fit" descriptive relationship. Linear regression and multiple regression was conducted using the Stata statistical software package. Radius-3 integration was found to most accurately describe variation in the data when combined with population density, and thus was used for the remainder of the analysis.

Preliminary correlation between Radius-3 Integration and observed pedestrian counts resulted in a very low correlation ($R2 = 0.23$, $p < 0.001$). Multivariate analysis incorporating the average population density of each axial line was then conducted, comparing Radius-3 Integration and population density with observed pedestrian counts. This resulted in a more accurate correlation, yielding an R2 of 0.56 and a p-value of less than 0.0001.

4.6 Addition of Employment Density

Further analysis of outlying data points revealed that many of the points within the Central Business District (CBD) fell significantly outside of the predicted regression line. Because very few people lived within the downtown area of Oakland, the low population density of these outlying points resulted in lower correlation. A large number of people work in the CBD during business hours however, most of whom live elsewhere and were therefore not counted in Census 2000 population counts of downtown. It was hypothesised that this employee population was responsible for the large pedestrian volumes observed in the counts for this area.

To account for this variation, employment figures from the 1997 State of California Economic Census were added to the population density. This data was only available at the zip code level, so employment density per census block was determined by dividing the total number of employees found in that zip code by the total area of that zip code. This resulted in an employee per square mile measure for the entire zip code. This figure was then multiplied by the area of each block group within that zip code to determine the average distribution of employees per block group. The resulting employment population density was added to the population density from the 2000 census, producing a more accurate picture of the number of people present during peak hours.

When these density modifications were applied to the multivariate regression, a correlation coefficient of 0.7717 and a p-value of less than 0.0001 was achieved. This indicates that when taken together, population density and Radius 3 Integration values accurately described approximately 80% of the citywide variation in observed pedestrian volume. Figure 5 displays the results of the multivariate correlation.

Equation	Obs	Parms	RMSE	"R-sq"	F	P
b	42	3	0.065944	0.7717	107.1285	0

b	Coef.	Std. Err	.t	P>|t|	[95% Con	f. Interval]
a	0.000377	3.02E-05	12.48	0	0.000316	0.000439
c	4.98E-06	1.83E-06	2.73	0.01	1.27E-06	8.70E-06
_cons	0.580927	0.021755	26.7	0	0.536666	0.625187

Figure 5. The correlation between observed pedestrian volume, Integration, and population density increased upon utilising employment density data in addition to population density. (R2=0.7717, p < 0.0001)

4.7 The "Volume Co-efficient"

This correlation formed the basis for translating population/semployment density and Integration values into quantitative estimations of pedestrian volume. A "volume co-efficient" was created to extrapolate pedestrian volumes for the remaining intersections in the city that were not covered by existing pedestrian counts. Analysis of the relative contribution of Integration and density to the multivariate correlation found that Integration was responsible for approximately 55.01% of the correlation and density was responsible for approximately 44.99% of the correlation. This was referred to as the relative weight of each variable. These relative weights were then multiplied by each observed pedestrian count to attain a proportional distribution of pedestrians for both Integration and density. This was called "proportional Integration" and "proportional density". Thus if 100 pedestrians were counted at an intersection, the proportional quantity associated with Integration would be 55 pedestrians, while the proportional quantity associated with density would be 45 pedestrians.

Once observed pedestrian counts were proportionally segmented based on Integration and density, these values were divided by the actual Integration and density values to obtain a "pedestrians per proportional Integration" value. The same was done for density. The resulting "volume co-efficient" empirically linked Integration and density values to observed pedestrian counts, allowing predicted pedestrian counts to be created from Integration and density alone.

4.8 Final Pedestrian Risk Index

Figure 6. Annual pedestrian – vehicle crashes as reported by the California Highway Patrol. Note the concentration within the downtown area

After quantitative pedestrian volumes (i.e., pedestrian exposure) were estimated for the remaining axial line segments and intersections, three years of California Highway Patrol pedestrian – vehicle collision data were added to the GIS. A total of 1,067 incidents at 730 intersections were utilised over a three year period between 1996 and 1999. The total number of collisions at each intersection was divided by three to determine the average annual collision rate. Figure 6 illustrates the distribution of collisions through-out Oakland.

$$\frac{\text{Annual Pedestrian Vehicle Collisions}}{\text{Average Peak Hour Pedestrian Volume}} = \text{Relative Pedestrian Risk}$$

Figure 7. Equation to derive relative pedestrian risk at each intersection in Oakland

The final Pedestrian Risk Index was created using the simple equation included in Figure 7. For each intersection, annual pedestrian – vehicle collisions were divided by exposure (represented by average peak hour pedestrian volume) to determine relative pedestrian risk.

