# Using GIS to Measure Connectivity: *An Exploration of Issues*

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# Table of Contents

# Introduction

## *Benefits of Bicycling and Walking*

As gas prices hover near $2.50/gal, and health experts continue to point out the growing obesity epidemic in the US, the ability to bike and walk around your community becomes an important transportation alternative. People choosing to ride or walk rather than drive are typically replacing short automobile trips, which contribute disproportionately high amounts of pollutant emissions. Since bicycling and walking contribute no pollution, require no external energy source, and use land efficiently, they effectively move people from one place to another without adverse environmental impacts.

Bicycling and walking can also help alleviate congestion and stressed transportation systems. With over 40% of all trips in the United States being two miles or less (FHWA, National Personal Transportation Survey, 1995), walking or bicycling can serve as an important mobility option. Nationally, the number of vehicle miles traveled (VMT), rates of car ownership, and trips have continued to grow, which has increasingly stressed transportation systems (primarily roadways) and contributed to congestion (NPTS, 2003). Bicycling and walking require less space and infrastructure when compared to automobile facilities. Improvements made for bicyclists often result in better conditions for other transportation users as well. For instance, paved shoulders, wide curb lanes, and bicycle lanes not only provide improved conditions for bicyclists, but also often contribute to safer conditions for motorists and a reduction in roadway maintenance costs as well.

Walking and bicycling are also good choices for families. A bicycle enables a young person to explore her neighborhood, visit places without being driven by her parents, and experience the freedom of personal decision-making. More trips by bicycle and on foot mean fewer trips by car. In turn, this means less traffic congestion around schools and in the community, and less time spent by parents driving kids around. There are also more opportunities to speak to neighbors and more "eyes on the street" to discourage crime and violence. It is no accident that communities with low crime rates and high levels of walking and bicycling are generally attractive and friendly places to live.

The extent of bicycling and walking in a community has been described as a barometer of how well that community is advancing its citizens' quality of life. Streets that are busy with bicyclists and walkers are considered to be environments that work at a human scale, and foster a heightened sense of neighborhood and community. These benefits are impossible to quantify, but when asked to identify civic places that they are most proud of, residents will most often name places where walking and bicycling are common, such as a popular greenway, river front project, neighborhood market, Main Street, or downtown.

## *Importance of Connectivity*

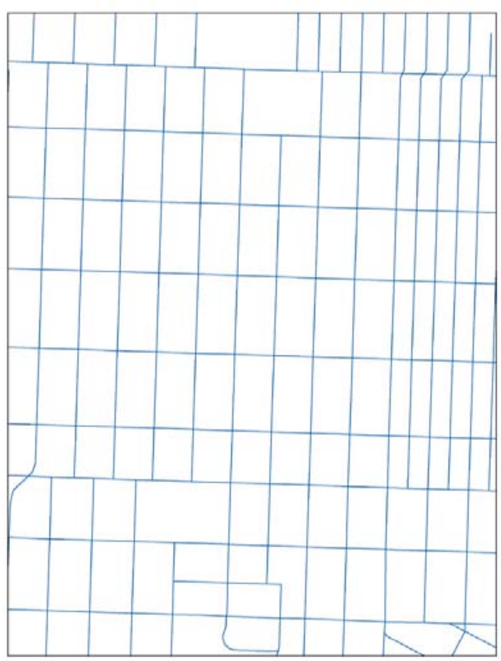
It is difficult to bicycle and walk safely and comfortably around a community where connections are few and far between. The Victoria Transport Policy Institute states that, "*Connectivity* refers to the directness of links and the density of connections in path or road network. A well-connected road or path network has many short links, numerous intersections, and minimal dead-ends (cul-de-sacs). As connectivity increases, travel distances decrease and route options increase, allowing more direct travel between destinations, creating a more accessible and resilient system." (Online TDM Encyclopedia, www.vtpi.org, viewed 11/11/05)

Past roadway design practices have traditionally favored a hierarchical street network concept, with local, collector and arterial streets designated and designed with the primary purpose of funneling automobile traffic (Figure 1). This type of roadway design makes more extensive use of cul-de-sacs and dead ends, requiring travel on the larger arterial streets for most trips.

Figure 1 – Hierarchical street network


A more connected road system provides a greater number of route options and decreases out-of-direction travel by providing more direct routes, making bicycling and walking more appealing (Kulash, Anglin, Marks 1990) (Figure 2).

Figure 2 – Connected street network



## *Purpose*

The purpose of this paper is to examine the different methods used in measuring connectivity, and to evaluate the effectiveness and limitations of those methods by drawing on examples from running connectivity measurements on different sized study areas. The study is broken into the following sections:

- Defining the various connectivity measures used, providing background on each of the measures, and commenting on the reasons underpinning the use of that particular measure.
- The methodology used in creating and evaluating the data using a Geographic Information System (GIS). This discussion includes an examination of the various steps taken to clean and process the data, as well as the various tools used that are available in GIS, and the assumptions and tradeoffs through that process. This study will hopefully prove useful for replication of the various measures calculated in this study in the future.
- An analysis of the connectivity measurement calculations to highlight the power, as well as limitations, of the GIS methods and data choices available for the calculations.
- Conclusions about the usefulness of the protocol used, as well as lessons learned from creating the methodology outlined in this study.

## Connectivity Measures

Table 2 contains the eight different connectivity measures analyzed in this study and draws heavily upon the work of Dr. Jennifer Dill, School of Urban Studies and Planning, Portland State University (2005). Definitions necessary for a greater understanding of the connectivity measures are provided in Table 1 and Figure 3.

Table 1. Connectivity Definitions

| *Word/Phrase* | *Definition* |
|---|---|
| Link | A roadway or pathway segment between two nodes. A street between two intersections or from a dead end to an intersection. |
| Node | The endpoint of a link, either a real node or a dangle node |
| Real node | The endpoint of a link that connects to other links. An intersection. |
| Dangle node | The endpoint of a link that has no other connections. A dead-end or cul-de-sac. |
| Circuit | A finite, closed path starting and ending at a single node. |

Figure 3. Connectivity Definitions

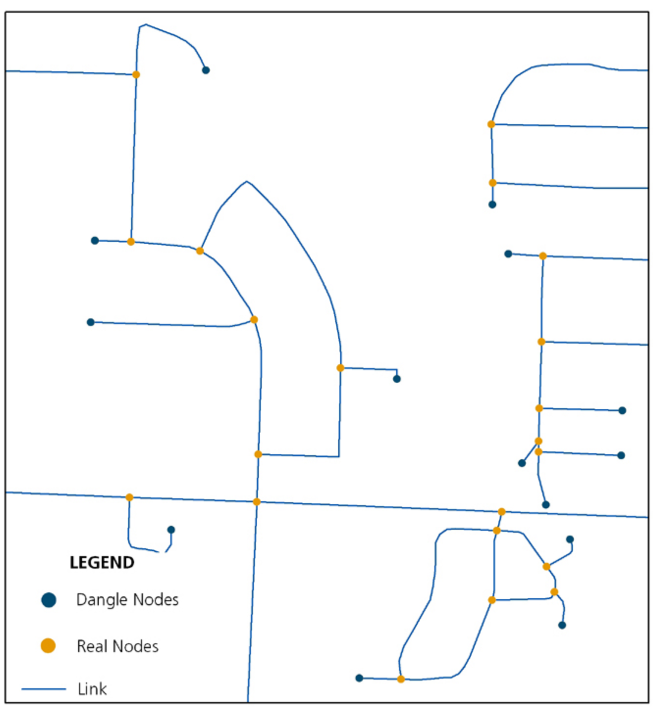


Table 2. Connectivity Measures

| ***Measure*** | ***Definition*** | ***Calculation*** | ***Comments*** |
|---|---|---|---|
| Intersection Density | Number of intersections per unit of area | # Real nodes area / area | A higher number would indicate more intersections, and presumably, higher connectivity (See Figures 1 and 2). |
| Street Density | Number of linear miles of street per square mile of land | Total street length per unit of area / area | A higher number would indicate more streets, and presumably, higher connectivity. |
| Connected Node Ratio (CNR) | Number of street intersections divided by the number of intersections plus cul-de-sacs | # Real Nodes / # Total Nodes (real + dangle) | The maximum value is 1.0. Higher numbers indicate that there are relatively few cul-de-sacs and dead ends, and presumably a higher level of connectivity. |
| Link-Node Ratio | Number of links divided by the number of nodes within a study area | # Links per unit of area (streets) / # Nodes per unit of area | A perfect grid has a ratio of 2.5. This measurement does not reflect the length of the link in any way |
| Average Block Length | Block lengths can be measured from the curb or from the centerline of the street intersection. The GIS measures the street length from center of intersection to center of intersection. | Sum of link length per unit of area / # of nodes per unit of area | Shorter blocks mean more intersections and therefore a greater number of routes available. |
| Effective Walking Area (EWA) | A ratio of the number of parcels within a one-quarter mile walking distance from an origin point to the total number of parcels within a one-quarter mile radius of that origin point. | Taxlots within ¼ mile walking distance of origin point / Taxlots within ¼ mile radius | Values range between 0 and 1, with a higher value indicating that more parcels are within walking distance of the pre-defined point. The higher value reflects a more connected network. |
| Gamma Index | Ratio of the number of links in the network to the maximum possible number of links between nodes. | # Links per unit of area / 3*(# Nodes – 2) | This measure comes from geography. Values range from 0 to 1. |
| Alpha Index | Ratio of the number of actual circuits to the maximum number of circuits. | (# Links - # Nodes) + 1 / 2*(# Nodes) - 5 | This measure comes from geography. Values range from 0 to 1. |

## *Analyzing the Connectivity Measures*

The eight connectivity measures in Table 2 were calculated for the Portland Metro region as defined by the urban growth boundary (UGB). The unit of measurement for the region-wide calculations was the census tract. Portions of those census tracts crossing the UGB were included. Dill (2005) identified several reasons for using census tract as the unit of analysis.

