Space Syntax: Regional Planning for Bicycles

Connor J. White

Utah State University

Follow this and additional works at: https://digitalcommons.usu.edu/etd

Part of the Landscape Architecture Commons, and the Urban, Community and Regional Planning Commons

Recommended Citation
White, Connor J., "Space Syntax: Regional Planning for Bicycles" (2018). All Graduate Theses and Dissertations. 7290.
https://digitalcommons.usu.edu/etd/7290

This Thesis is brought to you for free and open access by the Graduate Studies at DigitalCommons@USU. It has been accepted for inclusion in All Graduate Theses and Dissertations by an authorized administrator of DigitalCommons@USU. For more information, please contact digitalcommons@usu.edu.
SPACE SYNTAX: REGIONAL PLANNING FOR BICYCLES

by

Connor J. White

A thesis submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

in

Bioregional Planning

Approved:

______________________
Barty Warren-Kretzschmar, Ph.D.
Major Professor

______________________
Ziqi Song, Ph.D.
Committee Member

______________________
Keith M Christensen, Ph.D.
Committee Member

______________________
Richard S. Inouye, Ph.D.
School of Graduate Studies

UTAH STATE UNIVERSITY
Logan, Utah

2018
ABSTRACT

Space Syntax: Regional Planning for Bicycles

by

Connor J. White, Master of Science

Utah State University, 2018

Major Professor: Dr. Barty Warren-Kretzschmar
Department: Environment and Society

This study used Space Syntax to determine if it could be used to plan for bicycles at a regional scale such as Cache County. It was compared to a standard that is already used by planners, Bicycle Level of Service (BLOS). Both analyses use different methods and produce different results. The analyses were modeled, and the results were visually compared to one another by identifying linkages with the same score. Two statistical analyses, a Paired-Sample t-Test and Cohen’s kappa were also used to compare the similarities between models. At a regional scale, the two are not similar. Traffic volume was added to the Space Syntax analysis to see if it would become a more valid representation of BLOS. This had no effect but did change the Space Syntax analysis.

The local scale was also tested to see if the scale would make them more similar to one another. The Space Syntax analysis was analyzed for just the road segments within the city of Logan. The results remained the same as the regional scale. Traffic volume was also added to this scale, and the results were the same as the regional scale. It was determined that Space Syntax is not a valid representation of BLOS. Both analyses have advantages and disadvantages to using them when planning for bicycles.
Space Syntax: Regional Planning for Bicycles

Connor J. White

This study focused on using a mapping tool, Space Syntax, to analyze the connectivity of the Cache County road network and its use to plan for bicycles. Space Syntax is being compared to another method that is already used by city planners called Bicycle Level of Service, or BLOS. The two analyses used data from Cache County and, after they were modeled and evaluated, a statistical analysis was done to see how similar one is to the other. The analyses were done at both a regional and a local scale. At both scales the analyses were not similar.

Data was added to the Space Syntax analysis at both scales to see if it would influence making it more similar to BLOS. Adding the data had no effect in making them similar. It was determined that Space Syntax and BLOS are not similar and more research would need to be done to attempt to make them similar. They both have advantages and disadvantages to them when being used for planning for bicycles. One is not necessarily better than the other, as they are two different methods that could be used.
ACKNOWLEDGMENTS

I would like to thank Jeff Gilbert at Cache Metropolitan Planning Organization for making available to me traffic data for the research in this thesis. I would especially like to thank my committee members, Barty Warren-Kretzschmar, Keith Christensen, and Ziqi Song, for their support and assistance throughout the entire process.

I give special thanks to my family, friends, and colleagues for their encouragement and support as I worked on the initial research and to the completed outcome of this paper.

Connor J. White
## CONTENTS

<table>
<thead>
<tr>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABSTRACT .......................................................................................................................... iii</td>
</tr>
<tr>
<td>PUBLIC ABSTRACT ................................................................................................................. iv</td>
</tr>
<tr>
<td>ACKNOWLEDGMENTS ........................................................................................................... v</td>
</tr>
<tr>
<td>LIST OF TABLES ................................................................................................................... vii</td>
</tr>
<tr>
<td>LIST OF FIGURES ............................................................................................................... viii</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CHAPTER</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. INTRODUCTION ................................................................................................................ 1</td>
</tr>
<tr>
<td>II. METHODOLOGY ............................................................................................................. 5</td>
</tr>
<tr>
<td>Space Syntax .................................................................................................................... 7</td>
</tr>
<tr>
<td>Bicycle Level of Service ................................................................................................. 9</td>
</tr>
<tr>
<td>Statistical Analysis ....................................................................................................... 15</td>
</tr>
<tr>
<td>Adding Traffic Volume to Space Syntax ........................................................................ 16</td>
</tr>
<tr>
<td>III. REGIONAL SCALE RESULTS .................................................................................... 18</td>
</tr>
<tr>
<td>Space Syntax Analysis .................................................................................................... 18</td>
</tr>
<tr>
<td>Bicycle Level of Service ............................................................................................... 18</td>
</tr>
<tr>
<td>Paired-Sample t-Test ....................................................................................................... 21</td>
</tr>
<tr>
<td>Cohen’s Kappa ................................................................................................................ 22</td>
</tr>
<tr>
<td>Discussion .......................................................................................................................... 22</td>
</tr>
<tr>
<td>IV. ADDING DATA TO SPACE SYNTAX AT A REGIONAL SCALE .................................. 24</td>
</tr>
<tr>
<td>Results ............................................................................................................................... 24</td>
</tr>
<tr>
<td>Paired-Sample t-Test ........................................................................................................ 24</td>
</tr>
<tr>
<td>Cohen’s Kappa ................................................................................................................. 25</td>
</tr>
<tr>
<td>Discussion .......................................................................................................................... 25</td>
</tr>
<tr>
<td>V. LOCAL SCALE RESULTS ............................................................................................ 28</td>
</tr>
<tr>
<td>Space Syntax Analysis .................................................................................................... 28</td>
</tr>
<tr>
<td>Bicycle Level of Service ............................................................................................... 28</td>
</tr>
<tr>
<td>Paired-Sample t-Test ........................................................................................................ 31</td>
</tr>
</tbody>
</table>
vii