5. Findings:

The results of this analysis are mapped in Figure 8. This map displays predicted volumes by street segment, with darker shades of grey representing higher volume streets. As to be expected, the highest pedestrian volumes were found in the downtown area, whose streets account for nearly 5% of total city-wide pedestrian volume even though the area only comprises 1% of total street area. The mean peak hour pedestrian flow for downtown was found to be 245 pedestrians per peak hour, although several main arterials exhibited much higher volumes. Other clusters of high pedestrian volume were found to the north and east of Lake Merritt, as well as in East Oakland, centred around the intersection of Fruitvale Avenue and Foothill Boulevard.

Figure 9 also displays pedestrian risk as a function of annual pedestrian accidents divided by predicted peak hour pedestrian rates. A list of the city's "Dirty Dozen", or 12 most dangerous intersections was derived using this Pedestrian Risk Index. Surprisingly, it can be seen that 10 of the 12 most dangerous intersections were clustered in the eastern area of the city, an area with relatively low pedestrian volumes. Of the 12, only one is the in the downtown area. This finding reveals that although the highest volume intersections may be within the downtown area, these intersections are much safer than those in East Oakland because they accommodate a greater number of pedestrians with fewer pedestrian accidents, even though they may have a higher number of absolute pedestrian crashes.

Figure 8. Relative Pedestrian Risk Index. Predicted pedestrian volume is represented by shades of grey, with darker streets representing higher volumes. Balloons represent intersections with high relative pedestrian risk, expressed as a function of annual collisions per peak hour pedestrian

Figures 9 and 10 provide detailed examples using two intersections; one in downtown Oakland and one in East Oakland. The first intersection examined is one of the most dangerous intersections in downtown Oakland. This intersection experienced an average of three (3) pedestrian – vehicle crashes per year and had an estimated peak hour pedestrian flow of 114 people per hour. By dividing the number of annual accidents by the peak hour pedestrian flow, it was found that this intersection experienced an average of .0294 annual pedestrian collisions per peak hour pedestrian. In other words, an average pedestrian had a 2.9% per year chance of being hit by an automobile at this intersection. In contrast, one of the most dangerous intersections in East Oakland experienced an annual average of four (4) pedestrian – vehicle collisions, but experienced an average peak hour pedestrian flow of only 39.2 pedestrians per hour. Although this intersection experienced a similar level of collisions as the one in downtown, it carried approximately three times less pedestrian volume, resulting in a Risk Index score of .1020 annual collisions per peak hour pedestrian. In other words, pedestrians were approximately 3.5 times more likely to be involved in a collision at the intersection in East Oakland than they were at the intersection in downtown.

Similar rates were computed for every intersection in the city. The final Pedestrian Risk Index ranked each intersection in the city for risk, defined by the number of annual collisions per average peak hour pedestrian.

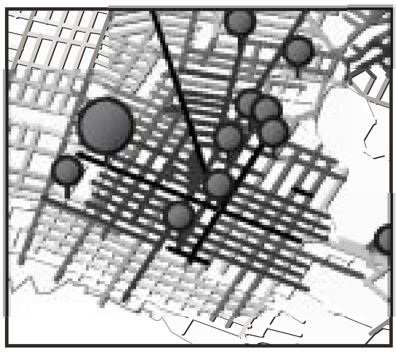

Figure 9. Intersections in downtown experience slightly more pedestrian – vehicle collisions per year than the intersection in East Oakland, but carry approximately three times more peak hour pedestrians, indicated a lower accident rate per peak hour pedestrian than that in East Oakland

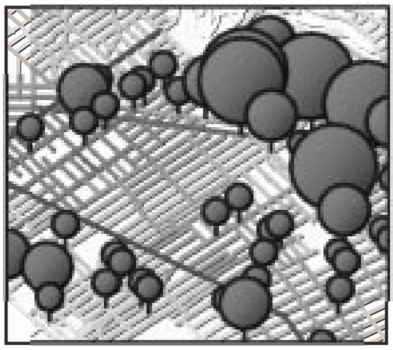

Figure 10. Intersections in East Oakland experience both lower collisions, but also lower pedestrian volumes. In terms of relative risk, intersections in East Oakland are approximately 3.5 more dangerous than those in downtown