> First, the median size of census tracts in the region resembles the probable walking and cycling area for an individual. Existing travel surveys show that most walking trips are well under one mile and most bicycle trips are under five miles. The median size of a census tract in the Portland region is 1.16 square miles, and the mean is 9.39 square miles. Traffic analysis zones (TAZs) for the region are generally smaller, with a median size of 0.37 square miles. Therefore, it's likely that a persons walking or cycling trip would extend beyond one TAZ. Second, census tract boundaries are relatively stable over time and can be used in any area of the U.S. Third, there is a reasonable number of census tracts (under 400) compared with 1,247 TAZs.

Additionally, the connectivity measurements were analyzed using a half-mile buffer around a randomly selected taxlot. This analysis was conducted to compare the census tract connectivity measurement with a more localized measurement for a specific point within the tract(s). Using buffers presented methodological problems discussed further in this study.

# Methodology

## *Geographic Information Systems (GIS)*

Two different GIS programs were utilized in calculating the connectivity measurements for this research. While frustrating at times to move between two different systems - ArcView 3.3 and ArcGIS 8 – the differences in flexibility and functionality of each program proved better suited for various tasks. Both programs are commonly used and are commercially produced and licensed by ESRI (www.esri.com).

The most useful functions provided by the base versions of the mapping programs reside in ArcGIS 8 - the Buffer Wizard and the Geoprocessing Wizard. The Buffer Wizard allows rings to be drawn around features (points, lines, or polygons) at a specified distance from that feature. This was used in creating 0.5-mile buffers around selected taxlots as described in the previous section. This feature is also available in ArcView. To utilize the Buffer Wizard, the map must have defined map units; otherwise the buffers cannot be processed. The Geoprocessing Wizard in ArcGIS will perform several different operations, including:

- Dissolve features based on an attribute –This operation aggregates features that have the same value for an attribute that is specified.
- Merge layers together – This operation appends the features of two or more layers into a single layer. Attributes will be retained if they have the same name.
- Clip one layer based on another – This operation uses a clip layer like a cookie cutter on the input layer. The input layer's attributes are not altered.
- Intersect two layers – This operation cuts an input layer with the features from an overlay layer to produce an output layer with features that have attribute data from both layers.
- Union two layers – This operation combines features of an input layer with the polygons from an overlay layer to produce an output layer that contains the attributes and full extent of both layers.

Additionally, four ArcScripts downloaded from the ESRI website (http://arcscripts.esri.com/ ) proved highly beneficial in processing the data and calculating connectivity measurements. ArcScripts create extensions for the mapping program and are written and contributed by ESRI's user community. The ArcScripts utilized were:

- Point & Polyline Tools v1.2 – available only for ArcView. Created by Soren Alsleben. The following descriptions are taken from the ESRI download of this extension. This extension contains a collection of tools to convert and / or modify point and polyline themes. The tools used in this study include:
    - Polyline Consolidator – Consolidates adjacent polylines with identical endpoints between existing network nodes (dangle and real nodes). Consolidated lines are reconstructed to avoid redundant and / or missorted vertices.
    - Polyline Nodes Extractor – Extracts nodes of a polyline theme. Nodes are classified as dangle, real, and vertex.
    - Snap Point 2 Polyline – Snaps (moves) points within a selectable map distance onto a polyline. The points are snapped to the closest vertex of the nearest polyline. The density of the polyline's vertices can be increased by adding virtual vertices without writing changes to the polyline theme.
- XTools – available for ArcView. Mike DeLaune at the Oregon Department of Forestry created the XTools extension, which contains useful vector spatial analysis and shape conversion. XTools performs the various features described for the GeoProcessing Wizard above, as well as:
    - Identity – This operation creates a new theme by overlaying two sets of features, and the output theme contains all the input theme features and only those portions of the Overlay theme features that overlap the Input theme.
    - Recalculate Area, Perimeter, Length, Acres, Hectares – This operation calculates the area, perimeter, acres and/or hectares for a polygon, and length for a line.
    - Convert Shapes to Centroids – This operation creates a new point shapefile from the center points (centroids) of a polygon. A centroid of a shape is the spatial location of its "center of mass".

- XTools Pro 3.0 – available for ArcGIS. This extension performs the same operations as described above, but is written in a different programming language to work in ArcGIS.
- Identify Features Within a Distance – available for ArcView. This extension lets you identify features that are within a specified distance of each set of input features.

ArcView was utilized for the usefulness of the Point & Polyline Tools v1.2 extension. The tools and extensions described above were used in isolating and cleaning the data so that the connectivity measures could be calculated and analyzed. The tools and extensions are highlighted further in the study when they were utilized.

Additionally, further steps in evaluating the connectivity measures are reliant upon Network Analyst, an extension not available in ArcGIS 8. Network Analyst is available as part of ArcGIS 9, the latest mapping program from ESRI. However, organizations and jurisdictions are still in the process of updating software, and when the calculations for this research were performed, ArcGIS 9 was not yet available. ArcGIS 8 was utilized for its more powerful GeoProcessing features, as well as a more user-friendly display and interface.

## *Data Collection*

The data for the study comes from Metro, the regional government that includes Portland, OR. Metro maintains the Regional Land Information System (RLIS), and makes portions of that database available for purchase. For the purposes of this study, the only necessary data from RLIS was the complete street network and census tracts (unit of analysis), as well as the taxlot data used for additional analysis.

As noted earlier, the unit of analysis for the study is the census tract. The study also used an "artificial" unit of analysis of 0.5-mile buffer around origins for further calculations. The discussion of the problems associated with this "artificial" unit of analysis is discussed further in Examples / Shortcomings.

There are some noticeable shortcomings in basing the connectivity measurements on the street network. The street network contains no details about a particular street's suitability for biking or walking, leading to assumptions in the connectivity measurements based only on the presence of a street. Additionally, using only the street network does not account for off-street paths, pedestrian accessways, etc. This shortcoming is explored further using the street network around Gabriel Park in SW Portland as an example.

To make a more robust shapefile containing both on- and off-street networks from which to calculate connectivity measures would depend greatly upon the jurisdiction or jurisdictions that are being analyzed. The extent and amount of data that is available varies greatly from jurisdiction to jurisdiction – finding those with both good records of the street network as well as the off-street path system would not be easy. Furthermore, some jurisdictions might keep data files for on-and off-street networks in different bureaus, say the Office of Transportation for streets and the Parks and Greenspaces for off-street paths. Consolidating these separate databases might present difficulties. For the example later in the study, the off-street path system was based on personal knowledge as well as an examination of the aerial photo. This is time consuming and only possible through first-hand experience with the study area.

On the other hand, there are some clear benefits in using only the street network. Using the protocol defined below, the street network becomes the only data required from a jurisdiction, making it highly likely that the protocol will be replicable. However, as described further below, part of the protocol involves creating a local street network with no highways or freeways. Using RLIS, this was a straightforward process. Unfortunately, the attempts to use TIGER (**T**opologically **I**ntegrated **G**eographic **E**ncoding and **R**eferencing system) files provided by the US Census Bureau (http://www.census.gov/geo/www/tiger/) to create the local street network proved more problematic than expected, as the street feature type (Ave, Blvd, Bridge, Ramp, etc) was generally left blank in the TIGER database. However, the protocol remains fairly straightforward and quickly followed, without the addition of further information about the presence and condition of sidewalks, bike lanes, paths, etc.

### *Protocol*

In calculating connectivity measurements, the study concentrated on the local street network – streets where bicycle and pedestrian use is legal and potentially expected. For that reason, all non-local streets need to be removed from the streets dataset. This was accomplished by using the metadata for the streets layer as a key. The streets dataset contains a column labeled FTYPE, which identifies the street feature type. Using the metadata description for the FTYPE, the researcher selected out all freeways, expressways and on/off ramps.

However upon a closer examination of the data, the researcher discovered an error. Using the RLIS street data, removing the on/off ramps resulted in the removal of both the local bridge connections and the highway/freeway bridge ramps. Removing the highway/free bridge ramps was the goal; we did not want them to be counted as additional links within the census tract. The removal of the local ramps was unexpected. This is particularly problematic in the Portland, OR downtown area, where a number of local bridges provide connectivity across the Willamette River (See Figure 4). This creates links with false dangle nodes, as well unconnected links that in reality provide excellent bicyclist and pedestrian connectivity.

For example, the bridge at the bottom of Figure 4 is the Hawthorne Bridge, a primary east west connector in the city that over 3500 bicyclists alone use daily. However, with the elimination of the on/off ramps from the street network, the link is cut off and ends with a dangle node, disrupting the network connectivity and not a true reflection of reality. The only method available at this point is to physically examine the ramp data, and manually exclude on/off ramps associated with freeways while keeping other, local ramps in the dataset. This is the same method recommended in the

University of Minnesota Twin Cities Walking Study GIS Protocol in correcting for Interstate/ramp intersections (143). This can be a time and labor intensive process, especially for larger study areas in a city such as Portland or the Twin Cities, where a number of local and freeway bridges exist.

