Walking the Built Environment: Modeling Walkable Urban Networks in Portland

The Benefits of Modeling Walkability

Walkability is a concept that has been used in the fields of urban studies, urban planning, urban design, community development, policy, and transportation over the past two decades. Walkability relates to many intersectional aspects of city planning, from encouraging efficient use of urban space by promoting high density development and public transit infrastructure to promoting economic development and commercial development by attracting a diversity of services to pedestrian and transit-oriented neighborhoods. The benefits of understanding walkability and promoting walkability are: more efficient land use, reducing traffic congestion and CO2 emissions, reducing urban sprawl by encouraging density, improving accessibility and response to environmental justice concerns, and improved public health. A wealth of information exists that relates neighborhood walkability to physical activity and health.

Towards a Better Walkability Model

Given the benefits of understanding walkability and measuring walkable areas, this study seeks to improve the accuracy and precision of walkability metrics using GIS tools. A problem that we seek to address is the widespread use of census tracts, census block groups, and other predefined spatial units as the target feature for conducting walkability analyses. In this study, we seek to improve these metrics by measuring walkability at the raster cell level and visualizing the city as a continuous measure of walkability. For this project, we were tasked with creating a walkability model of the city of Portland, the result of which can be used to analyze walkability down to a resolution of 60 square feet.

Defining the Core Elements of Walkability

To measure walkability we adapted aspects of walkability metrics from other studies over the past two decades. Luckily, much of the work from other walkability studies had been previously synthesized in an extensive literature review by Agampatian (2014) as they mapped walkability in New York City. In this review of walkability literature, five elements were found to influence walkability:

- Residential and Commercial Density
- Land Use Diversity
- Proximity to Amenities
- Street Connectivity
- Environmental Friendliness

Table 1 Residential Density Calculations Transformed to Units Per Acre

Zone Code	Definition	Units per acre
SFR1	Single family - detached housing with minimum lot size from 35,000 sq. ft.	1.244571429
SFR2	Single family - detached housing with minimum lot size from 15,000 sq. ft. to a net acre	2.904
SFR3	Single family - detached housing with lot sizes from about 10,000 sq. ft. to 15,000 sq. ft.	3.4848
SFR4	Single family - detached housing with lot sizes around 9,000 sq. ft.	4.84
SFR5	Single family - detached housing with lot sizes around 7,000 sq. ft.	6.222857143
SFR6	Single family - detached housing with lot sizes around 6,000 sq. ft.	7.26
SFR7	Single family - detached housing with lot sizes around 5,000 sq. ft.	8.712
SFR8	Single family - detached housing with lot sizes around 4,500 sq. ft.	9.68
SFR9	Single family - detached housing with lot sizes around 4,000 sq. ft.	10.89
SFR10	Single family - detached or attached housing with lot sizes around 3,500 sq. ft.	12.44571429
SFR11	Single family - detached or attached housing with lot sizes around 3,000 sq. ft.	14.52
SFR12	Single family - detached or attached housing with lot sizes around 2,900 sq. ft.	15.02068966
SFR13	Single family - detached or attached housing with lot sizes around 2,700 sq. ft.	16.13333333
SFR14	Single family - detached or attached housing with lot sizes around 2,500 sq. ft.	17.424
SFR15	Single family - detached or attached housing with lot sizes around 2,300 sq. ft.	18.93913043
SFR16	Single family - detached or attached housing with lot sizes around 2,000 sq. ft.	21.78
MFR1	Multi-family - single family, townhouses, row houses permitted outright. Max density permitted is 15 units / net acre.	15
MFR2	Multi-family - single family, townhouses, row houses permitted outright. Max density permitted is 20 units / net acre.	20
MFR3	Multi-family - single family, townhouses, row houses permitted outright. Max density permitted is 25 units / net acre.	25
MFR4	Multi-family - single family, townhouses, row houses permitted outright. Max density permitted is 30 units / net acre.	30
MFR5	Multi-family - single family, townhouses, row houses permitted outright. Max density permitted is 35 units / net acre.	35
MFR6	Multi-family - single family, townhouses, row houses permitted outright. Max density permitted is 45 units / net acre.	45
MFR7	Multi-family - single family, townhouses, row houses permitted outright. Max density permitted is 85 units / net acre.	85
MUR1	Mixed Use Commercial & Residential with FAR maximum of about 0.3	6.534
MUR10	Mixed Use Commercial & Residential with FAR maximum of about 12.5	272.25
MUR2	Mixed Use Commercial & Residential with FAR maximum of about 0.5	10.89
MUR3	Mixed Use Commercial & Residential with FAR maximum of about 0.7	15.246
MUR4	Mixed Use Commercial & Residential with FAR maximum of about 1.25	27.225
MUR5	Mixed Use Commercial & Residential with FAR maximum of about 1.5	32.67
MUR6	Mixed Use Commercial & Residential with FAR maximum of about 1.75	38.115
MUR7	Mixed Use Commercial & Residential with FAR maximum of about 2	43.56
MUR8	Mixed Use Commercial & Residential with FAR maximum of about 3	65.34
MUR9	Mixed Use Commercial & Residential with FAR maximum of about 4	87.12

