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Pedestrian Volume Modeling for Traffic Safety and Exposure Analysis: The Case of Boston, Massachusetts

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This paper examines three types of pedestrian volume models in light of their usefulness for estimating pedestrian exposure for pedestrian safety research. The need for pedestrian flow data as part of pedestrian exposure and safety analysis is outlined, and the background of each type of model is discussed. It then selects the space syntax network analysis model to estimate pedestrian volumes for the city of Boston, Massachusetts. It was found that the model was able to accurately predict pedestrian flows (r-squared 0.81, p-value < 0.0001) after incorporating distance to transit stops and major tourist attractions. These findings suggest that in addition to estimating pedestrian volumes in geographic locations where data is not available, pedestrian volume modeling can also be useful for estimating pedestrian volumes in future conditions. Planning and policy implications are discussed, as are directions for future research.

INTRODUCTION

Transportation demand modeling has a long history and a complex heritage *(1,2)*. The need to estimate the amount, type, and distribution of vehicular traffic in cities is well recognized and traffic models have played an important part in the planning of modern urban growth since the late 1950's *(3,4)*. The need and ability to model pedestrian movement is a more recent development, however, resulting from an increased interest in the public health, environmental, economic, and social benefits of walking. New advances in computational power and understanding have made such modeling approaches feasible, giving rise to the emerging field of pedestrian volume modeling and simulation.

One important field where this research is being applied is in the field pedestrian safety and exposure analysis. The Federal Highway Administration (FHWA) and the National Highway Traffic Safety Administration (NHTSA) have identified accurate pedestrian exposure as one of the least understood and most important areas of research for pedestrian planners and decision makers *(5)*. The term "exposure" originates from the field of epidemiology and is defined as the rate of contact with a potentially harmful agent or event *(6)*. Pedestrian exposure is therefore defined as a pedestrian's rate of contact with potentially harmful vehicular traffic *(7)*. In practical terms, this can be measured by pedestrian volume (as expressed in units of pedestrians per hour or per year). Pedestrian risk can therefore be defined as the annual number of vehicle pedestrian collisions divided by the annual estimated pedestrian volume at a given intersection *(7,8,9)*.

While many American cities have access to pedestrian crash data through police reports, relatively few cities have accurate estimations of pedestrian volume. Without pedestrian volume counts to determine walking rates, however, cities may be left with an incomplete picture of actual pedestrian risk. High volume intersections may experience a large number of collisions per year, for example, but they may be relatively safer per pedestrian than intersections which experience less annual collisions but also less pedestrian usage. This data mismatch often results in policy prioritization 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).

Pedestrian volume modeling offers a potential solution to this challenge. A great deal of recent literature has explored aspects of the physical and social environment that encourage or stimulate walking *(10, 11)*. Physical factors such as residential population density, mixed land use, street connectivity, and adequate pedestrian facilities have been identified as key physical variables that influence the number and types of walking trips. *(12, 13, 14, 15)*. Unfortunately little of this has been translated into practical solutions for planners in need of pedestrian volume estimation.

This paper compares three different types of pedestrian volume models available to transportation and pedestrian planners, discusses possible criteria for evaluation, and then uses one of these approaches (space syntax) to estimate pedestrian volumes for the city of Boston, Massachusetts. Space syntax was chosen because this approach builds upon previous research estimating exposure for geographic areas for which data were not available *(7)*. It attempts to extend this research by estimating future pedestrian volumes

which result from changes in the urban environment. It is hoped that this might allow planners to estimate future pedestrian exposure resulting from proposed or on-going development projects in their city.

The case of the civil engineering project known as "the Big Dig" is used to test the space syntax approach for this utility. The results of this approach are then analyzed and compared to the other modeling approaches. The paper closes with a discussion of the role of pedestrian volume modeling in the transportation planning process and their potential utility for further pedestrian safety research.

OVERVIEW OF PEDESTRIAN VOLUME MODELING TOOLS

Pedestrian volume modeling has several fundamental differences from vehicle modeling. These differences pose significant challenges to traditional traffic modeling approaches and require new methods for estimating pedestrian trip behavior *(16)*. Kerridge and colleagues, note that pedestrian trips are less homogenous than vehicle trips in terms of journey purpose and their route choices are less well defined *(17)*. Pedestrian trips are also often parts of larger trips or tours of connected trips which use other modes, such as walking to or from a bus or subway stop. The pedestrian network can also be much harder to define than vehicular networks because cities and buildings have numerous pathways available to pedestrians that are not available to vehicles. Finally, many unrecorded intermediate stops or pauses can be made when traveling through urban environments on foot that cannot be made in automobiles.