Figure 4. Local bridge on/off ramps


Once the local street network has been defined as described above, the data was processed using the Polyline Consolidator in Point & Polyline Tools to clean the shapefile. This is a time intensive procedure, taking a couple of hours for the Portland, OR dataset to run. In the end, the number of records went from 97,011 records in the original streets file to 68,728 records in the cleaned, local street network file.

Using this new shapefile, the Polyline Nodes Extractor (without vertices) in Point & Polyline Tools was utilized to create the nodes (intersection) shapefile. For the connectivity measurements, only the real and dangle nodes are necessary, the vertices show points along the link, but do not correspond to an intersection. For the Portland Metro area (area within the UGB as of January 2004) this results in 37,469 real nodes and 13,700 dangle nodes.

Now we have the two necessary shapefiles:

- Clean local street shapefile and
- Nodes shapefile with real and dangle nodes.

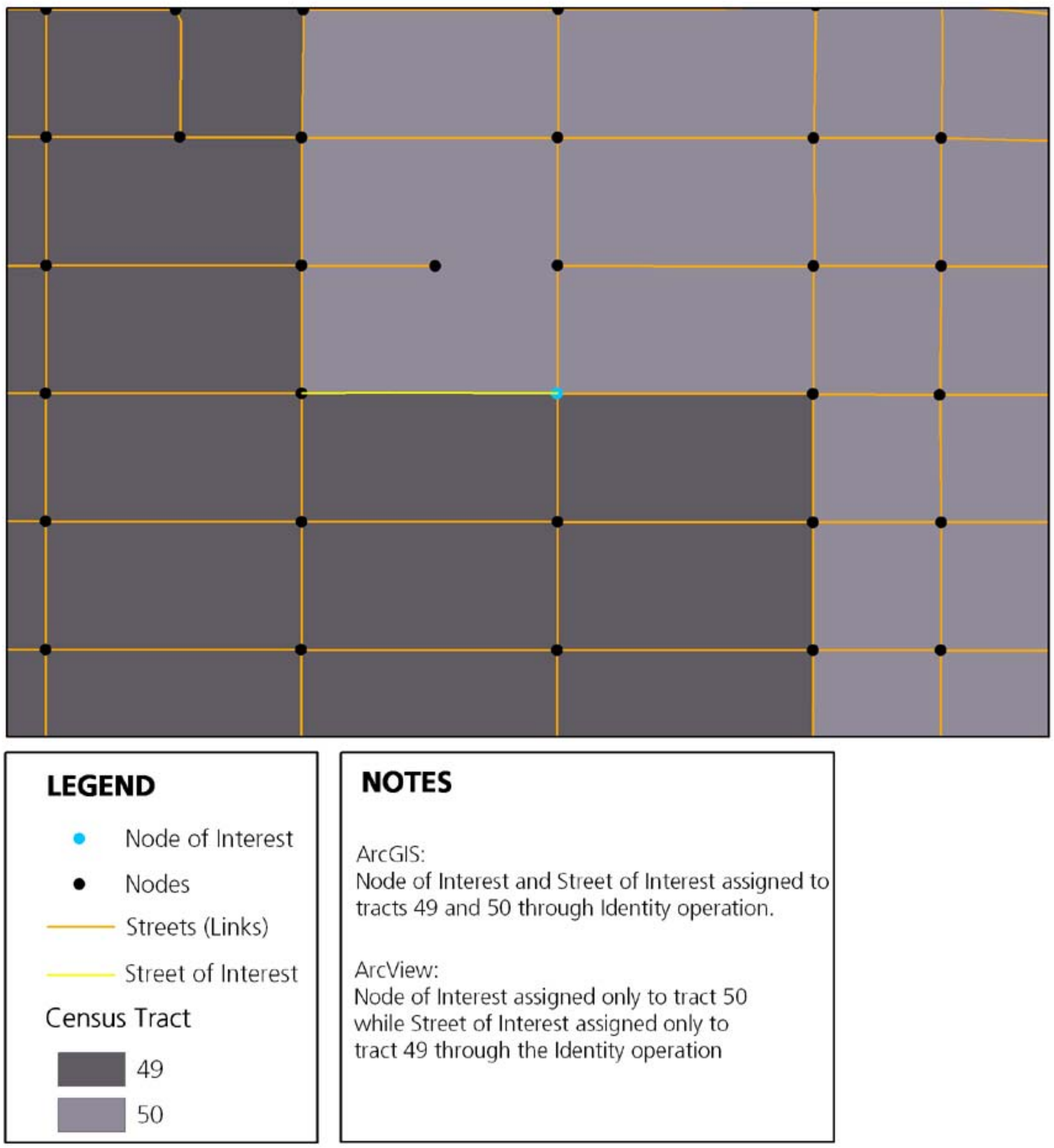
Add in census tracts to the map view and we are almost ready to calculate our connectivity measures.

Prior to calculating the connectivity measures for the individual census tracts, we need to assign each link and node to a census tract so we can accurately summarize the counts for each census tracts using Pivot Tables in Microsoft Excel. The most straightforward method is using XTools; perform an Identity operation on each of the two shapefiles to get census tract numbers associated with each shape. However, this creates problems. To isolate the problems, the researcher created a test map using 772 nodes, 1397 streets, and 10 tracts from NW Portland, and performed the Identity operation in both ArcView and ArcGIS. The results returned by each GIS are quite interesting.

Performing the Identity operation in ArcGIS resulted in the creation of 952 nodes, an increase of 23% more nodes, with the nodes on the border of multiple tracts being assigned to all the tracts. For the streets, 1397 streets became 1550 streets, with similar, but not the same, results.

Performing the Identity operation in ArcView returned very different results. In the node shapefile, 772 nodes stayed 772 nodes, with nodes on the border of multiple tracts being assigned to only one of the border tracts, not all of them. For the streets shapefile, the original 1397 streets became 1427 streets, more than the original file, yet only a 2% increase in the number of streets, compared with an 11% increase in the number of streets when the Identity operation was performed in ArcGIS (See Figure5). Without a much better understanding of the programming governing the two programs, a reasonable explanation is difficult to identify. However, some of the discrepancies can be explained.

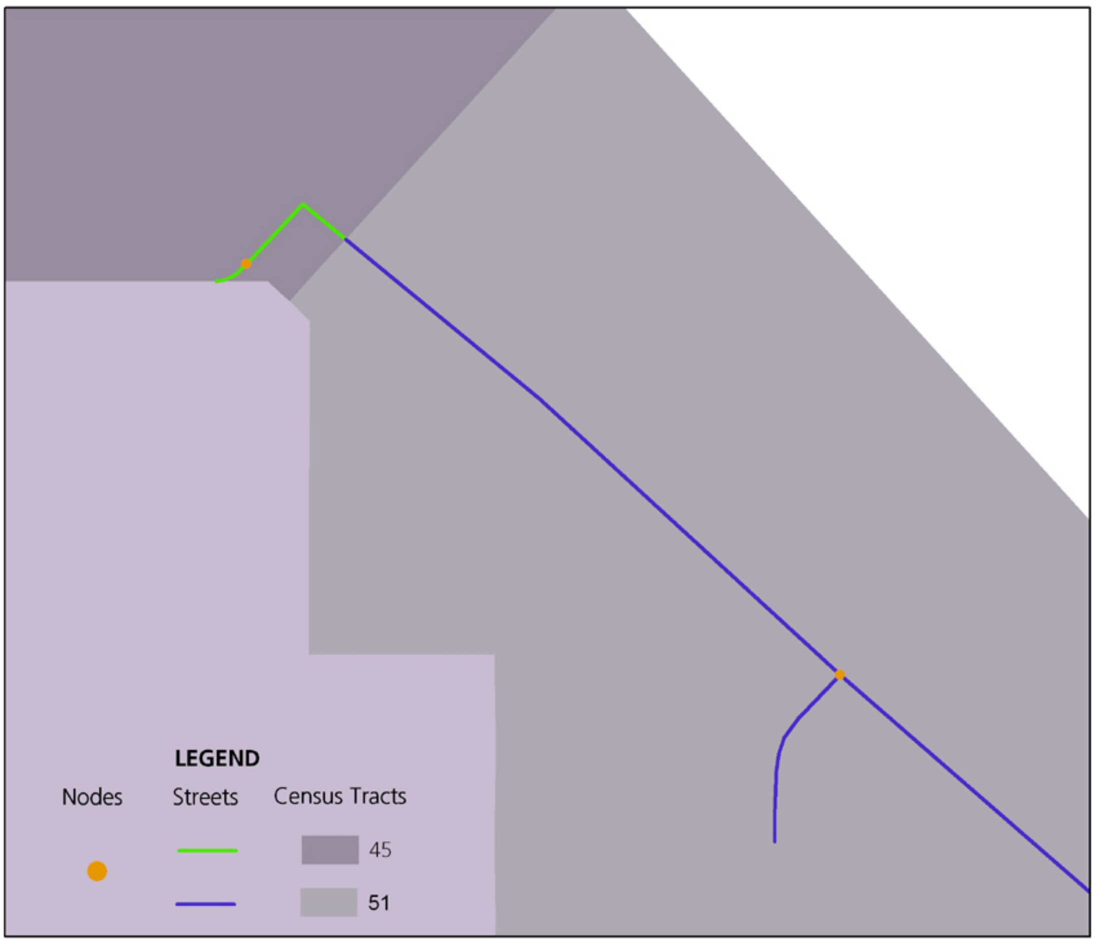
Figure 5 – ArcGIS / ArcView tract border example



There are two primary reasons for the discrepancies noticed:

1. The streets / links are determined by the presence of nodes. No node, the link continues. In some areas of town, the links curve and pass through more than one tract, resulting in the assignment of two (or more) tract numbers in both ArcView and ArcGIS (Figure 6) This accounts for some of the 2% increase seen in the number of streets in ArcView after the Identity operation, as well as a portion of the 11% increase in the number of streets in ArcGIS.