Residential Density

Density has been found to correlate with chances of densely packed networks of diverse amenity locations and walkable city infrastructure. Density can be measured with estimates for population density, household density, employment density, retail density, and establishment density (Agampatian, 2014:10). For the purpose of this study we chose to use residential density as a measure of urban density without capturing the commercial employment density aspects that other studies have used. We made this decision because commercial density is somewhat captured in the mixed-use residential land uses that are embedded in this layer, in the land use diversity layer, and in the proximity to commercial locations layer. To measure residential density we used the land use map layer used by the Portland Metro regional government for urban planning. We were able to extrapolate density relationships from the diverse number of single-family, multifamily, and mixed-use residential categories of the land use planning spatial data set.

To calculate residential density for the model, we used detailed land-use categories from the zoning shapefile provided by RLIS. We used only categories of residential land-use that included Single-Family, Multi-Family, and Mixed-Use Residential land-use types found in Table 1. To calculate residential density, a standard unit was derived from the definitions given by the Metro RLIS metadata. Multi-Family Residential was already categorized by units per acre. The number of units per acre for each Single-Family Residential class was calculated using lot sizes given in Table 1. The number of lots given in square feet that would fit into an acre were calculated and listed in the table. Mixed-Use Residential was a little more difficult to transform because the units provided by METRO are listed by the Floor to Area Ratio (FAR). These are scales that influence the height allowance for buildings in dense land classifications. An FAR of 1:1 (or 1) means that 100% of the area can be utilized at 1 story, or 50% of the lot at 2 stories. A 2:1 FAR means that a 2 story building can cover 100% of the lot -- and so on. To estimate the number of units per acre in MUR Zones, a standard metric of 2,000 square feet per unit was used and then multiplied by the existing FAR in each zone. After residential land use classes were converted to units per acre scores were standardized to 1 to 100 scale using the reclassification tool in ArcGIS.

Land-Use Diversity

Land use diversity signifies a high degree of difference among various location services and other pedestrian destination points. Diversity of destination points is another element of walkability. Thus, areas having easy access to the necessary amenities to meet people's needs, i.e. grocery stores, shopping centers, schools, and public transit stops, as well as a variety of sources of entertainment and green spaces, are considered to be more walkable. High land use diversity is expected to reflect low travel times between destination points. This is also an aspect of density and proximity. To measure land use diversity, other studies have incorporated measuring land use mix, mean entropy index, dissimilarity index, entropy index, and the percentage of non residential buildings (Agampatian, 2014:10). For this study we use a relatively simple approach of counting the number of land used types within a moving window buffer zone for each raster cell. This is an approach taken by Tomalty et al. (2009); Tucker et al. (2009); Brownson et al. (2009); and Robitaille et al. (2009). This approach of using focal statistics to calculate this number for each raster cell works fairly well for this study, meaning that we get a fairly accurate idea of how many land use types exist in proximity to each raster cell. Other studies might only count the number of land use types within a predetermined aerial unit, such as census tracts. This does not allow for the degree of accuracy that we are striving for and is not an advised technique. For walkability metrics that are using predefined aerial units to make these calculations, the dissimilarity index or entropy index would be more accurate for estimating land use diversity within a given area.

Table 2 Amenity Layers

Amenity Locations
Grocery Stores
Schools
Libraries
Transit Stops
Community Centers
Shopping Locations
Banks

To approximate land-use diversity general land-use classes (shown in Table 2) were used to calculate the number of land-use types within a 300 meter radius of each 60 meter raster cell. This was calculated using the focal statistics tool in ArcGIS. The resulting raster gave a simple score of how many land-use types exist within the boundary radius. The raster was then reclassified to a scale of 1 to 100 in order to standardize the scale for the final weighted sum.