The goal of a pedestrian volume model is to predict or estimate pedestrian volume based on certain assumptions about pedestrian travel including trip generation levels, mode choice, trip distribution and route choice. More generally, pedestrian volume models are mathematical models that combine existing data with key assumptions to estimate volumes in existing conditions where data are unavailable or to estimate future conditions when key variables in the model change.

A large number of simulation models have been proposed that could be useful for pedestrian exposure analysis. Different models often use different inputs and outputs and knowledge of these models are often difficult to obtain *(18,19,20,21,22,23)*. Many of these models have been developed in Europe, Japan, and the United Kingdom in journals which are less accessible for American researchers, or exist as project reports in the grey literature of government agencies and private firms.

This paper attempts to classify major developments in pedestrian volume modeling research and to discuss how they might be of use for American researchers interested in pedestrian safety, exposure, and volume modeling.

State of the Practice

Attempts to understand pedestrian movement dynamics date back nearly four decades. Most early studies focused on the behavior of pedestrians in confined circumstances such as subways, airports, or building entrances because these were easier to understand *(24,25,26)*, but others sought a broader understanding of pedestrians in urban environments such as central shopping districts *(10,11)*..

In recent years measurement tools have become more powerful and sophisticated, resulting in more useful and complex models of pedestrian movement prediction. Many of these models have been developed for specific purposes, but all share the goal of helping planners and architects create efficient, comfortable, and safe pedestrian facilities *(27)*.

For the sake of clarity, this paper divides these models into three approaches and discusses each in turn. The approaches are:

1.   Sketch plan models
2.   Network analysis models
3.   Microsimulation (or agent based) models

The difference between each approach is their scale of application, their necessary inputs, and their most frequent outcomes. Sketch plan models focus on regional demand estimation, network analysis models focus on city-wide and neighborhood levels, and microsimulation focuses on single or a small number of streets, intersections, open spaces, or building interiors.

Although individual models often differ in their assumptions and techniques, most fall within this general typology of pedestrian models. The following section discusses each in turn relative to these criteria, citing relevant examples for each where possible.

Sketch plan models estimate pedestrian volume at the statewide or regional levels. These models were among the first models attempted by planners and researchers and use simple planning guidelines and to produce "rules of thumb" estimates of pedestrian volume based on key indicators such as square footage of office space, parking capacity, vehicular traffic movements, and movement levels in similar environments *(28)*. These models have been applied in large regional and multi zone urban environments where estimates of pedestrian volumes are desirable, but where high accuracy or more detailed estimations are not required *(29,30,31)*. Pushkarev and Zupan and Behnam and Patel were among the first researchers to attempt to forecast pedestrian volumes using this approach. They used commercial land use space and observed counts to estimate sidewalk volume levels in Manhattan and Milwaukee, respectively *(10,11)*. Swords and colleagues used population and employment density plus transit access at the statewide level to create a Pedestrian Potential Index (but not pedestrian volumes) for the State of New Jersey *(32)*. Finally, the regional land use growth model INDEX has been used in many cases to estimate regional pedestrian suitability (but not pedestrian volumes) using indicators such as population density, parcel side, and network continuity *(33)*.

The second category is network analysis models. These models are more detailed than sketch plans models and can estimate volumes for street segments and intersections over an entire city or neighborhood. Although the models vary in technique, most use a variation on the four step modeling approach to generate and distribute trips based upon assumptions about the amount of walking trips in a study area and various route choice algorithms *(34,35,36)*. Ness and colleagues used this approach in their analysis of the city of Toronto, where they divided the area into traffic analysis zones and then code the links between these zones based on the street network and various "friction factors". Trip generation and distribution was then measured to create an origin-destination matrix, and trips were then distributed using a gravity-based model *(37)*. Ercolano and colleagues

used traffic analysis zones, mode split assumptions based on peak vehicle volumes, and a network assignment model *(38)*.