Figure 6. Street passing through multiple tracts




2. The street segments are not consistently in line with the census tract borders when added to the map in the GIS. This results in a street being assigned to only one of the two tracts (Figure 7), or having a portion of the street being assigned to one tract while another portion of the same street,

between the same two nodes, being assigned to the neighboring census tract (Figure 8). For calculating purposes, the former circumstance is more problematic. In the latter example, the link will still be counted as existing in both census tracts, while in the former example, the link will only be counted in one of the two census tracts.

Is this because the street and the census tract border do not line up in the physical real world, or is it an error in the creation and interaction of one (or both) of the files within the GIS? After closer examination, it is likely the latter case for the majority of our examples. At some point, someone manually digitized the street network and the census tract network to create the files now contained within the GIS, providing room for error in the process. In the near future, the files will be created digitally as well, using GPS technology to digitally map the streets and tracts.

The US Census Bureau website defines a census tract as a, "small, relatively permanent statistical subdivisions of a county. Tracts are delineated by a local committee of census data users for the purpose of presenting data. Census tract boundaries normally follow visible features, but may follow governmental unit boundaries and other non-visible features in some instances; they always nest within counties." Within an urban area, visible features are often the street network. Furthermore, Figure 7 illustrates that different links of the same street joined to the same node can be assigned to either one or both of the census tracts, depending on the physical relationship between the census tract file and the street file. This type of error occurred in both GIS platforms, although we'll see that the percent error is relatively low.

Figure 7. Street segment assigned to one tract

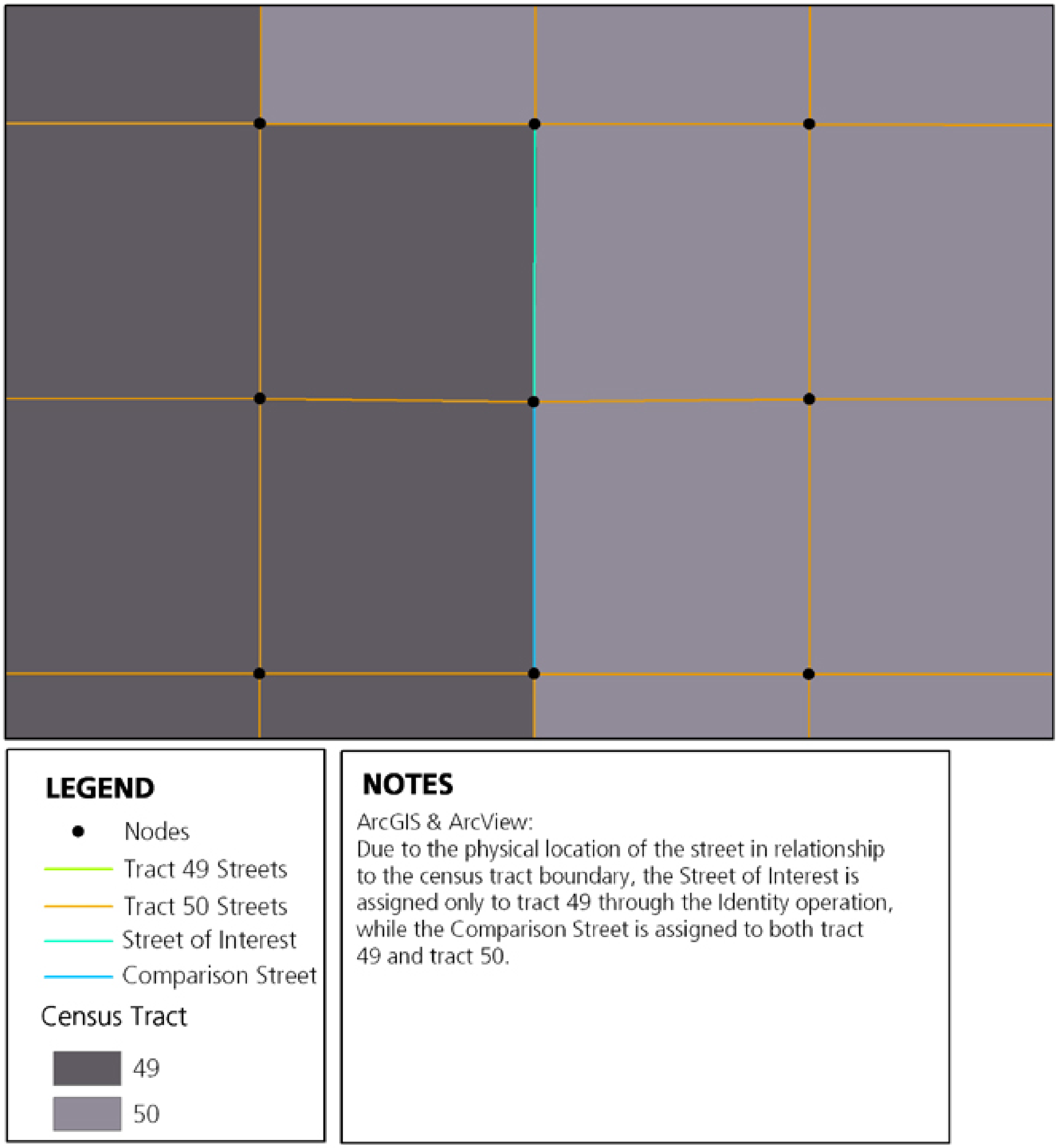
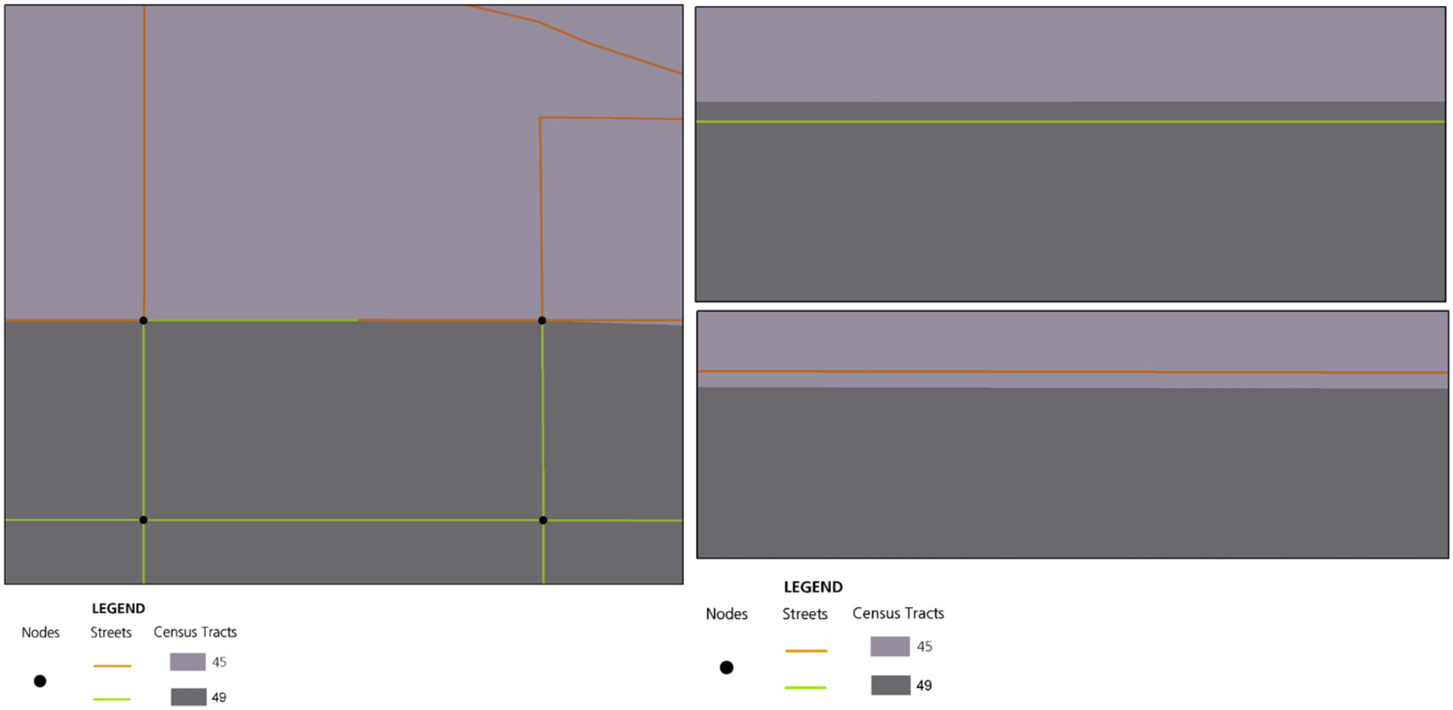


Figure 8. Street segment assigned to two tracts




What is the tolerance for assigning the links to tracts when this occurs? Both GIS show that the tolerance is very low indeed, with measurements recording less than 0.02 feet (about a ¼ of an inch) difference between the location of the street and the location of the census tract border.