Cohen’s Kappa .............................................................................................................31
Discussion .....................................................................................................................32

VI. ADDING DATA TO SPACE SYNTAX AT A LOCAL SCALE ..................33

Results ........................................................................................................................33
Paired-Sample t-Test ..................................................................................................33
Cohen’s Kappa ............................................................................................................33
Discussion .....................................................................................................................34

VII. FINAL DISCUSSION .........................................................................................37

REFERENCES ............................................................................................................42

APPENDIX: AXIAL LINE CONVERSION .................................................................44
# LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>FHWA’s 5-point pavement condition rating</td>
</tr>
<tr>
<td>2</td>
<td>Bicycle Level of Service categories</td>
</tr>
<tr>
<td>3</td>
<td>Valid percentages of both Space Syntax and BLOS</td>
</tr>
<tr>
<td>4</td>
<td>Advantages and disadvantages of Space Syntax and BLOS</td>
</tr>
</tbody>
</table>
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Location of Cache County, Utah</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td>Space Syntax Method diagram</td>
<td>7</td>
</tr>
<tr>
<td>3</td>
<td>Bicycle Level of Service Method diagram</td>
<td>9</td>
</tr>
<tr>
<td>4</td>
<td>Space Syntax analysis with added Data Method diagram</td>
<td>16</td>
</tr>
<tr>
<td>5</td>
<td>Space Syntax analysis at a regional scale</td>
<td>19</td>
</tr>
<tr>
<td>6</td>
<td>Bicycle Level of Service at a regional scale</td>
<td>20</td>
</tr>
<tr>
<td>7</td>
<td>Comparison of Space Syntax and BLOS analyses at a regional scale</td>
<td>21</td>
</tr>
<tr>
<td>8</td>
<td>Space Syntax with added traffic volume at a regional scale</td>
<td>26</td>
</tr>
<tr>
<td>9</td>
<td>Comparison of Space Syntax analysis with added traffic volume, BLOS, and original Space Syntax analysis at a regional scale</td>
<td>27</td>
</tr>
<tr>
<td>10</td>
<td>Space Syntax analysis of Logan, Utah</td>
<td>29</td>
</tr>
<tr>
<td>11</td>
<td>Bicycle Level of Service of Logan, Utah</td>
<td>30</td>
</tr>
<tr>
<td>12</td>
<td>Comparison of Space Syntax and BLOS analyses of Logan, Utah</td>
<td>31</td>
</tr>
<tr>
<td>13</td>
<td>Space Syntax with added traffic volume for Logan, Utah</td>
<td>35</td>
</tr>
<tr>
<td>14</td>
<td>Comparison of Space Syntax analysis with added traffic volume, BLOS and original Space Syntax analysis of Logan, Utah</td>
<td>36</td>
</tr>
</tbody>
</table>
CHAPTER I
INTRODUCTION

Bicycles are an important and growing mode of transportation and have become important in millions of people’s daily lives all over the world. In the United States, cycling makes up a small percentage of commuters but has increased from 488,000 in 2000 to about 786,000 in 2008-2012 (McKenzie, 2014). During this time frame, cycling had the largest percent increase over any other commuting mode, which shows that it plays an important role in many of the nation’s local transportation systems (McKenzie, 2014). It has many positive impacts on both the environment and the public’s health making it an important element in sustainable transportation systems. The pollution and noise are low, it causes fewer accidents, it does not require extensive infrastructure, and it helps reduce obesity (Manum & Nordstrom, 2013). In the United States, efforts have been introduced to promote non-motorized transit development, such as the Inter-Modal Surface Transportation Efficiency Act of 1991 (ISTEA) and the Transportation Equity Act of the 21st Century (TEA-21), which provide funding and guidance for the support of infrastructure and education programs across the nation (Raford, Chiaradia, & Gil, 2005). For these reasons planning for cycling has become an important part of today’s society.

Planning for bicycles is important to maximize the potential for people to use this mode of transportation. The general consensus in planning is that there is a strong connection between transportation decisions and the built form. There is also a connection between built form and health-related physical activities (Rybarczyk & Wu, 2014). Implementing infrastructure that supports cycling expands and complements transportation options (McKenzie 2014). These options as well as making alternative
modes more accessible that are perceived as safe and desirable more accessible, could help to achieve a more sustainable transportation network (Rybarczyk & Wu, 2010). Rybarczyk found that recreational cyclists would be willing to commute more if a suitable cycling environment were provided (Rybarczyk & Wu, 2010). Some places are even attempting to turn to more suitable forms of tourism in the form of cycling and have become aware of its environmentally friendly use in rural areas (Ritchie & Hall, 1999). Progressive planning for cycling requires an understanding of where cyclists travel and what affects their decisions along the routes they travel (Winters et al., 2010). Local systems as well as larger regional ones should be looked at.

Bicycle planning occurs at multiple levels, including municipal, county, regional, and state levels. Regional planning for bicycles is intended to complement local planning consistency between communities, counties and regions (Aytur et al., 2011). To help address community problems with traffic congestion, air quality, health, safety, and the vitality of neighborhood commercial areas, many local, regional, and state authorities have begun to pay greater attention to non-motorized transportation (Replogle, 1995). Researchers such as Kaneko and Fukuda (1999), have focused on regional transit-oriented development planning because recent studies show urban spatial structure has limited local development conditions and opportunities (Lin and Li, 2005). Regional planning comprehensively designs the spatial structure based on the transportation systems in the area and focuses on the distribution of activities. (Lin & Li, 2005) As sustainable practices must be grounded in local places, they must also embrace broader scales if they are to be successful (Blickstein & Hanson, 2001). Also, by highlighting
linkages across scales, people appreciate how their local decisions and actions have impacts not only locally but also regionally (Blickstein & Hanson, 2001).