Table 3 Land Use Classification

Zone	Definition
COM	Commerical
FUD	Future Urban Development
IND	Industrial
MFR	Multi-Family Residential
MUR	Mixed-Use Residential
PF	Public Facilities
POS	Parks and Open Space
RUR	Rural Residential
SFR	Single-Family Residential

Proximity to Amenities

Proximity to amenities is a measure of the number of destination locations give in in an area. A higher number of amenity locations equates to a higher walkability score, i.e. a location that is within walking distance to a school and a grocery store will get a higher score then a location within walking distance to a school only. To measure proximity to amenities other Studies have used distance between point of origin and closest location; total distance between point of origin and all destinations; average distance between point of origin and the number of destinations; portion of residence within walking distance of defined diverse uses; hectares of parks and playgrounds per capita; proximity to schools; density of food outlets; proximity to food outlets; food stores per 10,000 people; number of supermarkets within 1,000 m; distance to nearest transit stop; number of transit stops; retail points, serve point, schools and jobs within walking distance to transit; and distance to closest recreational facility (Agampatian, 2014:17). For this study we have found as many destination point features as possible to represent in a 'proximity to amenities' layer. This list is given in Table 1. We've calculated the walking distance buffer on the street network for each destination layer. We'll take the weighted sum of each destination layer to calculate the total walkability score for proximity to these destinations.

To calculate walkable distance to amenities, we first had to determine relevant walkable distances for each amenity type and then gather point shapefiles representing the locations of each amenity type and then finally create service area buffers using Network Analyst. The network dataset used for this project was created using the clipped RLIS streets shapefile from the street connectivity calculation and contains the necessary attributes to perform the service area problem in Network Analyst. Service area polygons were created individually, as amenities did not share the same relevant walkable distances. With the amenity point shapefile loaded as the 'locations' in the service area problem, we set the break value to the walkable distance, chose to generate detailed polygons, and chose to merge the boundaries of overlapping service area polygons. Each individual polygon dataset generated (one for each amenity type) was then converted to raster using the Polygon to Raster tool. The reclassify tool was then used to classify the raster into two classes, 1-0, where all values 1 or greater were set to 1 and NoData values were set to 0.

Street Connectivity

Street connectivity measures how densely connected streets and sidewalks occur in a study area in order to represent minimal transportation barriers and ease of travel for pedestrians. This influences how well pedestrians are able to reach their destinations. Dead ends and limited intersections are considered to negatively impact walkability. Measures of street connectivity have utilized categorizing types of streets; intersection counts or density; 4-way intersections per unit land area; alpha index; connectivity index; and the gamma index (Agampatian, 2014:10). For this study we have incorporated an intersection density and sidewalks density to incorporate street connectivity as an element of walkability. Technically the presence of sidewalks is an aspect of the last walkability element, environmental friendliness, but we have incorporated it into the street connectivity layer to reduce the complexity of our methods.

To calculate the density of walkable street connectivity, the first step was to remove as much of the unwalkable streets from the RLIS streets shapefile (unwalkable meaning highways/freeways/etc). Street types are coded into a range of numeric values within the attributes of the streets shapefile, so a range of coded values for unwalkable street types was determined and selected using a query. The selection was then switched to select only the walkable street types and a new layer created based on that selection. Next, the Clip tool was used to remove all the streets outside of the Portland boundary. The Create Junction Connectivity is a script tool created by Linda Beale in 2012 and was used to read the clipped street shapefile and create points at every line intersection, with the option to only create points where more than two lines meet and to ignore dead-end junctions. The Kernel density tool was then used to generate a kernel density raster of the point shapefile, with a cell size of 60, a search radius of 60 feet, and processed to the extent of the Portland boundary shapefile. Finally, the Reclassify tool was used to reclassify the kernel density raster into classes (1-50) using natural breaks method.

To calculate the density of sidewalks, the first step was to use the Clip tool to remove all the sidewalks that were outside of the Portland boundary shapefile. The clipped sidewalks shapefile was then used as the input for the Kernel Density tool using a cell size of 60, a search radius of 60 feet, and processed to the extent of the Portland boundary shapefile. The resulting raster was then reclassified into classes (1-50) using natural breaks method.