6. Discussion

This project dealt with several challenges of interest to Space Syntax researchers wishing to utilise axial line analysis for applied planning projects. First, the project demonstrated the value and applicability of the method in solving a specific need in the United States urban planning community: that of pedestrian exposure data needed to estimate pedestrian risk. Second, it did so by converting relative integration values to quantitative pedestrian volume predictions. Third, the project attempted to integrate land-use variables into the model, such as employment concentrations and residential density. Fourth and last, the project utilised both axial lines and intersections as units of analysis.

The creation of a Pedestrian Risk Index for the City of Oakland allowed planners to identify the most dangerous intersections in the city, relative to the amount of utilisation they received. It thus filled an important gap in city officials' knowledge by providing reasonably accurate estimations of pedestrian volume that would have been too costly or time intensive to obtain.

The issue of data availability is an important one to emphasise. Although pedestrian safety is becoming increasingly important nationwide, it is still given relatively little funding and staff attention. Urban planners wishing to improve the condition of their walking environment are often faced with the need to make difficult decisions based on limited information, incomplete data, and limited funding. This situation limits the effectiveness of pedestrian planning initiatives and can result in wasted or unsuccessful efforts. In order to implement successful pedestrian policies that make a difference in the walkability of American cities, it is important that planners have access to reasonably reliable pedestrian volume data.

This project demonstrated that Space Syntax can fill this need using a minimum of additional input. The key inputs to this project, Census 2000 and employment statistics, are freely available online for nearly every major metropolitan city in the United States. Many states also collect data on pedestrian – vehicle collisions through highway patrol and local police reports. The other major piece of information used in this study was a sufficient number of pedestrian counts. These counts were used to both test the accuracy of the Space Syntax model and to translate its output to quantitative volume predictions. While it is still necessary to conduct some pedestrian counts to verify the model, this project utilised existing pedestrian counts that were gathered as part of past planning studies. Many cities have such counts available. For those that don't, this method enables cities to conduct a much smaller, representative sample of counts and extrapolate these counts to the entire city using just integration and population density. This combination of readily available data and a reduction in the amount of necessary data makes Space Syntax an appealing option for cities requiring pedestrian volume measurement.

From a public policy perspective, one major surprise emerged from the application of this technique. It was expected that higher volume intersections would experience proportionally higher collision rates. This was found not to be the case. Contrary to expectation, some of the most dangerous intersections experienced lower incidences of collisions, but also lower pedestrian volumes. This finding indicates that other variables not analysed in this study are more important factors in determining pedestrian risk than simply volume alone. These variables likely include variations in automobile traffic and speed, intersection/crossing design, or demographic characteristics of the surrounding population (a high proportion of children or elderly residents, for example).

From a methodological standpoint, the conversion of Integration values and population/employment density into actual pedestrian volume estimations appears to be a novel use of Space Syntax. This approach allows planners to circumvent the data limitations explored earlier, using commonly available census information and standard Space Syntax outputs. The use of a "volume co-efficient" based on empirical measurement of the relationship between Integration, density, and observed pedestrian volumes, enables reasonably accurate volume estimations to be made based on objective measurements. This has the potential to add significant value to future Space Syntax analyses by translating the relative predictions of movement potential into absolute, ordinal values such as the number of peak hour pedestrians.

The “volume co-efficient” approach also has several limitations that need to be explored further. First and foremost, the “proportional Integration and density” multipliers that translate these values into pedestrian counts are only as accurate as the initial correlation between integration, density, and observed volume. Assumptions made in the correlation phase, such as averaging the integration value of axial lines for each intersection, may significantly reduce the accuracy and effectiveness of this approach. If the initial correlation is less accurate, due to too few pedestrian counts, pedestrian counts distributed in an imbalanced fashion throughout the study area, or any number of reasons, than these errors will be compounded in the volume estimation phase. Despite these limitations, the use of a “volume co-efficient” has significant potential, given additional research and refinement.