To begin regional scale planning for cycling, Space Syntax will be applied because it is a tool used to effectively plan transportation systems. The Space Syntax approach, or Space Syntax Theory, can be defined as “a set of techniques for the representation, quantification, and interpretation of spatial configuration in buildings and settlements” (Hillier & Hanson, 1989). In Space Syntax, streets, squares, rooms, and fields are understood as voids, other impediments, or obstructions that restrain pedestrian traffic and/or the visual field (Klarqvist, 1993). Within Space Syntax, networks may be analyzed in different ways. Angular segment analysis treats each segment as a separate node of a graph, with a fractional depth value assigned to each line based on the angle of intersection with its neighboring lines (Raford et al., 2005). Point-based modeling is based on flexible concepts of characteristics derived from urban street maps as points. These points are representative of the network structure in the sense that, within an urban environment, people make a decision while navigating where to head next when they reach these points (Jiang & Claramunt, 2002). Research shows how movement patterns are powerfully shaped by spatial layout, patterns of security, and insecurity. Insecurity is affected by spatial design, this relation shaping the evolution of the centers and sub-centers that makes cities livable. Spatial segregation and social disadvantage are related in cities and buildings, which can create more interactive organizational cultures (Space Syntax Network, n.d.). Paul (2011) concluded in his article, Axial Analysis: A Syntactic Approach to Movement Network Modeling, that Space Syntax is an alternative model for traffic and can assist planners by reducing the time it would take to conduct surveys. By
using Space Syntax when planning for cyclists, the “fastest cognitive routes” can be found. Raford and colleagues found it to be the best solution when planning for accessibility for cyclists and could help planners create a hierarchy model (Raford et al., 2005).

However, Space Syntax has not been used to plan regional scale bicycle transportation. Space Syntax methods for modeling non-motorized travel remains underdeveloped, which is due to the limited availability of data for non-motorized vehicles, the errors resulting from the small numbers of non-motorized trips in travel survey data, and the lack of detailed transportation networks for non-motorized travel (Winters et al., 2010). Because of this, it may be difficult to create accurate Space Syntax models that reflect the travel patterns of cyclists. Therefore, the purpose of this study is to explore the use of Space Syntax to plan for bicycles at a regional scale and to be a guide for planners.
CHAPTER II
METHODOLOGY

This study will explore the use of Space Syntax to plan for bicycles at a regional scale by comparing the connectivity results of Space Syntax with the level of service projected by Bicycle Level of Service (BLOS) (Landis, Vattikuti, & Brannick, 1997). BLOS is used as a comparison as it is the accepted method used by planners to project level of service demand. Prior studies have used Space Syntax at a city level, but never a regional scale, to identify uses for bicycle planning. There are three research questions for this study: (1) How can Space Syntax be used as a tool to plan for bicycles at a regional scale? (2) Is the Space Syntax method a comparable use to BLOS when planning for bicycles? (3) If not, can additional data be added to Space Syntax to make it more comparable and a simpler method used to plan for bicycles?

The study area is Cache County, Utah (Figure 1). Cache County is located in northern Utah and consists of 19 cities (Cache County, n.d.), with a population of 120,783 people; the majority of the population are Caucasian. There are 39,752 households in the county as of 2015, and it has grown since then (U.S. Census Bureau, 2015). The county seat and largest city is Logan, where Utah State University is located. Cache County extends to the Idaho border, with Cache Valley running down the center of the county, bounded by the Wellsville Mountains on the western edge and the Bear River Mountains on the eastern edge.
Figure 1. Location of Cache County, Utah.
**Space Syntax**

Space Syntax, according to methods developed by Hillier and Hanson (1989), uses linkages or pathways (i.e., streets, sidewalks) between urban space and human movement through those spaces. Space Syntax was originally developed to model pedestrian movement through urban spaces. Since then it has been applied to other contexts, such as archaeology, criminology, information technology, urban and human geography, anthropology and cognitive science (Space Syntax Network, n.d). Depthmap, an open source software package based on Space Syntax, was used to create a bicycle demand model using axial line analysis. Figure 2 diagrams the method used for this research.

![Figure 2. Space Syntax Method diagram.](image)

Axial line analysis is one of several units of space measures which may be used within Space Syntax. It has become the predominant choice to quantify traffic estimations (Paul, 2011) and represents the topology of the space. Axial lines in their simplest form are intersecting line segments derived from a roadway structure or map. A
road network can be turned into a minimal set of lines that pass through one another, connecting them within the system to create the axial map (Paul, 2011). Part of axial line analysis is the mean depth which represents how accessible the line segment is from all other segments.

Before Depthmap could be used to run the axial analysis, the data needed to be configured to work within the program. The data needed to work within Depthmap was taken from a road layer, provided by Cache Metropolitan Planning Organization, within ArcGIS and converted into a dfx format for import into Depthmap. Once the data file was in the correct format and imported, it was then converted into an axial map. After the axial map was created, “Run Graph Analysis” was run. When this function was used, it was important to weight everything by connectivity.

The results of Space Syntax are connectivity values between 1 and 6 for each road segment, with 6 being the most connected. This is the inverse of BLOS, where 1 is the most connected. Therefore, to facilitate comparison, the results were imported back into ArcMap and inverted. The axial analysis was exported as a MapInfo file (*.mif) and converted using the conversion tool for ArcGIS installed in the binaries directory.