What are the next steps? Depending on the accuracy required and the time available, there are two directions to go.

1. In ArcGIS, apply the Identity feature on all streets and nodes as described above. The results: reasonably confident in the accuracy in assigning nodes to the correct census tract(s), with slightly less confidence in assigning all streets to the correct census tract(s). This presents problems as documented in Figure 7, since the lack of the complete network will skew some of the calculations for the connectivity measures. As an example, let's look at Tract 50, one of the tracts where links and nodes were assigned to only one tract, rather than multiple tracts (Figure 9, Tables 3 and 4).

Figure 9. Tract 50 Streets / Nodes

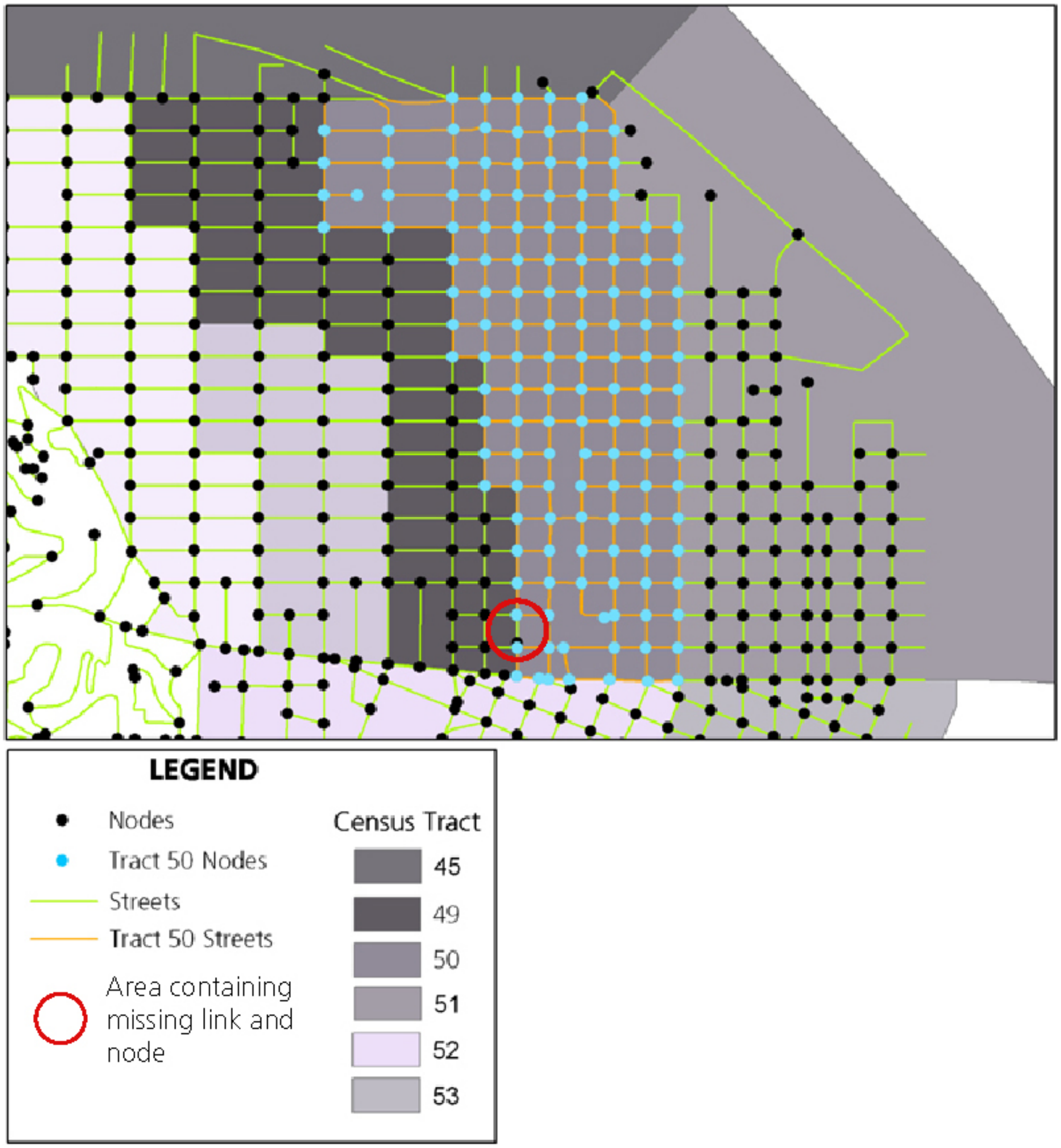



Table 3. Count of Nodes and Links for Tract 50

| | GIS Count | Corrected Count | % Difference |
|---|---|---|---|
| Real Nodes | 134 | 134 | 0 |
| Dangle Nodes | 3 | 4 | 33 |
| Total Nodes | 137 | 138 | 0.7 |
| Links | 237 | 239 | 0.8 |

### Table 4. Connectivity Measure Calculations

| Measure | GIS | Corrected GIS | % Difference |
|---|---|---|---|
| Intersection Density | 470.18 | 470.18 | 0 |
| Street Density | 42.50 | 43.08 | 1.3 |
| Connected Node Ratio | 0.98 | 0.97 | -0.7 |
| Link-Node Ratio | 1.73 | 1.73 | 0.1 |
| Average Block Length | 466.85 | 469.71 | 0.6 |
| Gamma Index | 0.59 | 0.59 | 0.1 |
| Alpha Index | 0.38 | 0.38 | 0.2 |

As Tables 3 and 4 illustrate, the difference between the measures using the counts from the GIS and the counts from the corrected GIS are very small, particularly considering the labor and time investment necessary for manually correcting for all 289 census tracts used in this study. Manually correcting the link/node values for one tract took 15-20 minutes, which would increase the total computation time by nearly 80 hours.

2. However, if 100% accuracy is necessary, a longer, more involved method applicable in ArcView is detailed below:

- Create buffers around each of the census tracts, essentially expanding the size of the census tract border by the size of the buffer. The buffer size established can be chosen by the researcher, although it probably shouldn't be any larger than 25 feet. For this research a buffer of 10 feet was chosen.
- Using XTools, Intersect the buffer with the street shapefile and the nodes shapefile. Create new shapefiles from those street and nodes that are within the buffer.
- You now have 4 shapefiles:
    - Clean local streets completely within one census tract
    - Clean local streets on border of census tract
    - Nodes completely within one census tract
    - Nodes on the border of census tract

The next steps are for the streets and nodes on the border of census tracts.

- Use Identify Features Within a Distance extension on file for objects (either streets or nodes) within 10 map units. This creates two files, an object.comp file and a street input file.
- For streets, recalculate the border street lengths using XTools.
- Join the border shapefile with the object.comp file to get the object attributes appended to the line ID in object.comp file.
- Using Excel, merge the object.comp file with the file containing objects completely within one census tract to return with one complete object file. Some of the objects (streets and nodes) are in more than one tract for calculation purposes.

Result:

- One file with clean, local streets with census tracts attached. Some streets appear in more than one tract.
- One file with clean nodes with census tracts attached. Some nodes appear in multiple census tracts.

We are now ready to calculate the connectivity measurements.

## Examples / Shortcomings

In addition to the examples shown in the previous section that highlighted difficulties in cleaning and manipulating the data, this study also highlights two other difficulties that arose during the calculations portion of the research.

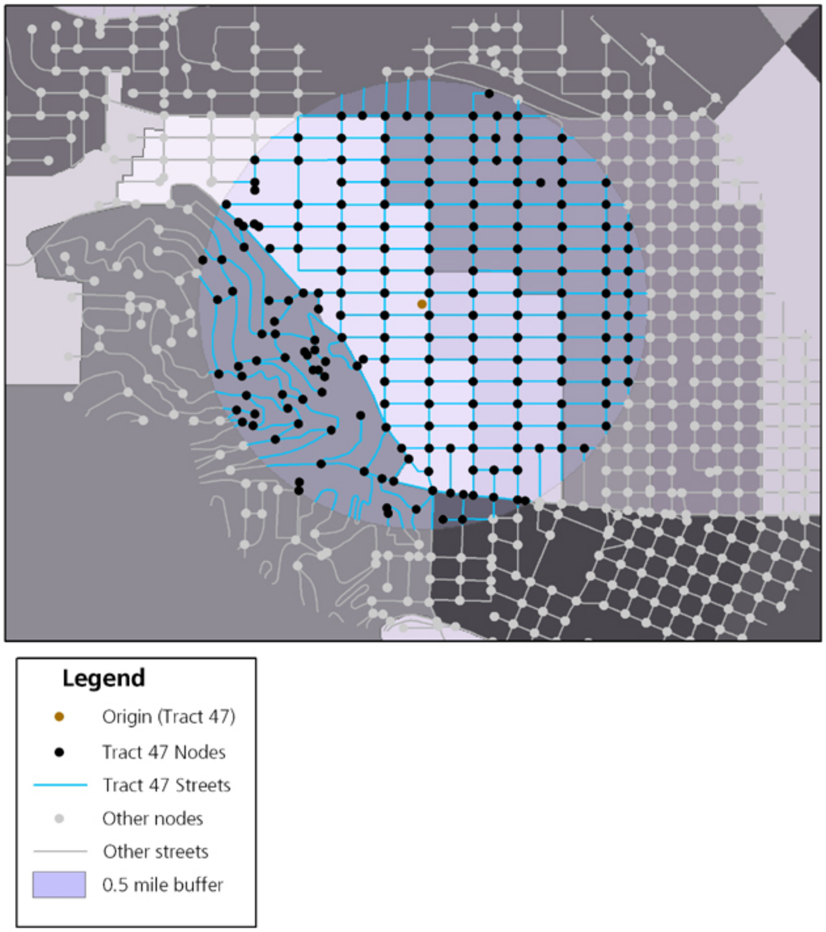
### *Creating Artificial Boundaries*

Existing travel surveys show that most walking trips are well under one mile, so using census tracts, although slightly easier from a processing standpoint, may not capture as accurate information about the connectivity of a pedestrian's area as a smaller unit of measurement. After calculating the connectivity measurements for the census tracts in the Portland metro region, researchers wished to compare the census tract connectivity measurements against the connectivity measurements for a smaller, artificial boundary of 0.5 miles. Eleven census tracts were chosen to give a good breadth of connectivity and street lengths based on the author's knowledge of the Portland metro region.