The integration of land use variables such as residential and employment density also added additional explanatory power to the model. The initial regression of Integration and observed pedestrian counts were rather low. Only after the addition of population and employment density did the descriptive power of the model increase. Even with this increase in accuracy, the Space Syntax model under estimated the volume of several high volume line segments in and around the downtown area. Observations made on the streets surrounding a recreational park just east of downtown (Lake Merritt) found that the park experienced over four times the predicted pedestrian volume. Anecdotal evidence indicates that the lake is a popular place for joggers during peak hours of the day, implying that street connectivity and population density alone cannot account for this variation.

A similar phenomenon was observed on several of the busiest streets within the CBD. There are three underground stations within downtown Oakland that connect the city to the surrounding region by way of the Bay Area Regional Transit (BART) train system. These downtown stations experience high ridership from employees working in the CBD. It is therefore likely that the model’s under prediction of these streets was related to their connection to regional mass transit systems.

These observations reflect the findings of other pedestrian trip generation literature that support the theory that street connectivity is one part of an integrated complex of variables effecting levels of walking activity, including not only population and employment density, but land use mixture, trip purpose, and transit connections (Cervero and Radisch, 1995; Landis, et al., 1999; Kitamura, et al., 1997).

Of lesser importance, this study differed in emphasis from traditional Space Syntax methodology by shifting the unit of analysis from the axial line to the intersection level. It was necessary to analyse Integration at the level of the intersection because both the observed pedestrian counts as well as the police reported collision data was intersection and not street specific. Because intersections are composed of at least two axial lines that may have difference Integration values, it was necessary to explore a variety of techniques to determine the most accurate approach. For this study, it was found that averaging the Integration value of all axial lines contributing to the intersection was the best technique. However, additional research may find better ways to analyse Integration values at the intersection level and could produce better results than those found in this study. It is important to keep this methodological challenge in mind however, because the vast majority of pedestrian safety and pedestrian planning research conducted in the United States focuses on the intersection as the unit of analysis and not the street segment.

7. Conclusion

This project generated much needed data for the City of Oakland's pedestrian plan. The analysis was successful in that it demonstrated some of major strengths of Space Syntax, primarily its high level of detail, analytical flexibility, and minimal need for extensive data collection. The model was able to incorporate whatever limited amount of pedestrian counts and land-use data was available in order to extrapolate pedestrian volume measurements on a city-wide basis.

Perhaps more importantly, the project also demonstrated that Space Syntax has a valuable role to play in the United States. Unlike traditional travel demand models which often analyse traffic at the Traffic Analysis Zone (TAZ) or census tract level, Space Syntax allowed for a much more detailed level of prediction. The model was also significantly less complicated than other advanced pedestrian modelling packages such as Paramics, which use micro-simulation, cellular automata, and other "agent-based" approaches requiring extensive preliminary programming. In addition to its value for pedestrian safety projects, Space Syntax could also be of use in a wide variety of planning and policies purposes. This combination of detail, flexibility, and lack of extensive data requirements makes Space Syntax an appealing option for cities with limited pedestrian planning resources.

This project is only a first step. A variety of methodological challenges were encountered during this project, including the translation of Integration values into quantitative predictions of pedestrian volume, the integration of more sophisticated land use variables into Space Syntax research, and the issue of axial line versus intersection analysis. Given additional time and resources, it is likely that significant improvements could be made to the approach, resulting in a better understanding of the issues involved and greater predictive accuracy.

Future efforts will be dedicated to improving the accuracy of the Oakland pedestrian volume model through integrating more specific land-use characteristics such as those explored recently by Stonor, Arruda Campos, and Smith (2002). Additional analysis using the volume predictions generated in this project could analyse the relationship between pedestrian volume and a variety of other factors including criminal activity, retail behaviour, and rates of physical activity and obesity. Many of these issues have already been or are already being explored by researchers in other parts of the world. (Hillier, 1996, 1999; Major, et al., 1998; Croxford, et al., 1995)

The 2000 FHWA report, which discussed pedestrian exposure, concluded that "decision-makers require data." Better pedestrian data will raise the priority of pedestrian issues in city and subdivision planning and will increase the likelihood of pedestrian design projects getting funded. Better data can also make communities more aware of pedestrian issues and can lead to a safer, more enjoyable urban experience. It is likely that as Space Syntax develops, it will become easier to use and more analytically robust, offering an improved capability to make valuable contributions to the urban planning process in the United States.