Once it was converted into a line file, the data was reimported into ArcMap, and the scale was inverted. VB Script as follows was used:

```vbnet
    dim n
    if [CONNECTIVITY] = 1 then
        n = 6
    repeated for each value starting with elseif and then end with endif

    In the “New_Connec=” field type “n”.
```
Bicycle Level of Service (BLOS)

The Bicycle Level of Service Model is a mathematical equation that is considered to be the most accurate method of evaluating the bicycling conditions of shared roadway environments. The model is based on research documented in Transportation Research Record 1578, which was published by the Transportation Research Board of the National Academy of Sciences (Sprinkle Consulting Inc., 2007). The model is a bicycle suitability or compatibility model due to factors such as directional traffic volume, number of lanes, the effective speed limit, heavy vehicle traffic, pavement conditions, and lane width. This model will be used on the same area being used for the Space Syntax analysis. Figure 3 diagrams the method used in this research.

![Figure 3. Bicycle Level of Service Method diagram.](image)
The formula for Version 2.0 of the Bicycle Level of Service Model is:

\[
\text{Bicycle LOS} = a_1 \ln(Vol_{15}/L_n) + a_2 SP_t (1 + 10.38HV)^2 + a_3 (1/PR_5)^2 +
\]

\[
a_4 (W_e)^2 + C
\]

Where:

- \(Vol_{15}\) = Volume of directional traffic in 15-minute time period
- \(L_n\) = Total number of through lanes
- \(SP_t\) = Effective speed limit
- \(HV\) = Percentage of heavy vehicles (as defined in the 1994 Highway Capacity Manual)
- \(PR_5\) = FHWA’s five-point pavement surface condition rating
- \(W_e\) = Average effective width of outside through lane

\(a_1: 0.507 \quad a_2: 0.199 \quad a_3: 7.066 \quad a_4: -0.005 \quad C: 0.760\)

\(a_1\) to \(a_4\) are coefficients established by multi-variate regression analysis.

The Bicycle Level of Service model was developed and run within ArcMap. Each variable needed to have data associated with it and in some cases calculated further then the base data provided. The data that was used for the model came from the Cache Metropolitan Planning Organization, with best professional judgment and base values provided by *Bicycle Level of Service: Applied Model* by Sprinkle Consulting Inc. (2007).

The volume of directional traffic in a 15-minute time period was calculated from the available data. The attribute from the road layer of the GIS data file that was used for this calculation was “DY_VOL_2WY” which stands for day volume of both sides of the road. This data was used because the roads were split into a right lane and a left lane.
within the data set, and this number represented both sides of that section. The formula to
get the 15-minute time period is:

\[ Vol_{15} = \frac{(ADT \times D \times K_d)}{(4 \times PHF)} \]

Where:

- \( ADT \) = Average Daily Traffic on the segment or link
- \( D \) = Directional Factor
- \( K_d \) = Peak to Daily Factor
- \( PHF \) = Peak Hour Factor

The “DY_Vol_2WY” data was used for \( ADT \); \( D \) was assumed to be 0.565, the \( K \) value was assumed as 0.1, and \( PHF \) was assumed as 0.95. The reason for assuming these values is due to limited data to accurately calculate them.

Total number of lanes was determined from the “ONEWAY” and “LANES” fields within the available data set. “ONEWAY” was meant to inform if the road was two-way directional or one-way while “LANES” contained the number of lanes for that segment. This field was manually entered.

The effective speed limit was another variable that need to be calculated from the available data. To do so, the field “FF_SPD” was used. This field contained the posted speed limit. The formula to calculate the effective speed limit is:

\[ SP_t = 1.1199 \ln(SP_p - 20) + 0.8103 \]

Where:

- \( SP_p \) = Posted speed limit (a surrogate for average running speed)
To run this equation, the data needed to be exported from ArcMap into a Microsoft Excel table as the field calculator in ArcMap cannot run the natural log function. After all the new data is generated, it can be reimported into ArcMap and then ArcToolBox can convert the file back into an attribute table.

Percent heavy vehicles was determined by taking the percentages from Sprinkle Consulting Inc. (2007) baseline scores and using best professional judgment when entering them into the attribute table. For Cache County, it was determined that any major thoroughfare would be considered as “High” (10) with some being “Moderate” (5). For everything else the baseline used was “Very Low” (1). These values needed to be entered manually.

Another attribute that needed to be entered manually was FHWA’s five-point pavement condition rating, using a combination of best professional judgment and available data. The data that was used to aid in creating the pavement condition rating was provided by Cache Metropolitan Planning Organization and was created by usRAP. The data was point source with multiple points on each section of a road which was overlaid with the BLOS road layer being used.

The fields used in creating the pavement condition rating are “Paved_shou” (Paved shoulder – left side), “Paved_sh_1” (Paved shoulder – right side) and “Road_condi” (Road condition). It should also be noted that an appendix that contained specification for all the coded data within the point source file was provided. Each field had a set of values, those being:

Paved shoulder – left and right side
Wide ($\geq 7.9ft$) = 1
Medium ($\geq 3$ to $< 7.9ft$) = 2
Narrow ($> 0$ to $< 3ft$) = 3
None = 4

Looking at the code, 1 is the best with 4 being the worst.

Road Condition

Good = 1
Medium = 2
Poor = 3

Again, 1 is the best with 3 being the worst.

It was determined that a new rubric needed to be created to determine the 5-point condition rating. The rubric created is shown in Table 1. The rating for the table is inverted from the data used because FHWA’s 5-point pavement condition rating rates 1 as the worst and 5 as the best. In the table, PS = Paved Shoulder and RC = Road Condition.

Table 1. FHWA’s 5-point pavement condition rating.