The space syntax approach uses a network modeling technique to estimate pedestrian movement potentials based on a graph "nearness" algorithm that measures route directness *(39, 40)*. It then uses pedestrian counts instead of a generation and distribution phase to calibrate these relative values and convert them into actual pedestrian per hour estimates. Hillier et al. and Penn et al. found that this approach estimated pedestrian volumes in central London with an r-squared of 0.77 *(41, 42)*. Stonor et al. combined distance to transit, land use composition, pedestrian crossing design, and signal phase information in a multivariate space syntax regression model of south London with 80% predictive accuracy *(43)*. Raford and Ragland incorporated residential and employment densities into their space syntax model of Oakland, California, yielding city wide pedestrian volume predictions with an r squared of 0.72 when compared to observed pedestrian traffic *(7)*. This approach offers a more economical way of network calibration then origin-destination surveys and has been used with relatively accuracy in hundreds of large scale real world projects in Europe and the United Kingdom.

The third and final type of approach uses microsimulation and agent based models. These models offer highly realistic simulations of small areas such as individual streets or intersections and enclosed spaces such as transit centers, airports, and malls. Microsimulation models use detailed virtual representations of their study area, either pre-determined or random origins and destinations, and specific rules for pedestrian navigation and movement to simulate thousands of individual pedestrians (or agents) in high volume conditions. Simulated pedestrians seek their destinations based on rules of movement such as avoiding collision with walls and other pedestrians and seeking the shortest route to their destination. The output of these individual interactions can then be analyzed and visualized.

Microsimulation draws heavily from the physical sciences for their rules about pedestrian behavior and are often based upon observations that crowds of people behave similar to flowing liquid in confined situations *(44,45,46)*. The emphasis on confined situations and high density flows has resulted in successful application for environments such as corridors and bottlenecks *(47,48,49)*, places free of automobile traffic such as subway and metro stations *(50,51,52)*, and for bridges and pedestrian walkways such as those used by pilgrims to Mecca *(53)*. Microsimulation and agent based models are often at the root of popular evacuation software packages such as SimWalk, Legion, and Exodus, but other models have begun to explore more complex origin destination matrices and performance in open ended urban environments *(54,55,56)*.

These approaches are summarized in **Table 1.** It can be seen that each of the three approaches are applicable for different scales of analysis. Each approach also produces different outputs, with vary degrees of accuracy and utility for pedestrian safety and exposure research. The following section describes the use of one approach using a space syntax model to estimate pedestrian volumes for the city of Boston, Massachusetts.

METHODOLOGY

To evaluate the utility of pedestrian volume modeling, a space syntax approach was chosen. This model was chosen because of its utility for estimating pedestrian volumes for each street segment at the urban scale. Another factor was its success in estimating exposure in past research.

The city of Boston, Massachusetts was chosen as a case to estimate future pedestrian volumes using the space syntax model. This city was chosen becaue it is currently nearing completion of a large civil engineering project in the downtown area, colloquially named "the Big Dig". This project will effect major changes in both pedestrian and vehicular circulation, and thus offered a good "natural experiment" to test the applicability of pedestrian volume modeling for future exposure conditions. **Figure 1** displays a map of downtown Boston with the location of the "Big Dig" highlighted in grey.

To estimate the changes involved with the Big Dig construction project, a space syntax model for existing and future conditions was created. The first modeled the time period of existing conditions, based upon data surveyed in August, 2004. For this model, the majority of important highway infrastructure had been completed but the pedestrian park was still under construction and thus unopened. The second time period modeled the final conditions of the area, based upon plans for the most recent designs of the Rose Kennedy Greenway park. This reflected the conditions of what the area will be like upon its completion.

The creation of the space syntax predicative model comprised six steps:

1) Base data collection
2) Pedestrian route network modeling
3) Processing for movement potentials
4) Collection of pedestrian counts to calibrate the model
5) Addition of land use, transit, and other variables
6) Testing the accuracy of the model
7) Forecasting future pedestrian volumes based upon network change

The first phase comprised base data collection. Geographic Information Systems (GIS) data for the downtown Boston area were procured from the Boston Redevelopment Agency (BRA) as part of the first step. This included the street and sidewalk network, building outlines, aerial photos, land uses, tourist trails, and underground public transportation stops. These data were freely available and easily accessed via the BRA's website.

After collecting and compiling data, the pedestrian route network was created using a GIS. TIGER road centerline, street network data from the BRA, and aerial photographs were used to trace every possible pedestrian path and open space in the downtown area. This included each block and street segment in the downtown accessible to pedestrians, including passageways through buildings, pedestrian malls, and existing parks and public spaces. A total of 468 elements were included in the pedestrian network.