#### *Data Manipulation*

From these 11 census tracts, three origin points were chosen at random from the taxlot shapefile obtained from Metro. A 0.5 mile buffer was placed around each origin, and the street network and node shapefiles clipped by each buffer using the GeoProcessing Wizard function in ArcGIS. (add in text from Calculating PRD). This is illustrated in Figure 10.

Figure 10. Half-mile buffer around origin in Tract 47




As Figure 10 illustrates, the half-mile buffer clips many of the street segments through the middle, leaving a number of street segments with only one node. Since a street segment is determined by the presence of two nodes (one on each end) this is problematic for connectivity measures. Calculating the connectivity measures for this buffer demonstrates why (Table 5).

Table 5. Connectivity measures for half-mile buffer

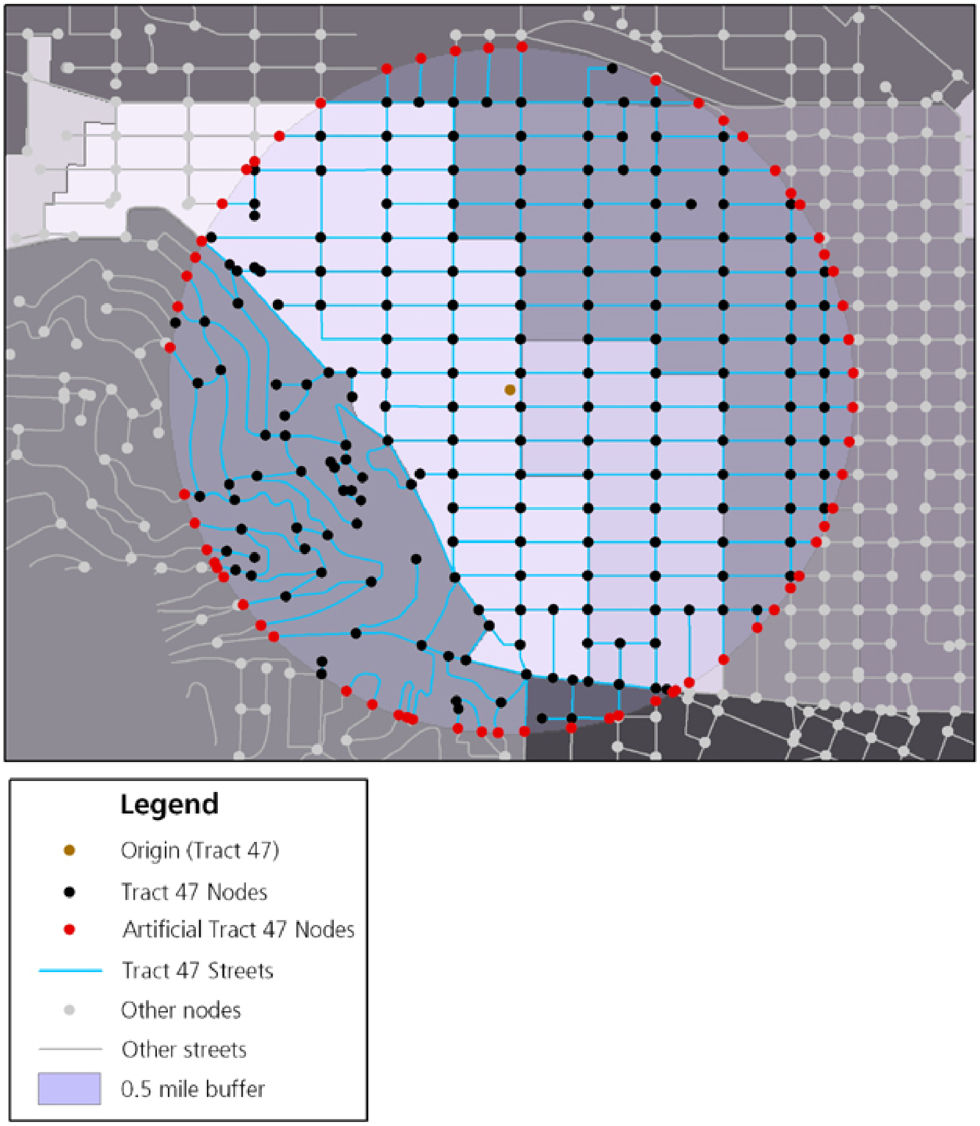
| Buffer ID | Intersection Density | Street Density | Connected Node Ratio | Link-Node Ratio | Average Block Length | Gamma Index | Alpha Index |
|---|---|---|---|---|---|---|---|
| 20.00 | 224.09 | 56.32 | 0.89 | 7.06 | 1179.65 | 2.38 | 2.99 |

A number of the measures show serious error when calculated using the 0.5 mile buffer as the unit of analysis. The more suspect measures are highlighted in orange in the table above. Without a node on the end, the "system" within the artificial boundary has too many links and not enough nodes. To correct for this, the researcher must correct for the missing nodes and enter them into the calculations (Table 6, Figure 11). This correction is accomplished by intersecting the buffer with the street shapefile. This will select all of the streets wholly within the 0.5 mile buffer. The street shapefile can then be converted to a coverage using the conversion tools in ArcToolbox. After conversion, utilize the clean and build commands to build nodes at each intersection (real and dangle) as well as the locations where the streets end at the buffer. Finally, do a spatial join with the intersected street shapefile with the nodes that comes from the coverage.

Table 6. Count of Nodes and Links for Tract 47

| | GIS Count | Corrected Count | % Difference |
|---|---|---|---|
| Real Nodes | 176 | 240 | 26 |
| Dangle Nodes | 22 | 22 | 0 |
| Total Nodes | 198 | 262 | 24 |
| Links | 1397 | 1397 | 0 |

Figure 11. Addition of nodes to half-mile buffer calculation




Correcting for the overabundance of links by just adding in additional nodes does not totally correct for the errors. Looking at the calculations in Table 7, the measures seem more reasonable, although still not accurate in many cases. Adding in additional nodes increases the intersection density, which was artificially low, while decreasing the last four measures in the table. However, certain measures, notably Gamma and Alpha index, are still out of the range (0-1.00) of expected values due to the incomplete nature of the street system as defined by the buffer.

Table 7. Connectivity measures for half mile buffer

| Connectivity Measure | Half-Mile Buffer (Figure 10) | "Corrected" Half-Mile Buffer (Figure 11) | % Difference |
|---|---|---|---|
| Intersection Density | 224.09 | 305.58 | 36 |
| Street Density | 56.32 | 56.32 | 0 |
| Connected Node Ratio | 0.89 | 0.92 | 3 |
| Link-Node Ratio | 7.06 | 5.33 | -25 |
| Average Block Length | 1179.65 | 891.49 | -24 |
| Gamma Index | 2.38 | 1.79 | -25 |
| Alpha Index | 2.99 | 2.15 | -28 |

As noted above, the lack of accuracy reflects, in part, the fact that the half-mile buffer does not create a fully contained system, and that many of the links, particularly in the southwest corner of Figure 11, contribute very little to the overall connectivity within our artificial system. To increase the accuracy of the connectivity measurements, the researcher needs to examine the street network and in addition to adding artificial nodes, remove street segments that do not connect to other portions of the network within the artificial boundary.

## *Using Street Network as Proxy for Bicycle/Pedestrian Network*

The VTPI description of connectivity describes either a path or road network. All of the calculations for this project have been done using the road network. There are advantages and disadvantages when relying solely on the road network. On the plus side, the dataset for the road network is easily obtained in most jurisdictions. This allows for the same calculations to be performed across jurisdictions, creating legitimate comparisons where it can be said the overall connectivity in Jurisdiction X is much better than Jurisdiction Y. On the negative side, in many places, including many areas in the Portland Metro region, the road network does not equate to the bicycle and pedestrian network. Connectivity measures are measuring just that, connectivity of the road network, and say nothing about suitability for biking and walking. A suitability index might include such measurements as: the presence of bike lanes, presence of sidewalk, traffic volumes, number of travel lanes. These have been addressed in several attempts at creating Bicycle and Pedestrian Compatibility Indexes. A good example of this disconnect is in SW Portland. A recent article in the Portland Tribune noted that only 15 percent of the streets in the Southwest Transportation District have sidewalks. Additionally, 45 percent of the city arterials with no sidewalks are in Southwest. Figure 12 shows census tract 66.02 from SW Portland, which will highlight the pros and cons of only relying on the street network. Census Tract 66.02 is bounded by SW 45th on the west, SW Vermont to the north, SW Multnomah Blvd to the south, and Bertha Blvd and I-5 to the east. Gabriel Park occupies a large segment of the western portion of the tract.