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>PS</td>
<td>4 + RC + 4</td>
<td>PS</td>
<td>4 + RC + 2</td>
<td>PS</td>
<td>2+3 + RC + 4</td>
</tr>
<tr>
<td>PS</td>
<td>4 + RC + 1</td>
<td>PS = 3+3 + RC + 1</td>
<td>PS</td>
<td>2+2 + RC + 1</td>
<td>PS</td>
</tr>
<tr>
<td>PS</td>
<td>3+4 + RC + 3</td>
<td>PS</td>
<td>2+2 + RC + 1</td>
<td>PS</td>
<td>1+1 + RC + 1</td>
</tr>
</tbody>
</table>
The last piece of data needed for the analysis was the Average effective width of the outside through lane. The baseline average again was used for this, being that of 12ft.

Once all the data is created, it must be exported into Microsoft Excel. This is due to natural log needing to be used in the equation. After the equation is calculated, the data can then be brought back into ArcMap and linked back to the line segments.

The results from the equation are stratified into service categories “A, B, C, D, E, and F” (according to the ranges shown in Table 2).

<table>
<thead>
<tr>
<th>Level of Service</th>
<th>BLOS Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>( \leq 1.5 )</td>
</tr>
<tr>
<td>B</td>
<td>( &gt; 1.5 ) and ( \leq 2.5 )</td>
</tr>
<tr>
<td>C</td>
<td>( &gt; 2.5 ) and ( \leq 3.5 )</td>
</tr>
<tr>
<td>D</td>
<td>( &gt; 3.5 ) and ( \leq 4.5 )</td>
</tr>
<tr>
<td>E</td>
<td>( &gt; 4.5 ) and ( \leq 5.5 )</td>
</tr>
<tr>
<td>F</td>
<td>( &gt; 5.5 )</td>
</tr>
</tbody>
</table>

For the comparison analysis, the level-of-service categories were changed to numeric values: A = 1, B = 2, C = 3… F = 6. This process is similar to what was done with the axial analysis inversion. This time Python needed to be used. The following code was used:

```python
def Reclass(BLOS_1):
    if (BLOS_1 <= 1.5):
        return 1
```
elif (BLOS_1 >= 1.5 and BLOS_1 <= 2.5):
    return 2

repeated for each value.

In the “BLOS_Sim =” field type “Reclass( !BLOS_1! )”.

**Statistical Analysis**

To analyze whether Space Syntax on its own compared to BLOS, two statistical analyses were run. Before the analyses could be run, the data needed to be combined into one table which was done within ArcMap. The first is a paired-sample t-test, which is a statistical procedure used to determine whether the mean difference between two sets of observations is zero. The second is a Cohen’s kappa coefficient which measures inter-rater agreement for qualitative (categorical) items. The kappa statistic varies from -1 to 1, where:

0 = agreement equivalent to chance.
+/- 0.1 – 0.20 = slight agreement.
+/- 0.21 – 0.40 = fair agreement.
+/- 0.41 – 0.60 = moderate agreement.
+/- 0.61 – 0.80 = substantial agreement.
+/- 0.81 – 0.99 = near perfect agreement
+/- 1 = perfect agreement.
Adding Traffic Volume to Space Syntax

The data that was chosen to be added to the Space Syntax analysis was the 15-minute traffic volume because it was a piece of data that was easily obtained and was available (Figure 4). The traffic volume needed to be changed into 1 through 6 values to make it easier to add to the Space Syntax analysis, as it is already 1 to 6. This is done by dividing all values by the highest traffic volume. All values are then between 0 and 1.

The values were then grouped into 6 different categories by creating equal segments. The segments were 0.17, 0.34, 0.51, 0.68, 0.85, and 1. Once all the values were 1 through 6, they could be added to the Space Syntax analysis. The formula that was used to add the values was a weighted formula and looks like:

\[
\frac{1}{2} \text{Space Syntax} + \frac{1}{2} \text{Volume}
\]

Figure 4. Space Syntax analysis with added Data Method diagram.
The results are then within the 1 through 6 range. Any number that had a 0.5 was rounded up. For example, if the number was 2.5, it was rounded to a 3. The process of creating this data was similar to what was done previously with all other data within ArcMap and Excel.
CHAPTER III
REGIONAL SCALE RESULTS

In this section, Cache County, Utah was used as a case study to demonstrate the proposed methodology.

**Space Syntax Analysis**

Figure 5 illustrates the results of the axial analysis. The findings show that the areas with the highest connectivity are located within the cities or around major intersections. As the distance increases from these areas the score becomes lower, with some of the edges having values of 6. There are not many values rated as 1 (high connectivity) or as 6 (low connectivity); most of the segments are in-between.

**Bicycle Level of Service**

Figure 6 shows the results of the Bicycle Level of Service model for the study area. The results indicate that roads with a lower volume of traffic and less heavy vehicles (i.e., trucks) have a higher level of service. The BLOS analysis had considerably more segments that are rated as a 1 (high level of service) and a 6 (low level of service) with a mixture of segments in-between, than the Space Syntax analysis. The BLOS analysis shows roads that are major thoroughfares as dark blue, as these roads have higher traffic volume and a higher percentage of heavy vehicles. The roads with the higher level of service are on the outskirts of the towns, rather than within them. Figure 7 shows a side-by-side comparison of both the Space Syntax and the Bicycle Level of Service analyses at a regional scale.
Figure 5. Space Syntax analysis at a regional scale.
Figure 6. Bicycle Level of Service at a regional scale.
The results indicated that the mean for Space Syntax (M = 4.71, SD = 0.667) was greater than the mean for BLOS (M = 4.09, SD = 1.745), t(8040) = 29.451, p = 0. The standardized effect size index, d, was 0.009 or less than 1%. Space Syntax and BLOS are not comparable and are very different from one another, as summarized in Table 3. Table 3 illustrates the valid percentages that answered “yes” to the individual values (values 1 through 6). BLOS is evenly distributed apart from having more values of 6, while Space Syntax is predominantly values of 5.