Then the pedestrian network was then processed using space syntax software to determine the relative movement potentials of each street. The MapInfo GIS software Confeego was used, which was freely available for academic use. This software converted the Boston pedestrian network into a link and node graph in order to perform a topological analysis of the mathematical nearness of each node in the network. This was then used to

estimate the movement potential of each street based upon a route choice algorithm specifying pedestrian preference for the most direct pathways with the least change of direction from all origins to all other destinations. The output of this stage was a quantitative measurement of movement potentials (called "integration" in space syntax parlance) based upon the relative accessibility of each street segment in the system.

Next, a detailed field survey of pedestrian flows was conducted to determine the relationship between the relative movement potentials calculated by the space syntax software and actual pedestrian volume. Observations were made at 82 locations through out the city by a team of 9 researchers, conducted in 5 minute segments every hour between 8 AM to 8 PM. Two days of observation were made, one on a weekday and one on a weekend during the first week in August. This allowed direct measurement of morning, lunchtime, and evening peak movement, as well as general movement during other periods of the day. Pedestrian movement was found to range from 0 pedestrians per hour to over 2,000 pedestrians per hour during the lunchtime peak. The pattern of peak pedestrian movement was found to be non-normally distributed, so it was transformed using the square root of observed values to in order to create a normal distribution for further statistical analysis.

Initial correlation of the model found that movement potentials correlated relatively poorly with observed movement in some areas (r-squared = 0.55, p < 0.0001). In order to account for various other influences, additional variables were added to each street segment in the GIS. These variables included land use type and square footage and are presented in **Table 2.**

In order to check the accuracy of the model including relevant additional variables, the study area was divided into four neighborhoods covering the entire downtown area. A step wise multiple regression analysis (MRA) was then conducted to measure the influence of each variable on existing observed pedestrian volumes. All variables were correlated individually and then step wise in groups to determine the optimal correlation combinations, given adequate p values, t rations, and statistical validity. The accuracy of the model was found to vary between neighborhoods and was mapped to visualize the changes in correlation over the geographic area of coverage.

The last step involved converting the calibrated model into future movement forecasts. After testing the accuracy of the model, the MRA equation for each neighborhood was used to estimate the influence of each input variable (such as accessibility or land use) on the output variable of pedestrian movement. These equations were then used to change the value of variables that would change after the completion of the infrastructure project, in particular pedestrian network accessibility and land uses. The final pedestrian movement forecasts for the entire city were then estimated using the equations derived from the calibration and multiple regression stage.

FINDINGS

Base Model

The quantification of the accessibility of the pedestrian network allowed for precise measurement of the changes for pedestrian resulting from the "Big Dig". The inclusion of other variables in the MRA allowed for additional layers to be added in the space syntax model and more accurate estimates of average pedestrian flows to be derived. Finally, the use of different phases of construction in the modeling process

allowed for estimates of future pedestrian volumes to be derived, which were used for pedestrian exposure estimates in future conditions.

The space syntax model was found to correlate differently for each of the city's four main neighborhoods. Pedestrian movement in the city center, including the city's financial district, was found to correlate with pedestrian movement potential, distance to the regional rail stations, and distance to underground transit stops (r squared=0.86; p<0.0001). Of these, pedestrian accessibility was found to be the most important variable (t ratio of 8.3 versus 2.5 for each of the other variables).

Pedestrian movement in the area around the proposed park itself was also found to correlated well with pedestrian movement potential (r squared=0.81; p value < 0.001.) The distance to two major tourist attractions were also found to be the explanatory variables, but pedestrian movement potential was found to be the most important variable (Although not ignorantly so, a t ratio of 6.87 was found for movement potential vs. 5.62 for distance major tourist attractions).

The space syntax model was also found to correlate well with pedestrian movement in the North End area (r squared=0.79; p< 0.01). As in the other neighborhoods, movement potential as a function of network accessibility was found to be the most important variable

Finally, the Bulfinch Triangle neighborhood was found to correlate well, but with statistically less significant results (r squared=0.85; p < 0.09). A possible cause for this lack of statistically significant correlation may be the fact that that fewer pedestrian samples were conducted in this area. This would have resulting in greater volatility in the measurement process and less accurate output. **Table 3** presents the results of all four correlation tests in each neighborhood, and **Figure 2** maps the accuracy of the model for the entire downtown Boston area, with the numbers representing the correlation co-efficient for each neighborhood.