Figure 12. Census Tract 66.02

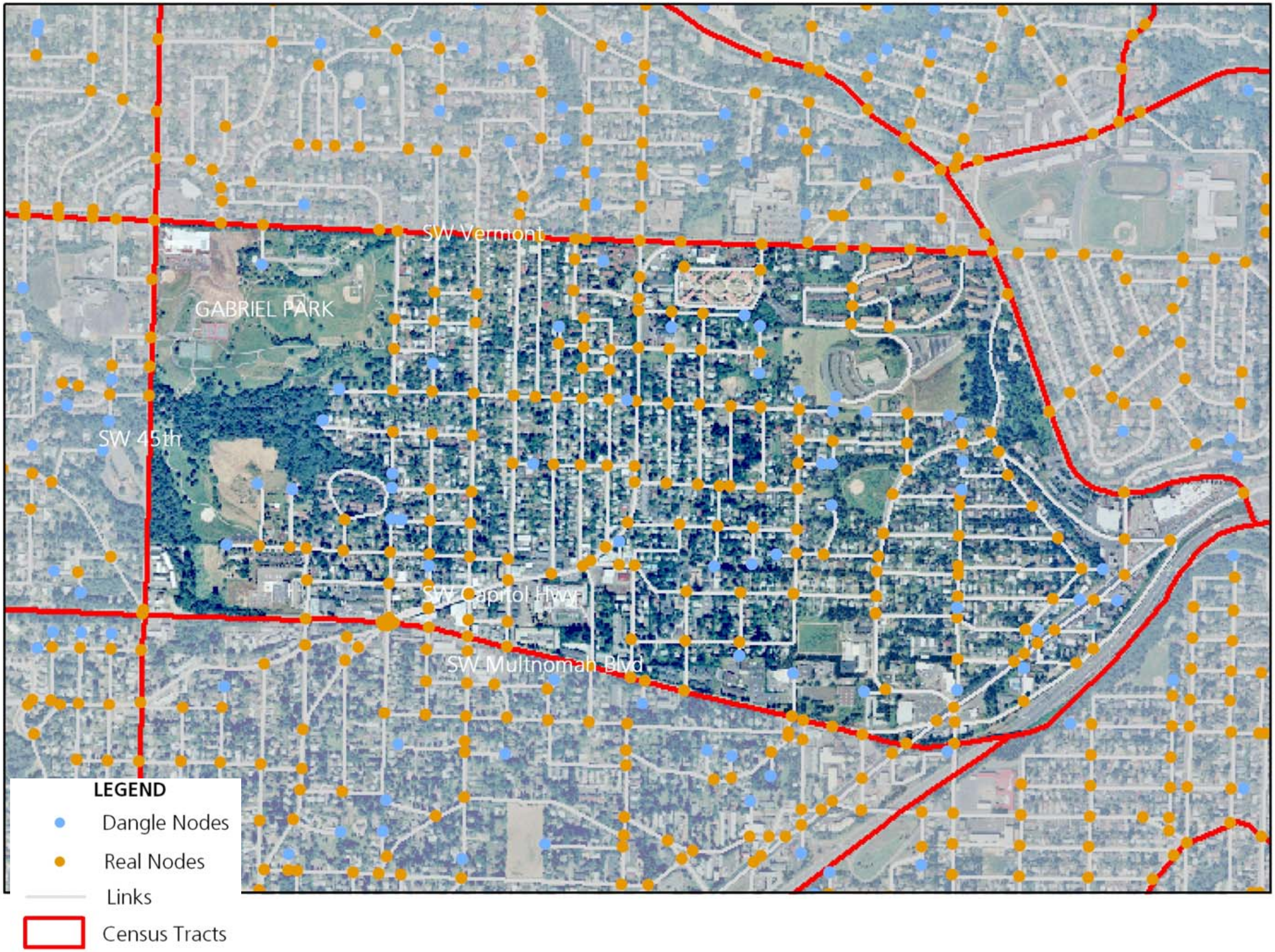


Figure 13 shows a close-up on the Gabriel Park aerial. Looking at the street network shown in Figure 13, there are a number of dangle nodes along the park's boundaries where the street network ends. However, from looking at the aerial and from personal observation, it's obvious that there are numerous pathways through the park that do not rely on the street network. In fact, traveling through the park is preferable to using the local streets, as SW 45th is a narrow, two-lane street with no bike lanes or sidewalks, while SW Vermont has only partial sidewalks. Unfortunately, using only the street network to calculate the connectivity does not capture the reality of the bicycle and pedestrian network.

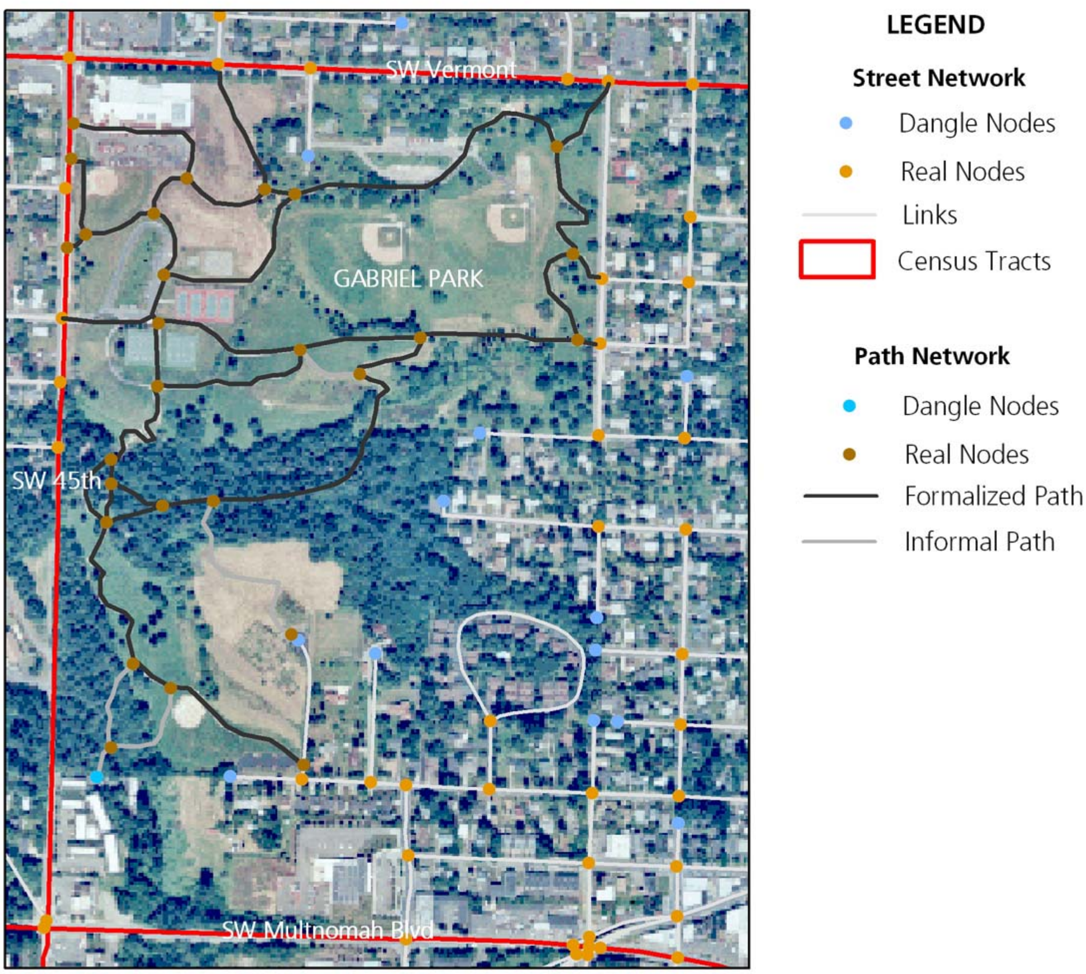
Figure 13. Gabriel Park

Figure 14 highlights both the street network and the path network, with new links and nodes added in for the path system through Gabriel Park. This better reflects the true bicycle and pedestrian network in Tract 66.02. Table 8 illustrates the total links and nodes added, as well as the original counts for the census tract.

Table 8. Tract 66.02

| | Added | Original Counts |
|---|---|---|
| Real Nodes | 27 | 188 |
| Dangle Nodes | 1 | 45 |
| Total Nodes | 28 | 233 |
| Links | 39 | 315 |
| Link Length | 2.86 | 22.64 |

Figure 14. Gabriel Park Paths



So how does a more accurate, complete bicycle and pedestrian network effect the connectivity measures for the census tract? As it turns out, very little. Table 9 shows the original connectivity measures for Tract 66.02 compared with the connectivity measures after the addition of the path network.

**Table 9. Connectivity measures for Tract 66.02**

| Connectivity Measure | Street Network | Street and Path Network | % Difference |
|---|---|---|---|
| Intersection Density | 191.25 | 218.72 | 14 |
| Street Density | 23.03 | 25.94 | 13 |
| Connected Node Ratio | 0.81 | 0.82 | 1 |
| Link-Node Ratio | 1.35 | 1.36 | 1 |
| Average Block Length | 513.09 | 515.82 | 1 |
| Gamma Index | 0.45 | 0.46 | 2 |
| Alpha Index | 0.18 | 0.18 | 0 |

The greatest increase is seen in the Intersection Density measurement, with a 14% increase. The Street Density measurement increased by 13%, and the rest of the measurements saw very little change. In fact, the Average Block Length actually rose slightly with the addition of all the links.