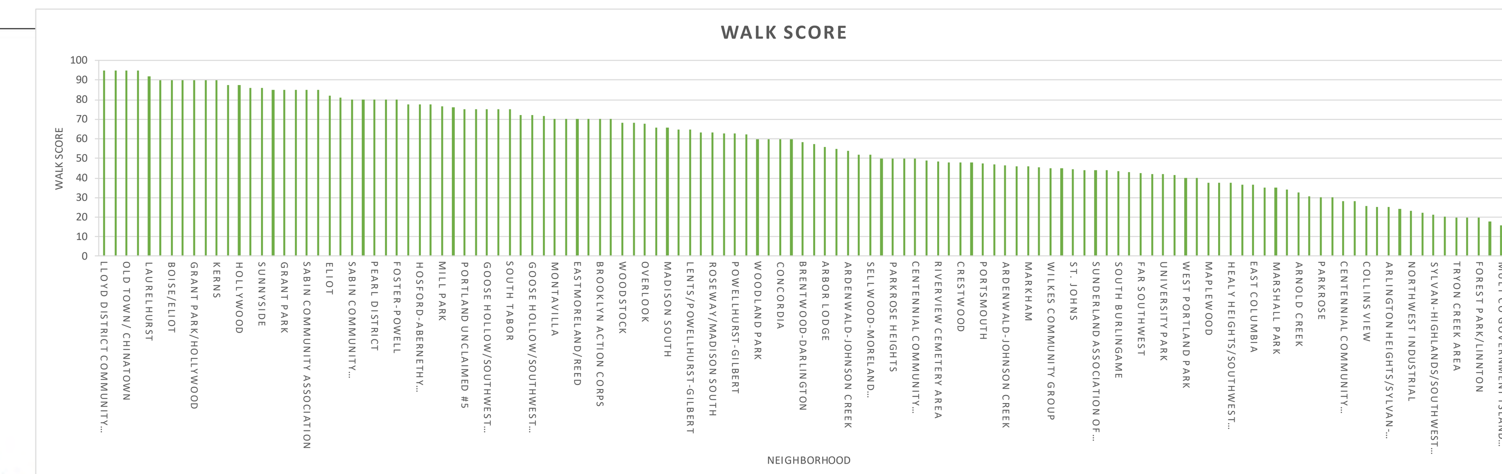
The two layers, density of sidewalks and density of intersections were added together using weighted sum, achieving a 1-100 scale layer of street connectivity.