Projected Changes in Pedestrian Flow

After testing the association between observed pedestrian volume and each variable in the space syntax model, the conditions of the model were changed to simulate the effect of the pedestrian park after its completion. **Figure 3** displays the estimated volume forecasts for each street in the downtown study area after completion.

It can be seen that several streets were found to experience major increases in pedestrian traffic, while others were found to experience less. The model found a major new axis of east west movement was likely to emerge along the State Street and the Quincy Market area, with peak movement rates up to 1,900 pedestrians per hour. The street running northwest from the regional rail station was also found to experience increased use, which was estimated to be approximately 1,450 pedestrian per hour. This was found to have a secondary impact on neighboring Washington Street, which was found to experience similar movement levels. The major north – south axis through the central business district (Federal Street) was also found to weaken slightly. This could be explained by the fact that movement was predicted to funnel east along Atlantic Avenue towards the wharf, or along Franklin Street in the same direction.

DISCUSSION

A space syntax pedestrian volume model was used to forecast future pedestrian flows in changed conditions in Boston, Massachusetts. It was found that model accurately described changes in pedestrian movement for each street and intersection in the downtown area. This suggests that such a model would be useful for providing the necessary input for a city-wide pedestrian exposure analysis, as discussed in the introduction.

Three categories of models were also discussed, of which the space syntax model was one example. Sketch plans models were found to be useful for large scale, statewide and regional estimations of pedestrian volume. Such models have the benefit of requiring little data collection and no prior training in mathematical simulation or computer modeling. They are able to offer quick estimations of pedestrian volume, but only at the aggregate level and often with questionable accuracy. Such models are also not able to assign realistic pedestrian volumes to specific streets or intersections. Because the level of detail is necessary for pedestrian exposure analysis it is argued that these types of models may be less applicable for urban pedestrian volume estimation.

Microsimulation models such as VISSIM or Legion are often extremely accurate at the site-specific level, with excellent levels of detail. Most are able to output convincing animations and graphics that allow planner a more intuitive understanding of proposed scenarios. Their major limitations are in their scale and complexity, however. Such models are currently only appropriate for site-specific simulations, covering at most an area of a few blocks or a large internal building. They also require advanced knowledge to operate, detailed data on environmental conditions, and can require significant effort to prepare and calibrate. Such models have been effectively used for simulating detailed interactions at specific intersections, such as crossing behavior between a given level of pedestrian movement and a given level of vehicle movement. But their level of detail and lack of pedestrian assignment capabilities suggests that they are less applicable for urban pedestrian exposure analysis.

Network analysis approaches such as space syntax may offer a balance between these strengths and weaknesses. Such models do not require as much data collection as microsimulation models, but also lack the level of individual detail and accuracy which they can provide. They may be more appropriate for urban exposure analysis, however, because network analysis models are able to assign pedestrian volumes to each street in large urban systems, something which is beyond the capability of most microsimulations. These reasons, and their success in past exposure analysis, lent themselves well to network analysis to the purposes of this paper.

Despite the findings of this and other research, additional research is necessary before pedestrian volume models become a widely accepted and practical solution. In particular a more extensive and rigorous inventory of pedestrian volume modeling methods and packages should be conducted. Testing of each model's accuracy should be conducted, preferably upon a shared data set. Sensitivity analysis and a systematic application against a wider variety of cases would also improve the utility of such models. Finally, the financial and information management requirements of each model should be evaluated above and beyond their technical applicability if such models are to be widely accepted by the urban planning research and practitioner communities.

CONCLUSION

The need for pedestrian flow data as part of pedestrian exposure and safety analysis was outlined, a model was presented to address this issue, and the background of the model's use for such a purpose in existing conditions was discussed. Findings suggested that in addition to estimate pedestrian volumes in geographic locations where data is not available, pedestrian volume modeling may also be useful for estimating pedestrian volumes in future conditions. This suggests that pedestrian exposure analysis could be used as part of a city's ongoing planning process by evaluating the effects of proposed changes.

Pedestrian volume as input to pedestrian facility planning is receiving increased recognition in policy and planning circles. Interest in and understanding of pedestrian models is increasing as well. Pedestrian modeling as a field is developing past the initial stages of development and is finding practical applications in industries around the world. Although no single solution exists, practitioners are nearing the point where they will be able to select from a wide variety of modeling tools to suite any given problem.