References

Campbell, B., C. Zegeer, H. Huang, and M. Cynecki, 1999, *Pedestrian Safety Research in the U.S.,* Federal Highway Administration, Washington, D.C., October

Croxford, B., Penn, A. and Hillier, B., 1995, "Spatial Distribution of Urban Pollution", in *Proceedings of the Fifth Symposium on Highway and Urban Pollution*, Copenhagen, Germany

Cervero, R. and Radisch, C., 1995, *Travel Choices in Pedestrian versus Automobile Oriented Neighborhoods*, *Working Paper 644*, Berkeley, CA, University of California at Berkeley

Florida Department of Transportation (FDOT), 1999, *Florida Pedestrian Planning and Design Handbook*, Prepared by the Highway Safety Research Center, Chapel Hill, NC, University of North Carolina

Frank, L. and Engele, P., 2001, "The Built Environment and Human Activity Patterns: Exploring the Impacts of Urban Form on Public Health", *Journal of Planning Literature*, 16(2), pp. 204 – 216

Frank, L. and Pivo, G., 1994, "Impacts of Mixed Use and Density on Utilization of Three Modes of Travel: Single-Occupant Vehicle, Transit, and Walking", *Transportation Research Record 1466*, pp. 44-52

Hillier, B., 1999, "The Common Language of Space: A Way of Looking at the Social, Economic and Environmental Functioning of Cities on a Common Basis", http://www.spacesyntax.org/publications/commonlang.html

Hillier, B., 1996, *Space is the Machine*, Cambridge, Cambridge, University Press

Institute of Transportation Engineers, 1998, *Design and Safety of Pedestrian Fatalities,* Washington, D.C.

Kitamura, R., Mokhtarian, P. A. and L. Laidet, 1997, "A micro-analysis of land use and travel in five neighborhoods in the San Francisco Bay Area", *Transportation*, 24, pp.125-158

Knoblauch, R., Nitzburg, M., Dewar, R., Templer, J., and Pietrucha, M., 1995, *Older Pedestrian Characteristics for Use in Highway Design*, Office of Safety and Traffic Operations Research and Development, FHWA, Washington, D.C.

Landis, B., Ottenberg, R., and Vattikuti, V., 1999, "The Roadside Pedestrian Environment: Toward A Comprehensive Level of Service", *Paper 990570*, Transportation Research Board Annual Meeting, Washington, D.C.

Major, MD, Stonor, T., and Penn, A., 1998, "Passengers, Pedestrians and Shoppers: Space Syntax in Design", *Passenger Terminal World*

Moudon, A.V., Hess, P, Snyder, M.C., Stanilov, K, 1997, "Effects of Site Design on Pedestrian Travel in Mixed-Use, Medium-Density Environments", *Transportation Research Record 1578,* pp. 48-55

National Highway Traffic Safety Administration, 1999, *Traffic Safety Facts,* Washington, D.C.

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

Schwartz, W., Porter, C., Payne, G., Suhrbier, J., Moe, P., Wilkinson III, W., 1999, *Guidebook on Method to Estimate Non-Motorized Travel: Supporting Documentation,* Publication No. FHWA-RD-98-166, Office of Safety and Traffic Operations Research and Development, FHWA, Washington, D.C.

Shriver, K, 1997, "Influence of Environmental Design on Pedestrian Travel Behavior in Four Austin Neighborhoods", *Transportation Research Record 1578*, pp. 64-75

Stonor, T., Arrua Campos, M.B., Smith, A., 2002, "Towards A Walkability Index", presented at Walk21 3rd Annual International Conference, Donostia – San Sebastian, Spain

U.S. Department of Health and Human Services, 1996a, "An Update: Prevalence of Overweight Among Children, Adolescents, and Adults: United States 1988-94", *Morbidity and Mortality Weekly Report 46,* pp. 199-202

U.S. Department of Health and Human Services, 1996b, *Physical Activity and Health: A Report of the Surgeon General*, Centers for Disease Control and Prevention, Atlanta, GA

Wegmann, F., Heathington, K.., Middendorf, D., Redford, M., Chatterjee, A., and Bell, T., 1983, *NCHRP Report 262: Planning Transportation Services for Handicapped Persons - User's Guide*, Transportation Research Board, Washington, D.C.

Zweig, C., Seiderman, C., Lagerway, P., Cynecki, M., Ronkin, M., and Schneider, R.h,b 2002, *Pedestrian Facilities Users Guide – Providing Safety and Mobility*, Publication No. FHWA-RD-01-102, Office of Safety and Traffic Operations Research and Development, Federal Highway Administration (FHWA), Washington, D.C.