Figure 7. Comparison of Space Syntax and BLOS analyses at a regional scale.

**Paired-Sample t-Test**

The results indicated that the mean for Space Syntax (M = 4.71, SD = 0.667) was greater than the mean for BLOS (M = 4.09, SD = 1.745), t(8040) = 29.451, p = 0. The standardized effect size index, d, was 0.009 or less than 1%. Space Syntax and BLOS are not comparable and are very different from one another, as summarized in Table 3. Table 3 illustrates the valid percentages that answered “yes” to the individual values (values 1 through 6). BLOS is evenly distributed apart from having more values of 6, while Space Syntax is predominantly values of 5.
Table 3. Valid percentages of both Space Syntax and BLOS.

<table>
<thead>
<tr>
<th>Value</th>
<th>Space Syntax</th>
<th>Bicycle Level of Service</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.3%</td>
<td>11.9%</td>
</tr>
<tr>
<td>2</td>
<td>0.6%</td>
<td>11.1%</td>
</tr>
<tr>
<td>3</td>
<td>7.9%</td>
<td>11.6%</td>
</tr>
<tr>
<td>4</td>
<td>10.8%</td>
<td>19.4%</td>
</tr>
<tr>
<td>5</td>
<td>79.8%</td>
<td>13.8%</td>
</tr>
<tr>
<td>6</td>
<td>0.6%</td>
<td>32.2%</td>
</tr>
</tbody>
</table>

**Cohen’s Kappa**

In this case the kappa value is -0.009, which is equivalent to chance, and there is almost no agreement between the two.

**Discussion**

The two analyses of Space Syntax and Bicycle Level of Service at the regional scale show no correlation. Space Syntax has fewer segments that are rated as 6 (low connectivity), and they are all located on the outer edges of the road network because they are the least connected. The higher connected routes are towards the center of the network, i.e., center of Logan. Bicycle Level of Service is scattered because it is an assessment of the level of service of the road segments and is based around multiple pieces of data. A majority of the road segments that have a high level of service are the local roads or the less frequently trafficked roads.

Using Main Street in Logan as an example, Space Syntax has a higher connectivity around the intersections and in the downtown area (Figure 5). The segments
between the intersections and further away from Main Street are less connective. However, the BLOS analysis shows that all of Main Street has a poor level of service (Figure 6). This is due to higher traffic volumes and a higher percentage of heavy vehicles. Neither analysis of Main Street matches the other.

A goal of this study was to determine if Space Syntax could be used as a tool to plan for cycling, which leads to the question: can Space Syntax be used as a tool to plan for bicycles at a regional scale, if other attributes, such as traffic volume, are added to the analysis? Will adding traffic volume make Space Syntax a closer representation to BLOS and make it an easier way to look at level of service? The next step that will be taken is to add the more readily obtained data from BLOS, such as 15-minute traffic volume, number of lanes, or effective speed limit, to the Space Syntax analysis. It may be possible by adding additional data to create a level of service model similar to BLOS. The advantages would be that the new model would be easier to run and quicker to obtain with less data collection. A formula will need to be created to add one or more of the variables to the analysis. An additional question this may lead to is: after the model is run, will it be applicable to other regions? I believe it will be, and it will work even better in those regions with more accurate information.
CHAPTER IV

ADDING DATA TO SPACE SYNTAX AT A REGIONAL SCALE

Space Syntax, when used alone, is not a valid representation to Bicycle Level of Service. This raised the question: can adding data to the Space Syntax analysis make it more similar to BLOS? BLOS is made up of several pieces of data added together to give a road segment a level of service rating. By adding data to the Space Syntax analysis, it may be possible to create the same effect.

Results

The new data gives a very different result than the original Space Syntax analysis. More of the values became 3s or lower, indicating that the roads have a higher connectivity/level of service. There are fewer 5s and 6s than the original, which are poorer or have a lower connectivity/level of service. The 1s are still centered around intersections, with a decreasing value as one moves outward toward the edges of the study area.

Paired-Sample t-Test

The results indicated that the mean for Space Syntax (M=2.93, SD=.411) was less than the mean for BLOS (M = 4.09, SD =1.745), t(8040) = -59.343, p = 0. The standardized effect size index, d, was -1.118. These results indicate that the two are significantly different from each other.
Cohen’s Kappa

In this case the Kappa value is -0.006, which is equivalent to chance, and there is almost no agreement between the two.

Discussion

Adding traffic volume in a 15-minute time period to the Space Syntax analysis (Figure 8) does not make the model closer to being a better representation to Bicycle Level of Service. In fact, the data makes Space Syntax less similar to BLOS. Focusing on Main Street in Logan again, some of the segments have changed to a low connectivity and match the results of the BLOS analysis. Those segments are closer to downtown Logan. In Cache County there may not be a high difference in the traffic volume across all the streets, and with a lower traffic volume it increases the value of the segment, meaning it becomes a better segment for cycling. Figure 9 shows a comparison of the original Space Syntax analysis alongside the addition of traffic volume and BLOS. Traffic volume on its own may not have been the correct choice to add to Space Syntax.
Figure 8. Space Syntax with added traffic volume at a regional scale.
Figure 9. Comparison of Space Syntax analysis with added traffic volume, BLOS, and original Space Syntax analysis at a regional scale.
CHAPTER V

LOCAL SCALE RESULTS

At the regional scale, Space Syntax was not a valid representation to Bicycle Level of Service. By reducing the scale of the analysis and focusing on Logan, Utah, it may make Space Syntax more comparable (Figure 12). This is because Space Syntax runs the analysis on the segments provided: with fewer segments, it changes the connectivity values due to the edge effect.