Significantly more research is necessary before pedestrian volume modeling becomes a standard, easily available, and cheaply executed practice. In the future, hybrid models combining several approaches are likely to develop with increased flexibility and power. As this occurs, the planning, engineering, and architecture professions will likely see increased benefits from pedestrian modeling, and demand may grow for its application to a wide range of issues and challenges. If the modeling process becomes more accessible and less expensive then the true value of pedestrian simulations as a decision support system and scenario planning tool for urban planning may be realized.

ACKNOWLEDGEMENTS

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Table 1 – Pedestrian Volume Modeling Approaches

Modeling Approach	Description	Primary Uses	Scale of Application	Data Sources	Strengths	Weaknesses
Sketch plans	Estimation of aggregate pedestrian volumes based on population level statistics	Providing regional and city wide estimates of pedestrian movement for large scale planning studies	State and regional level	Census statistics, land uses, movement samples	Simple, easily available data	Inaccurate, insufficient detail
Network analysis	Large scale estimates of pedestrian volume based on route choice assumptions and medium level urban modeling	Urban pedestrian volume modeling, exposure analysis	Urban and neighborhood level	Road and pedestrian network, Census statistics, land uses, movement samples	Large geographic coverage, good detail, reasonable accuracy, limited data requirements	Less complex then microsimulation models
Microsimulation or agent based	Simulation of individual pedestrian movement in crowds ("agents") based on complex behavioral rules and environmental modeling	Evacuation simulation, movement in confined environments (train stations, airports, malls)	Site specific level (individual streets, intersections, and enclosed environments)	GIS and CAD boundary layers for buildings and streets, origin and destination matrices, movement samples, rule based movement algorithms	Highly accurate, detailed, and visually communicative	Complex, steep learning curve, significant initial data requirements, smaller geographic coverage

**Figure 1 – Location of the "Big Dig" Project and Study Neighborhoods in
Downtown Boston, Massachusetts**

Table 2 – Additional Variables Included in the Space Syntax Model

Variable	Variable Type
Floor space per street	Continuous
Land use	Ordinal based on use (residential, retail, commercial, government, mixed)
Distance to transit	Ordinal (1 through 4 based on walking distances of 50, 250, 500 or 1,000 yards)
Distance to regional rail	Ordinal (1 through 4 based on walking distances of 50, 250, 500 or 1,000 yards)
Distance to tourist attractions	Ordinal (1 through 4 based on walking distances of 50, 250, 500 or 1,000 yards)
Pedestrianization	Dummy (0 or 1)
Tourist Trail	Dummy (0 or 1)

Table 3 – MRA Correlations between Observed Pedestrian Movement and Estimated Volume for Four Neighborhoods in Downtown Boston
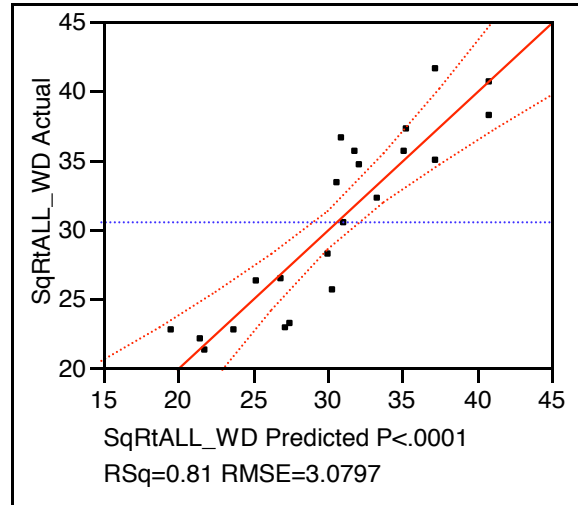
Southern Area
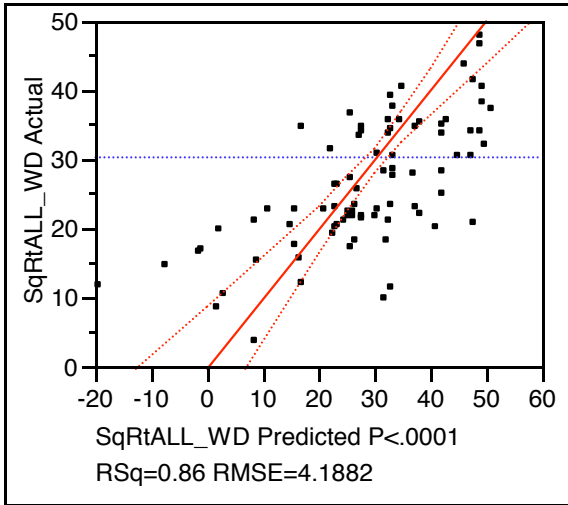
SqRtALL_WD Predicted P<.0001
RSq=0.86 RMSE=4.1882