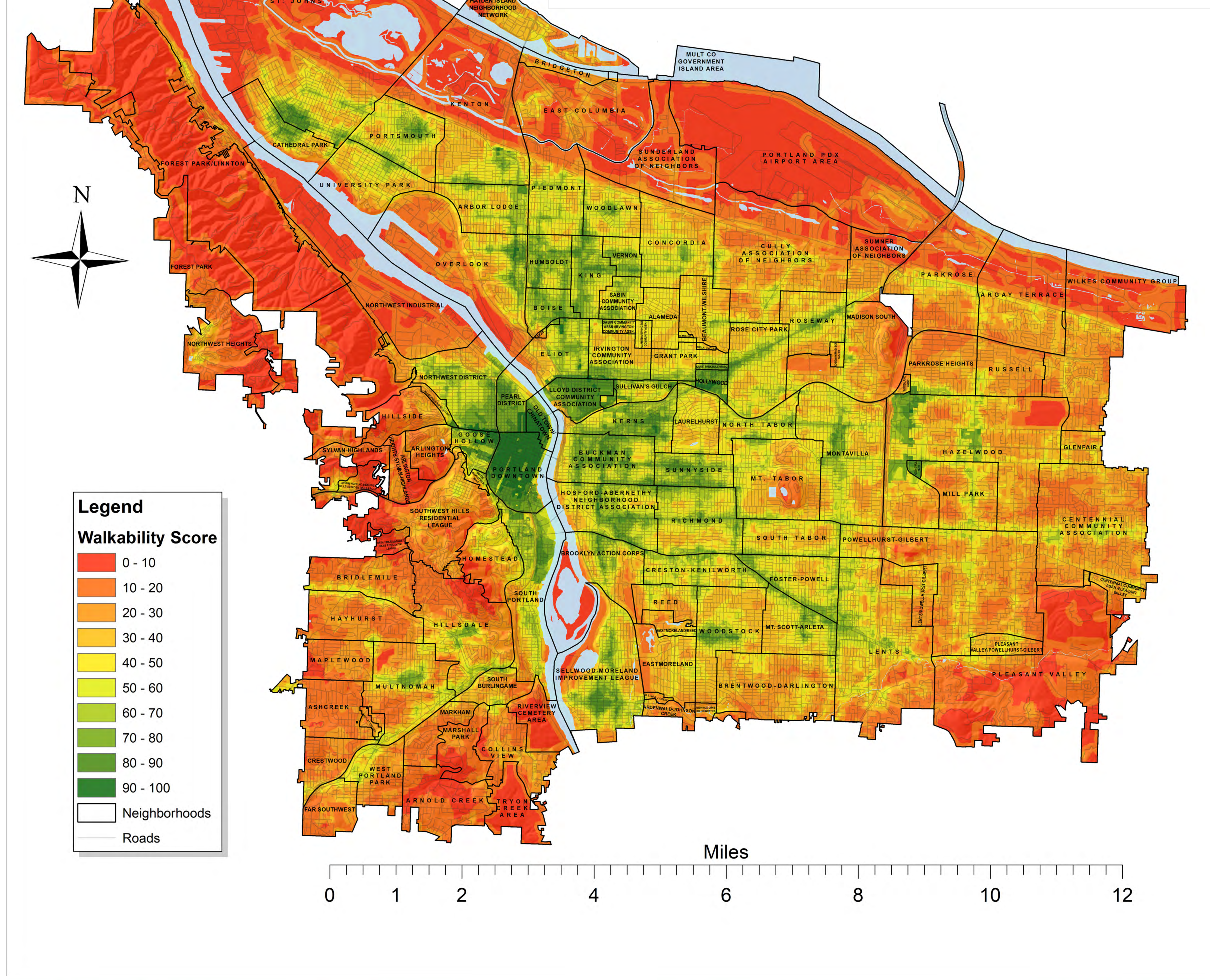
Environmental Friendliness

Environmental friendliness is an aspect of the built environment that relates the perceptions of safety in an area, the aesthetic, existence of sidewalks, and accessibility to parks and green space. Other studies have measured this as sidewalk length; sidewalk width; average census block area; percentage of street segments with visible litter, graffiti, or dumpsters; number of traffic lanes; sidewalk to road ratios; median housing age; traffic speed limits; bus and transit stops; and crime rates (Agampatian, 2014:19). In this study we have not included environmental friendliness as a layer in our walkability map. Instead, we have incorporated aspects of environmental friendliness into the layers of 'street connectivity' and 'proximity to amenities' by adding the sidewalk layer to street connectivity and the parks point destination layer to 'proximity to amenities'.

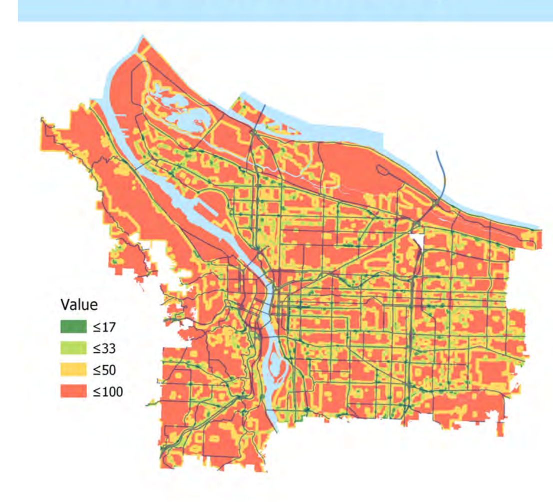
Method for Developing the Final Walkability Model

To build the model would begin with modeling each of our four chosen aspects of walkability -- residential density, land use diversity, proximity to amenities, and street connectivity. The final walkability map was created using the weighted sum of all four of these layers given equal weights. The idea to give all layers equal weights came from a walkability study by Lachapelle et al. (2011) referenced in Agampatian (2014:20). The final walkability model was constructed by calculating the weighted sum of raster for final four layers; Land-Use Diversity, Residential Density, Street Connectivity, and Proximity to Amenities. This score was reclassified to a scale of 0 to 100. The final neighborhood walkability scores were calculated





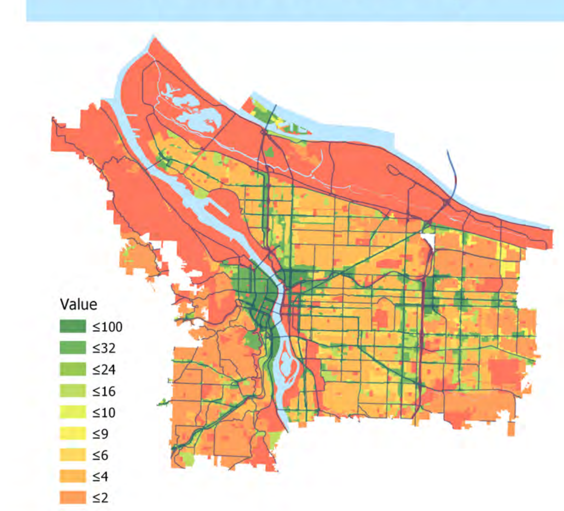
Land Use Diversity



Land use diversity signifies a high degree of difference among various location services and other pedestrian destination points. Areas having easy access to the necessary amenities to meet people's needs, i.e. grocery stores, shopping centers, schools, and public transit stops, as well as a variety of sources of entertainment and green spaces, are considered to be more walkable.

To approximate land-use diversity general land-use classes (shown in Table 2) were used to calculate the number of land-use types within a 300 meter radius of each 60 meter raster cell. This was calculated using the focal statistics tool in ArcGIS. The resulting raster gave a simple score of how many land-use types exist within the boundary radius. The raster was then reclassified to a scale of 1 to 100 in order to standardize the scale for the final weighted sum.