**Space Syntax Analysis**

Figure 10 illustrates the results of the axial analysis at the local scale for Logan. It indicated that the areas with the highest connectivity are those around major intersections and closer to the center of the city. The further from the center of the city you go, the lower the score becomes, with some of the edges being values of 6. The local scale analysis looks different than the regional scale because there are less paths to analyze changing the depth of each road.

**Bicycle Level of Service**

Figure 11 illustrates the results of the Bicycle Level of Service model. This model did not change from the previous regional scale. The map was scaled down to the local level, focusing on Logan. An advantage of using Bicycle Level of Service is that scale does not affect the values of the analysis.
Figure 10. Space Syntax analysis of Logan, Utah.
Figure 11. Bicycle Level of Service of Logan, Utah.
Figure 12. Comparison of Space Syntax and BLOS analyses of Logan, Utah.

**Paired-Sample t-Test**

The results indicated that the mean for Space Syntax (M=4.45, SD=0.893) was less than the mean for BLOS (M=4.80, SD=1.216), t(8040)= -10.046, p=0. The standardized effect size index, d, was -0.282.

**Cohen’s Kappa**

In this case the Kappa value is 0.018, which is equivalent to chance, and there is almost no agreement between the two.
Discussion

The analysis, when done at the local scale, also has no similarities. Space Syntax and Bicycle Level of Service are both very different models at this scale as well. Changing scales had no effect on making these two analyses similar. This still does not prove one to be better than the other. Using a local scale is another way to plan and analyze an area. With a local scale, it is possible to focus more on a specific area and improve that area. Space Syntax at this scale helps to show the connectivity very well and could be useful if that was the focus being evaluated. Bicycle Level of Service at this scale could help to locate specific areas that could be fixed to increase their level of service.

Looking at Main Street, Space Syntax has a high connectivity around the intersections once again, and the segments between them have lower connectivity (Figure 10). The downtown area has a higher connectivity all around. The BLOS analysis did not change from the regional scale (Figure 11). At the local scale, areas of interest can be focused on easily, and low level of service areas become clearer. Main Street is shown as a low level of service, which for cyclists indicates that it is a poor route to use. It also does not match any portion of the Space Syntax analysis. The higher level of service roads are further from Main Street. The same question that arose from the regional scale: will adding additional data, such as traffic volume, to Space Syntax make it a more valid representation of Bicycle Level of Service?
CHAPTER VI

ADDING DATA TO SPACE SYNTAX AT A LOCAL SCALE

Again, on its own, Space Syntax is not a valid representation of Bicycle Level of Service, even when focusing on Logan, Utah. By adding data to this scale, it may make Space Syntax a valid representation of the BLOS analysis.

Results

As before with the regional scale, the map has changed significantly. There are many more segments that have become lower numbers or have increased in connectivity/level of service, with less segments having poor or lower connectivity/level of service. A noticeable change is that Main Street changed to poor connectivity/level of service, which was suspected because of the higher traffic volume. Additionally, more local roads have increased in connectivity.

Paired-Sample t-Test

The results indicated that the mean for Space Syntax ($M = 2.92, SD = 0.615$) was less than the mean for BLOS ($M = 4.80, SD = 1.216$), $t(8040) = -68.885, p = 0$. The standardized effect size index, $d$, was $-1.820$. These results indicate that the two are significantly different from each other.

Cohen’s Kappa

In this case the kappa value is $-0.017$, which is equivalent to chance, and there is almost no agreement between the two.
Discussion

When adding 15-minute traffic volume to the Space Syntax analysis (Figure 13) for Logan, Utah, there are few similarities with BLOS. The results are similar to the regional scale results of adding data to the Space Syntax analysis. A noticeable change to the Space Syntax analysis, like in the regional scale analysis, is that Main Street becomes more defined and similar to the Bicycle Level of Service model. Also, more of the local streets or streets with lower traffic volumes have higher ratings.

Interestingly, roads that would be expected to have lower ratings are higher in the Space Syntax analysis, meaning that other pieces of data have created a lower rating in the BLOS analysis. An example of this is 400 N., which is a 6 in the BLOS analysis and has a high traffic volume, but it has a range of numbers from 1 to 5 in the Space Syntax analysis. Before traffic volume was added, 400 N. was a consistent value of 5, which is on the lower end of connectivity. A possible reason for this is the heavy vehicle percentage (i.e., trucks) in the BLOS analysis that is not present in the Space Syntax analysis. Main Street, in the new Space Syntax analysis is closer to matching the BLOS analysis. More segments have become lower connective values and range from 5 to 6. Similar to the regional scale, additional data may still be needed for the Space Syntax analysis to become a better representation of BLOS.

Figure 14 compares differences between the Space Syntax analysis with traffic volume added, the Bicycle Level of Service analysis, and the original Logan, Utah Space Syntax analysis.
Figure 13. Space Syntax with added traffic volume for Logan, Utah.
Figure 14. Comparison of Space Syntax analysis with added traffic volume, BLOS, and original Space Syntax analysis of Logan, Utah.
CHAPTER VII

FINAL DISCUSSION

The findings of this study show that the transportation analysis tool of Space Syntax and Bicycle Level of Service do not produce similar results. Both analytical approaches have advantages and disadvantages which planners should be aware of when using these tools to plan for bicycles.

Table 4 summarizes the advantages and disadvantages of the two different analysis tools that were identified during this study. One analysis type is not necessarily better than the other; rather, they assist in answering different questions and are used in different situations. Space Syntax has the advantage that it can identify connectivity of a road network well, and it can be processed quickly. Furthermore, Space Syntax requires only data about the road network, i.e., the lines and road segments that make up the network.

Table 4. Advantages and disadvantages of Space Syntax and BLOS.