Scaled Estimates
Continuous factors centered by mean, scaled by range/2

Term	Scaled Estimate	Std Error	t Ratio	Prob>|t|
Intercept	30.368126	0.892923	34.01	<.0001
MovPotential	17.313265	2.08278	8.31	<.0001
TransitDist	5.8015945	2.500096	2.32	0.0323
Rail Dist	-6.697017	2.438154	-2.75	0.0133

Wharf / City Area

SqRtALL_WD Predicted P<.0001
RSq=0.81 RMSE=3.0797

Scaled Estimates
Continuous factors centered by mean, scaled by range/2

Term	Scaled Estimate	Std Error	t Ratio	Prob>|t|
Intercept	30.501294	0.656603	46.45	<.0001
MovPotential	7.3106479	1.063979	6.87	<.0001
AttractDist	-6.843801	1.217462	-5.62	<.0001
AttractDist	-3.062365	1.577548	-1.94	0.0681

North End

SqRtALL_WD Predicted P=0.0088
RSq=0.79 RMSE=4.7208
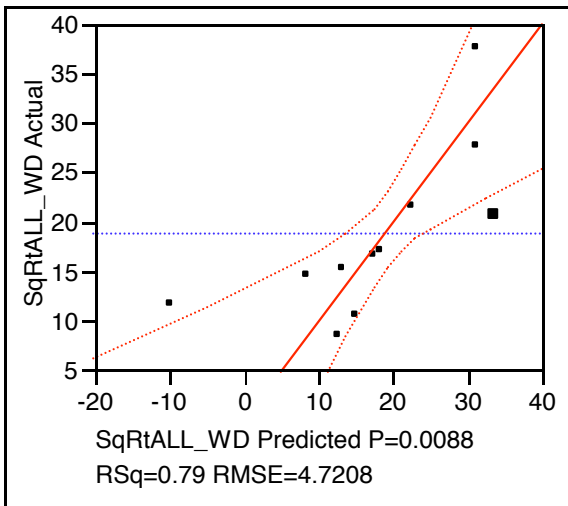
Scaled Estimates
Continuous factors centered by mean, scaled by range/2

Term	Scaled Estimate	Std Error	t Ratio	Prob>|t|
Intercept	18.846429	1.573602	11.98	<.0001
MovPotential	11.606795	3.842703	3.02	0.0234
AttractDist	0.2665158	2.585756	0.10	0.9213