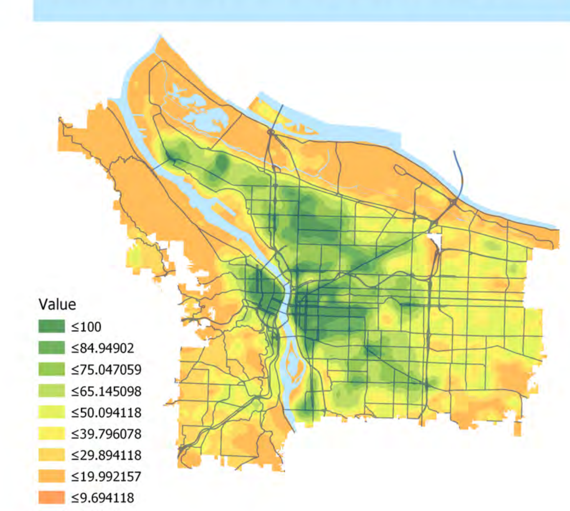
Residential Density



Density has been found to correlate with chances of densely packed networks of diverse amenity locations and walkable city infrastructure. "High density implies compact land development, reduced travel distances between departure sites and destination sites, and decreased dependence on motorized transportation…[and] is considered as an essential measure which is highly correlated with walking." (Agampatian, 2014:9).

To calculate residential density for the model, we used detailed land-use categories from the zoning shapefile provided by RLIS, transformed the units to housing units per acre, and reclassified them to a scale 1 to 100. (See Table 1).

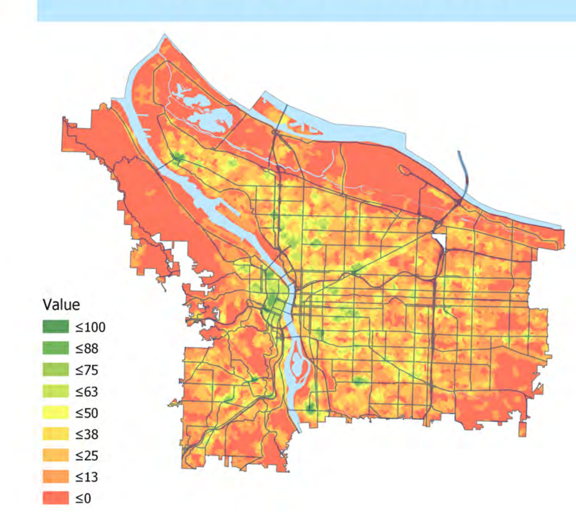
Street Connectivity and Sidewalks



Street connectivity measures how densely connected streets and sidewalks occur in a study area in order to represent minimal transportation barriers and ease of travel for pedestrians. This influences how well pedestrians are able to reach their destinations. Dead ends and limited intersections are considered to negatively impact walkability.

Street intersection density was calculated with kernal density of intersection points. Another kernal density raster was created using the sidewalk shapefile. These two layers were combined using weighted sum, and reclassified to a scale of 1 to 100.

Proximity to Amenities



Proximity to amenities is a measure of the number of destination locations give in in an area. A higher number of amenity locations equates to a higher walkability score, i.e. a location that is within walking distance to a school and a grocery store will get a higher score then a location within walking distance to a school only.

To create this layer we used a network distance buffer for each input point layer. Raster layers were created and reclassified giving areas within distance to each point a score of one. Finally, all of the point layers were combined using the weighted sum tool to add overlapping point buffers. The final proximity raster was reclassified to a scale of 1 to 100 for the final analysis.

Validation Technique 1: Comparing Census Transit-to-Work Estimates

To validate the walkability model we used two validation techniques. The first method for validating the model involved comparing walkability scores obtained by the model to census statistics about mode of transportation to work. If our walkability model is accurate then more people should walk to work in areas with high walkability or at least the number of people who drive to work should decrease. For this validation technique we decided to use block groups as a spatial unit to determine validation at a small geography. Block groups are not generally used in statistical analysis due to a high degree of sampling error, but can be valuable when aggregating to larger geographies. We're using block groups here with the intention of graduating to larger spatial units to further validate the model. We tested the correlation between walkability scores and mode of transportation to work -- a question from the US census. We expect that highly walkable block groups will have significantly negative correlation with the percent of people who drive to work and a positive correlation with the percent of people that walk to work.

The final validation results confirmed our hypotheses. Walkability was confirmed to have a statistically significant negative effect on driving to work and the distribution of 'driving to work' data is found to have a normal distribution. A positive relationship was found between walkability and 'walking to work,' however the distribution of 'walking to work' data was non-normal i.e. positively skewed. We tentatively accept the results of this validation technique, but further analysis is need. The distribution of walkability-score data was found to be slightly bimodal. The walkability-score data and 'walking to work' data must be transformed to achieve normal distribution before any final conclusions can be made about the validity of the model using this technique. This method of validation must also be performed at the census tract geography to obtain accurate results.