Even though we saw earlier how using a half-mile buffer around a chosen origin returned fairly inaccurate calculations when using the street network (Table 7), and how adding the path network to the street network didn't appreciably affect the connectivity measures for the entire census tract (Table 9), a first glance at Tract 66.02 indicates that a half-mile buffer calculation around one of the taxlots surrounding Gabriel Park might result in different calculations of the connectivity measures when the path network is also included. Figure 15 illustrates this concept.

Figure 15. Half-Mile Buffer Near Gabriel Park

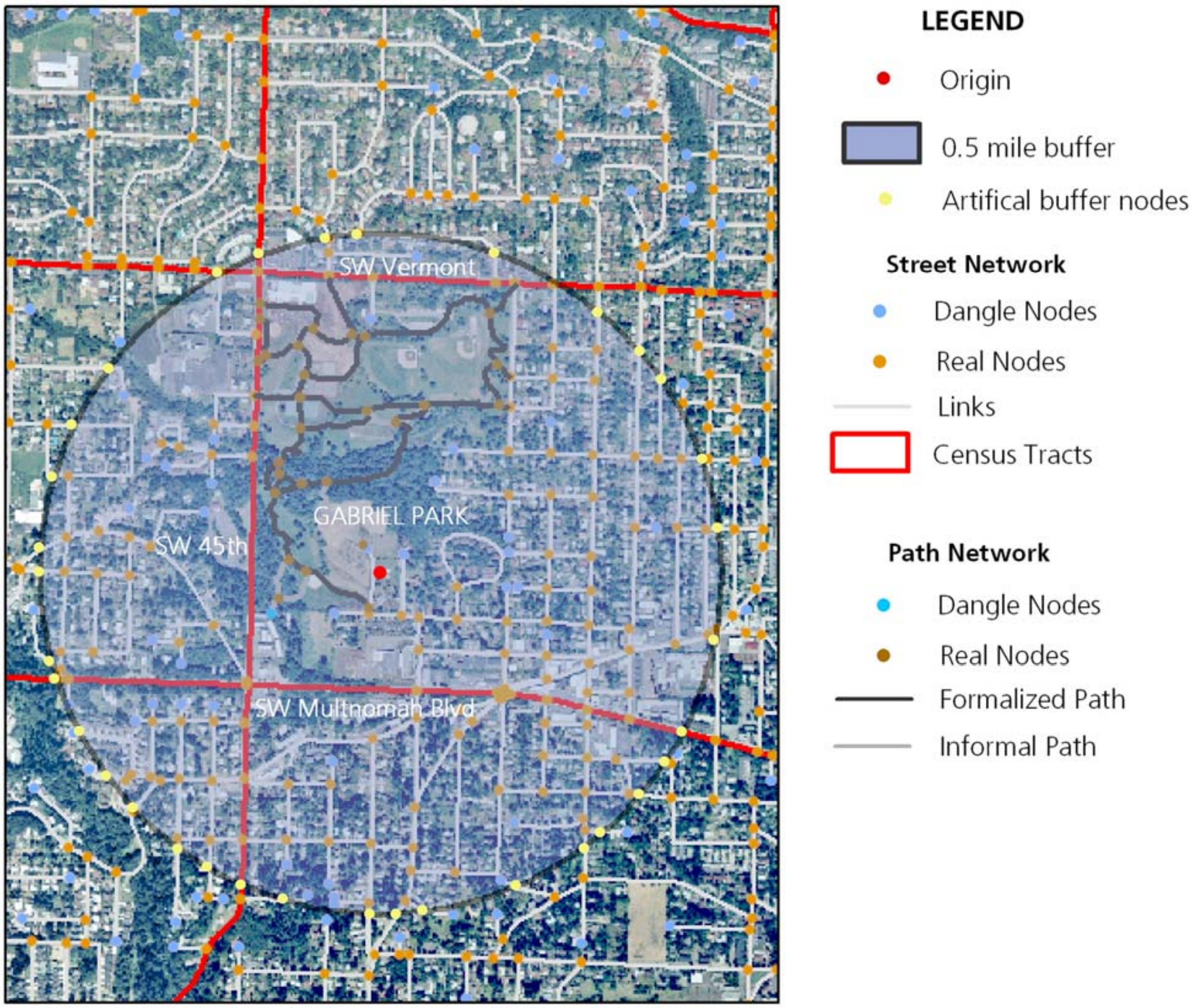



Table 10 shows the calculations for the connectivity measures of the half-mile buffer compared with the connectivity measures for Tract 66.02, the tract containing the point of origin in Figure 15 above.

Table 10. Connectivity measures for half-mile buffer

| Connectivity Measure | Half Mile Buffer (Street Network) | Half Mile Buffer (Street & Path Network) | % Difference |
|---|---|---|---|
| Intersection Density | 160.43 | 194.81 | 21 |
| Street Density | 20.27 | 20.28 | 0 |
| Connected Node Ratio | 0.78 | 0.81 | 4 |
| Link-Node Ratio | 1.54 | 1.53 | -1 |
| Average Block Length | 519.16 | 444.99 | -14 |
| Gamma Index | 0.52 | 0.52 | 0 |
| Alpha Index | 0.27 | 0.26 | -4 |

With the exception of the intersection density measure, which showed a 21% change with the addition of the path network, the other measures changed very little. And when compared with the Table 7, the trends within the tables are very similar. This may be due in part to the limited length of the additional links of the path network, as well as the limited number of additional nodes from the path network. In the half mile buffer calculations, 27 additional nodes came from the path network, while 34 nodes were created artificially. In this example at least, the additional work necessary to create and calculate the measures for the half-mile buffer is not warranted for almost any use of the various connectivity measures.

## Conclusions

There are a number of measures that can be used to determine connectivity. Dill (2005) provides a greater discussion of the relative merits of the various measures identified. This study illustrates that simply calculating the measures introduces some error that needs to be acknowledged in any use of the measure.

The protocol described in this study is well defined and can be fairly easily replicated with suitable data. Unfortunately, acquiring suitable data can be a difficult proposition. The protocol requires the local street network, however, ensuring that the street shapefile is indeed is of the local streets (where bicycle and pedestrian use can be expected) proved more difficult than anticipated when using the US Census Bureau files. Additionally, the absence of any off-street networks in the calculations must be acknowledged in any use of the measures. In processing the data, there are some trade-offs required in terms of accuracy and speed of calculation. Again, these need to be acknowledged in any use of the measure. However, utilizing the same protocol across jurisdictions ensures that the same types and scale of error are introduced in every calculation, allowing for accurate comparisons to still occur. And as described in the protocol section, there are more intensive manners in which to eliminate almost all calculating error.

Creating artificial boundaries to calculate connectivity measures presents a whole host of difficulties without returning highly accurate results, and is not recommended by the researcher as a necessary or worthwhile task unless it can be proved to be demonstrably useful. Even in the situation where the path network was added into the street network, the calculations were not any more useful than the overall census tract calculations.

The street network serves as an excellent proxy in many areas of the UGB, particularly in downtown and inner NE/SE Portland. Census tracts in those locations are defined by the street network, and almost all of the streets are bicycle and pedestrian accessible. However, it was surprising to find that the connectivity measures held up even in areas of town where the street network is not as an accurate indicator of the bicycle and pedestrian network, as was seen in the example of Tract 66.02. Even in that tract, in an area where bicyclists and pedestrians have many more options than shown through the street network, the connectivity measures did not improve greatly with the addition of the available off-street network. Perhaps the percentage area of Gabriel Park as a percentage of the total area in Tract 66.02 was too small, and that a tipping point exists where the street network will fail as a proxy, however the example used in this study did not find this point.

Overall, using connectivity measures as one of a series of measures when calculating a health or bikeability index seems appropriate, however utilizing the measures, or an index of the measures, requires a great amount of detail and explanation regarding the calculations of those measures. This study has outlined a method for measuring connectivity using GIS, highlighted the powers and limitations of the GIS, and explored some of the issues that must be addressed when attempting to calculate connectivity measures.

## Sources


Dill, Jennifer, 2005. *Measuring Network Connectivity for Bicycling and Walking*. School Of Urban Studies and Planning, Portland State University. Unpublished. Viewed online 11/11/05 at http://web.pdx.edu/~jdill/Dill_ACSP_paper_2003.pdf

ESRI. Various ArcScripts viewed 11/05 at http://arcscripts.esri.com/

Forsyth, Ann, Joel Koepp, J. Michael Oakes, et al. 2005. *Twin Cities Walking Study. Environment and Physical Activity: GIS Protocols.* University of Minnesota, Metropolitan Design Center. September 2005.

Kulash, Walter, Joe Anglin and David Marks, *Traditional Neighborhood Development: Will the Traffic Work?* Development 21, July/August 1990, 21-24

US Census Bureau. TIGER files. Downloaded 11/27/05 at http://www.census.gov/geo/www/tiger/

Victoria Transport Policy Institute. *Roadway Connectivity: Creating More Connected Roadway and Pathway Networks.* Online TDM Encyclopedia, 2005. Viewed on 11/11/05 at http://www.vtpi.org/tdm/tdm116.htm