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Space Syntax</th>
<th>Bicycle Level of Service</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identifies Connectivity</td>
<td>Based on one piece of data</td>
<td>Already used standard</td>
</tr>
<tr>
<td>Fast analysis to run</td>
<td>Scale changes results</td>
<td>Simple to run analysis</td>
</tr>
<tr>
<td>Only need a road network</td>
<td>Not used to plan for bicycles</td>
<td>Scale does not affect</td>
</tr>
<tr>
<td></td>
<td>Poor integration with ArcMap</td>
<td>Time consuming</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Analysis in ArcMap</td>
</tr>
</tbody>
</table>
In contrast, a disadvantage of Space Syntax for use in planning is that it depends on one type of data and further inputs or attributes. If a road network is not complete or is limited, the analysis will be hindered. In addition, when the scale of the analysis changes, the results will also change. This means that a new graph analysis must be analyzed, and a larger scale cannot be used to look at a smaller scale, i.e., using Cache County to look at Logan. Another disadvantage of Space Syntax is that not many studies have been done on the application for planning bicycle routes, and it is not the standard tool used. Something that was noticed when doing this study is that Space Syntax does not have good integration with ArcGIS, which could be a very useful tool as it is used by many planners. As this study shows, it is possible to import from Depthmap into ArcMap, but it is not a simple process. If the integration of the two programs was simpler, much more analysis could be done and at a quicker rate.

Bicycle Level of Service has the advantage of being used as the standard approach for transportation planning, and it is supported by transportation research. Another advantage is that the analysis is simple to calculate using the formula that has been developed and provided through transportation research. Furthermore, the scale at which the analysis is done does not affect the results, and the data and analysis can be compiled within ArcMap. In contrast, a disadvantage to using BLOS is the copious amount of data collection required for the entire road network. As with this study, not all the data can be collected or is incomplete, which will hinder the analysis and its results. Another disadvantage of using BLOS is that it can be time-consuming due to the data collection and calculations it must undergo to produce the results.
It is very evident that Space Syntax is not similar to Bicycle Level of Service. There are different possibilities as to why they are not similar. The first is that the two analysis tools have very different objectives and data requirements. Space Syntax analyzes the depth and connectivity of the road network, while BLOS takes in factors pertaining to traffic and the condition of the roads and does not look at the connectivity. BLOS also requires more types of data than Space Syntax, which I consider to be the major factor contributing to the disparate results of the two approaches. The problem may be that Space Syntax does not give a good representation of a level of service, but the analysis of connectivity is useful for planners. Connectivity could be used to find the gaps in the road network which need to be connected at a regional scale. This may help planners start to identify the connective routes that are important for a regional level bicycle plan.

Bicycle Level of Service is currently the standard technique used by transportation planners when planning for cyclists. The tool/procedure assists in assessing the roads and the level of service they would provide to those using bicycles as a mode of transportation. Knowing which roads have a lower level of service can help planners to plan safer and more pleasing bicycle routes. The assessment can also provide information about what roads need to be improved on to increase their level of service. Because BLOS also contains multiple data attributes, it makes it easier to determine what is causing a specific road segment to have a lower level of service, thus allowing the planner to attempt to correct that issue or to determine that the road may not be a safe route for cyclists.
Could Space Syntax and BLOS be used together when planning for bicycling, or could the connectivity factor be added to BLOS? Planners already use BLOS as a standard approach in transportation planning and thus may not require additional data. The information about connectivity that Space Syntax provides may improve the Level of Service model, as people tend to find the most direct or shortest route, which is based on connectivity. Adding information about connectivity to BLOS would require editing the BLOS algorithm and would add another step and additional data about connectivity. Obtaining the necessary data for BLOS is already difficult and time-consuming. As is the case in Cache County, regional planners do not always have access to all the required data for BLOS analysis.

The two analyses could be overlaid and evaluated to find roads with high levels of service and high connectivity, as those roads may be the ones that are going to be used more often. On the other hand, they could be overlaid to find the areas that need improvement. These two analyses do not need to be used separately; they could be used together or side-by-side.

Cyclists choose routes differently than those using other modes of travel (Liu et al., 2016, p. 2), whether it be the shortest route, the more aesthetically pleasing route, or the route with less cars. This makes planning for cyclists difficult or challenging. By using Space Syntax and BLOS, it is possible to better understand the choices cyclists may make, thereby assisting in planning safe and connective routes for cyclists.

This is only one study that has been done at the regional scale. The investigation was limited by the availability of data required for BLOS, i.e., percent heavy vehicles and FHWA’s five-point pavement surface condition rating. With additional and more
accurate data, the results for BLOS would have been different because this study needed to use baseline averages. It must be understood that not all locations will have the same results; rural areas will likely have difficulties, just as Cache County did, while more urban areas will have an easier time finding data. Should we be planning for bicycles at a regional scale if data is hard to obtain at that level? It may be easier to plan at a local- or city-scale and then look at the links between them to create a regional bicycling plan.

There is still more research to be done to validate the use of Space Syntax when planning for bicycles. A study done in a more urban area may produce better results due to a larger road network and more available data. Space Syntax is still being researched, and new approaches and applications are being developed for planning.
REFERENCES


APPENDIX

AXIAL LINE CONVERSION

Axial Line Conversion from map info into ArcGIS, e.g.,

C:/Program Files (x86)\ArcGIS\Desktop10.2\Bin as avmifshp.exe.

The syntax for the conversion is:

avmifshp.exe MIFSHAPE [LINE/POINT/POLY/TEXT] [mif_file] [shape_file]

The syntax that was used for this data set was:

"C:\Program Files (x86)\ArcGIS\Desktop10.3\Bin\avmifshp.exe" line

"C:\Temp\Cache_MI" "C:\Temp\Cache_Arc"