Figure 1 Walk-Score over Walk-to-Work

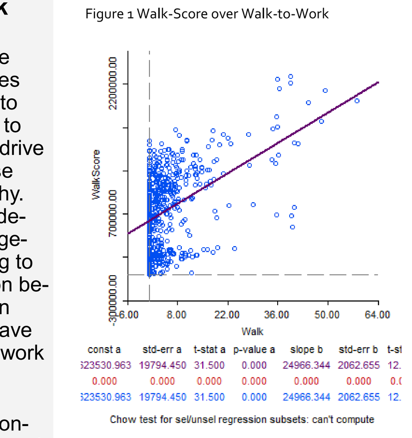
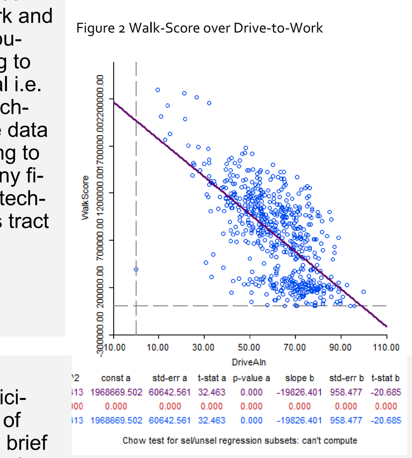


Figure 2 Walk-Score over Drive-to-Work

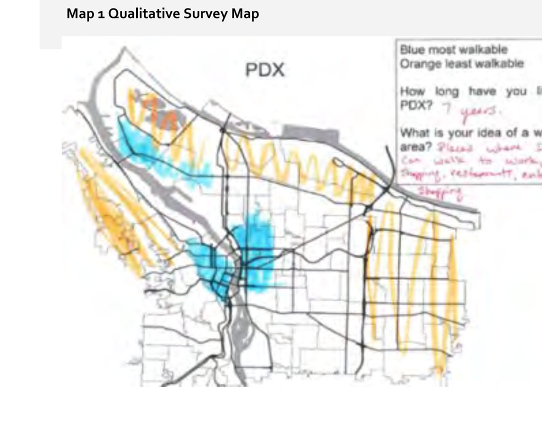


Validation Technique 2: Qualitative Survey

The second validation technique Performed using a qualitative survey given to participants selected at random. Participants were handed blank maps of the study area of Portland and ask to draw, mark, or indicate places that seem most walkable, give a brief description of what characteristics influence their perceptions of walkability, and how long they lived in Portland. The survey illustrated a spectrum of how people perceive walkability. The first thing we noted is that some people highlighted lines over roads and some people highlighted areas. People surveyed chose Buckman, Downtown, Eliot, Lloyd and Irvington as the top 5 most walkable neighborhoods. These are some of the innermost neighborhoods and generally have been the most walkable and commercially developed for the longest time. In addition, the businesses that are in these places lend themselves to pedestrian traffic such as restaurants and bars which are attributes that we did not include due to lack of data. The characteristics of walkability pie chart illustrates that attributes that contribute to a safe and pleasant walking commute, such as a pleasant environment and streetlights, were a priority to participants although we did not incorporate them into the model.

We find that the validation survey reflects similar walkability distributions that were achieved in the final results of the walkability model. Neighborhoods that were identified by respondents to be highly walkable are found in our final neighborhood walkability-score analysis to predict the degree of walkability in our analysis. Generally, respondents report a high degree of neighborhood walkability closer to the City Center and Inner Southeast neighborhoods. Many respondents note a line near 82nd Avenue or I-205 in the Southeast that separates walkability. While no clear distinction can actually made about a clear drop in walkability at these landmarks, there is a gradual decline in walkability moving further towards East Portland.