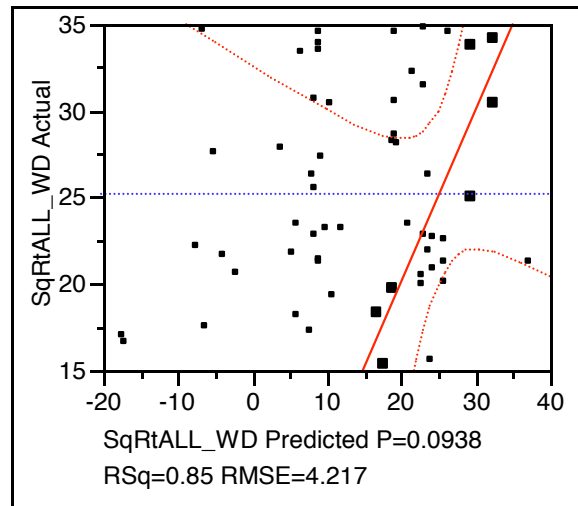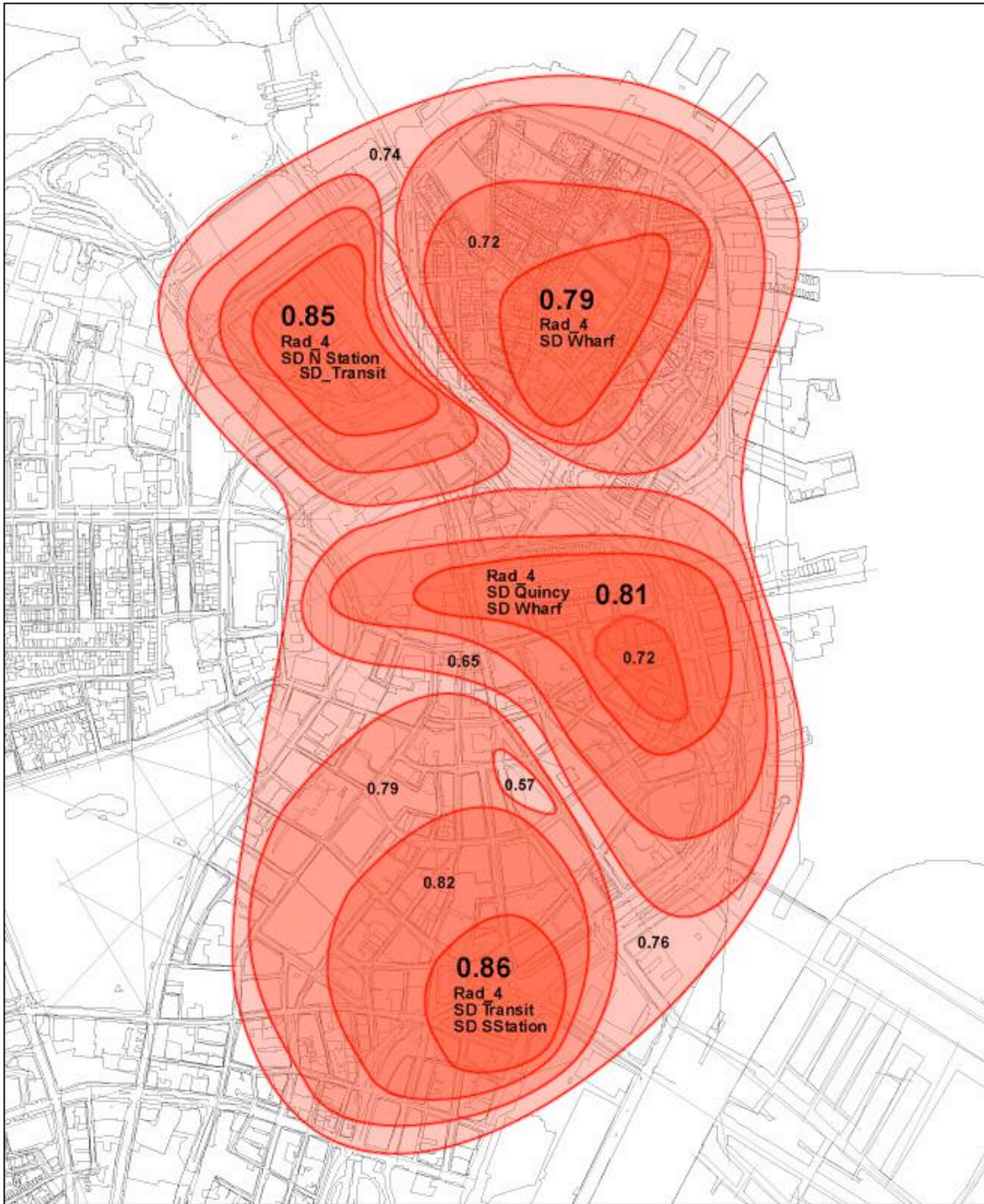**Bulfinch Triangle Area**

SqRtALL_WD Predicted P=0.0938
RSq=0.85 RMSE=4.217

Scaled Estimates
Continuous factors centered by mean, scaled by range/2

Term	Scaled Estimate	Std Error	t Ratio	Prob>|t|
Intercept	25.258017	1.593871	15.85	0.0005
MovPotential	-1.870684	5.419837	-0.35	0.7528
Rail Dist	-1.607209	2.158239	-0.74	0.5105
Transit Dist	-6.965615	3.872895	-1.80	0.1699

Figure 2 – Map of the Accuracy of the Space Syntax Model for Downtown Boston and with Detail for Four Neighborhoods

Paper revised from original submittal.

Figure 3 – Pedestrian Volume Forecasts for Future Conditions in the Study Area

Average Hourly Pedestrian Flow, Weekday

1,900 or greater	
1,750 to 1,900	
1,600 to 1,750	
1,500 to 1,600	
1,400 to 1,500	
1,300 to 1,400	
1,100 to 1,300	
1,000 to 1,100	
850 to 1,000	
750 to 850	
625 to 750	
500 to 625	
400 to 500	
275 to 400	
150 to 275	
50 to 150	