Map 1 Qualitative Survey Map



Map 2 Walkability Survey Choropleth

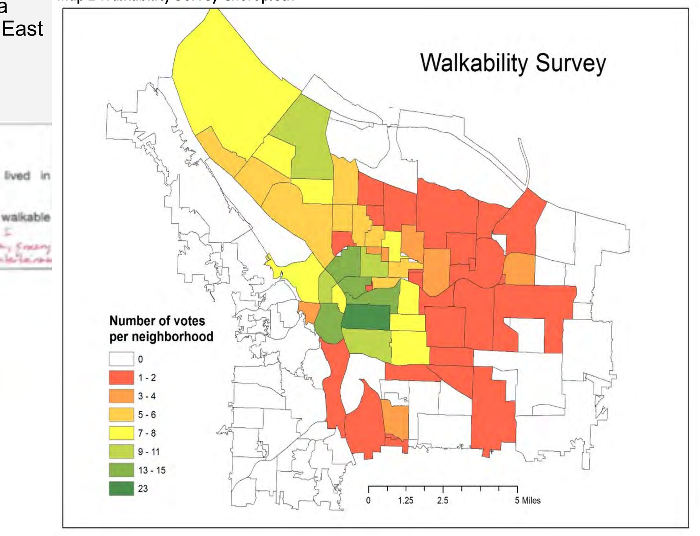


Figure 1 Survey Results

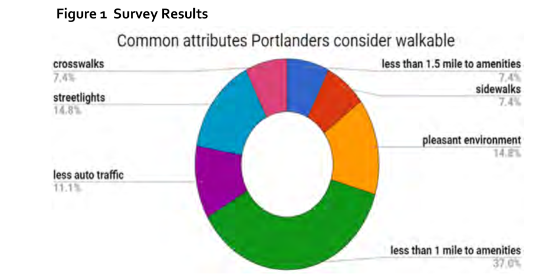


Table 5 Summary of Validation Participants

Survey participants		
Who	Number	How long lived in Portland
PSU Student	5	12 years
North Portland resident	4	11 years
SE Portland resident	3	6.5 years
SW Portland resident	3	4 years

Table 6 Survey Neighb Rankings

Neighborhood	Survey Score
buckman	23
Downtown	15
Eliot	14
Loyd	13
Irvington	11
Kenton	10
Boise	9
Kerns	9
Portsmouth	9
Arbor Lodge	8
St Johns	8
Brooklyn	7
Woodlawn	7
Cathedral Park	6
Grant Park	6
Hosford-	6
Overlook	6
Pearl	6
Piedmont	6
Sabin	6
Sunnyside	6
University Park	6
Vernon	6
Concordia	5

Discussion

Using dual validations scores, we are comfortable concluding that our walkability model successfully predicts walkability at a scale of 60 square feet. Because we have reliable estimates of walkability at such a fine spatial resolution, we are now able to calculate walkability scores for larger geographies like census tracts and neighborhoods. This is a central part of our argument, that walkability studies should be conducted at a finer scale first and then those figured used to make connections to census geographies and census statistics.

There are possible factors that influence walkability that we did not include in this model but could be included in future models. Many survey recipients indicated that their perceptions of walkability included the presence of street lights and crosswalks. More infrastructural features like these can be accounted for in future maps. Also, we didn't include measures of perceived crime, which also may contribute to area walkability.

Measuring walkability isn't a straightforward objective science. It is about diverse range of human perceptions and values. Standards for walkability are different for everyone. More effort must be taken to determine how walkability is constructed for different populations. Further research may define how walkability is conceived for the elderly or people with physical disabilities. The concept of walkability must be pressed further to understand the implications of defining walkability for marginalized groups and communities that have experienced historic disadvantage. As walkability is used to promote real estate development, the concept may link to neighborhood change and market driven displacement.

Conclusion

In the final model of neighborhood walkability, we calculated neighborhood scores by averaging the walkability raster scores within each neighborhood. The final neighborhood walkability score is the mean walkability raster score. The features of the validation survey map well onto the final neighborhood walkability results. We find that the model accurately predicts walkability. Table 4 shows the final neighborhood walk-scores created from our analysis. Lloyd District, Old Town, Buckman, Laurelhurst, Vernon, and Boise are among the top most walkable neighborhoods in Portland according to our estimates. Further analysis is needed to make comparisons among walkable and non-walkable neighborhoods in Portland. We have succeeded in establishing a base model for measuring walkability at a fine scale in Portland.

Table 4 Final Neighborhood Walk Scores

Neighborhood	Walk Score
LLOYD DISTRICT COMMUNITY ASSN./SULLIVAN'S GULCH	95
LLOYD DISTRICT COMMUNITY ASSOCIATION	95
OLD TOWN/ CHINATOWN	95
BUCKMAN COMMUNITY ASSOCIATION	95
LAURELHURST	92
VERNON	90
BOISE/ELIOT	90
IRVINGTON COMMUNITY ASSOCIATION	90
GRANT PARK/HOLLYWOOD	90
SULLIVAN'S GULCH	90
KERNS	90
SULLIVAN'S GULCH / GRANT PARK	88
HOLLYWOOD	88
MT. TABOR	86
SUNNYSIDE	86
KING	85
GRANT PARK	85
HAZELWOOD/MILL PARK	85
SABIN COMMUNITY ASSOCIATION	85
RICHMOND	85
ELIOT	82
NORTH TABOR	81
SABIN COMMUNITY ASSN./IRVINGTON COMMUNITY ASSN.	80
ALAMEDA/IRVINGTON COMMUNITY ASSN.	80
PEARL DISTRICT	80
ALAMEDA	80
FOSTER-POWELL	80

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