Exploring Bicycle Route Choice Behavior with Space Syntax Analysis

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Motivation

- Cyclists' route choice behavior is influenced by many factors. Travelers' cognitive understanding of the network configuration has been overlooked by previous studies.
- Space syntax theory can analyze travelers' cognitive understanding of the network configuration.
- The combination of space syntax theory and other bicycle-related attributes can provide better explanatory power in modeling cyclists' route choice behavior.

As a result, we want to explore the application of space syntax in modeling bicycle route choice behavior.

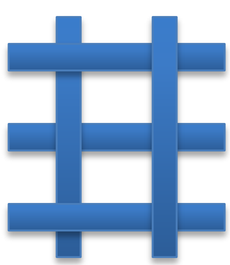
Space Syntax Theory

- Introduced by Hiller and Hanson 1984.
- Originally used in architecture to model the influence of the space structure of a building on the movement of people in it.
- Developed at the Space Syntax Laboratory at University College London.
- Has been applied in urban planning, transport, social interaction and spatial economics.

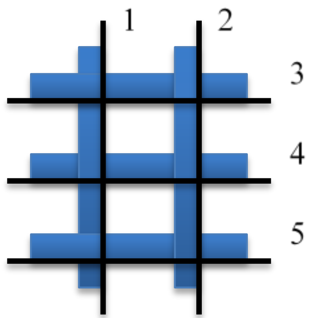
Introduction to Axial Analysis

- **Unit Space:** Axial line
- **Definition:** The straight road segment through which trip makers find their extent of visibility.
- **Axial Map:** Urban space such as roads and streets are modeled by axial lines.
- **Dual Graph:** Each axial line is represented as a node, and the intersections between axial lines are represented as links.

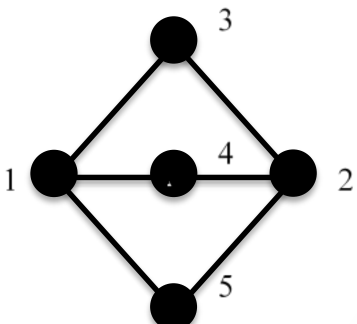
(a) Road network representation



(b) Axial map

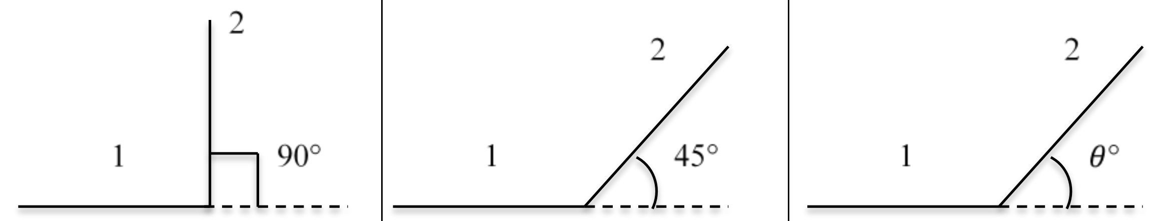


(c) Graph



Angular Segment Analysis

- Introduced by Turner (2001)
- Axial lines are broken into segments
- Step between two connected segments is weighted based on the angle between them.



(a) 1.0 step between line 1 and 2

(b) 0.5 step between line 1 and 2

(c) $\theta/90$ step between line 1 and 2

Global Integration and Local Integration

- **Integration**: It describes how closely (or distantly) the space is topologically accessible from all other spaces within a given system addressing its symmetricity and size.
  - **Global Integration:** It measures how closely or distantly each space is accessible from all other spaces of a system.
  - **Local Integration:** Integration analysis is restricted at a lower depth of connectivity to determine the accessibility of the space at a local or neighboring level. For instance, in an integration radius-3 analysis, only the space that are three depths away are considered.

Travel Demand Estimation

- Space syntax has been used to model different mode of transportation including vehicle, metro, bicycle and pedestrian.

  - Global integration ←→ Vehicular traffic
  - Local integration ←→ Pedestrian traffic

- Regression analysis is used to calibrate the correlation between integration and actual traffic volume.

No.	Source	Study area	R-square	Remarks
1	Hillier 1998	Baltic House area	0.773	Pedestrian
2	Hillier et al. 1987	Bransbury	0.641	
3	Hillier 1998	Santiago	0.54	Pedestrian
4	Hillier et al. 1987	Islington	0.536	Pedestrian
5	Eisenberg 2005	Waterfront, Hamburg	0.523	Pedestrian
6	Peponis et al. 1997	Six Greek towns	0.49	Pedestrian
7	Karimi et al. 2003	City Isfahan	0.607	Vehicular
8	Peponis et al. 1997	Buckhead, Atlanta	0.292	Vehicular
9	Paul 2009	City of Lubbock, Texas	0.18	Vehicular

Space Syntax in Modeling Bicycle

- Limited works have been done (i.e., Raford et al. 2007; McCahill and Garrick 2008; Manum and Nordstrom 2013)
- The results are not as ideal as expected.
- Bicycle traffic is a transportation mode that falls somewhere between vehicular and pedestrian traffic. A specific procedure and proper space syntax measurement needs to be determined.
- Other bicycle-related attributes also need to be considered.

Methodology

Statistical Modeling

Linear regression was used to analyze the relationship between bicycle volume and various segment attributes.

$$Y_a = \beta_0 + \beta_1 X_{1a} + \beta_2 X_{2a} + \cdots + \beta_m X_{ma}$$

where

Y_a = the bicycle volume on link a

X_{ma} = the value of explanatory variable m on link a.

β_m = model coefficient for variable m.

Methodology

Bicycle-related Attributes

(1) Link cognition: represented by space syntax measurements
(2) Segment bicycle level of service (BLOS): evaluated based on HCM (2010)
(3) Motor vehicle volume
(4) Link pollution: estimated based on a nonlinear macroscopic model of Wallace et al. (1998)
(5) Presence of bicycle facility on a link
(6) Average slope of terrain on a segment

Case Study

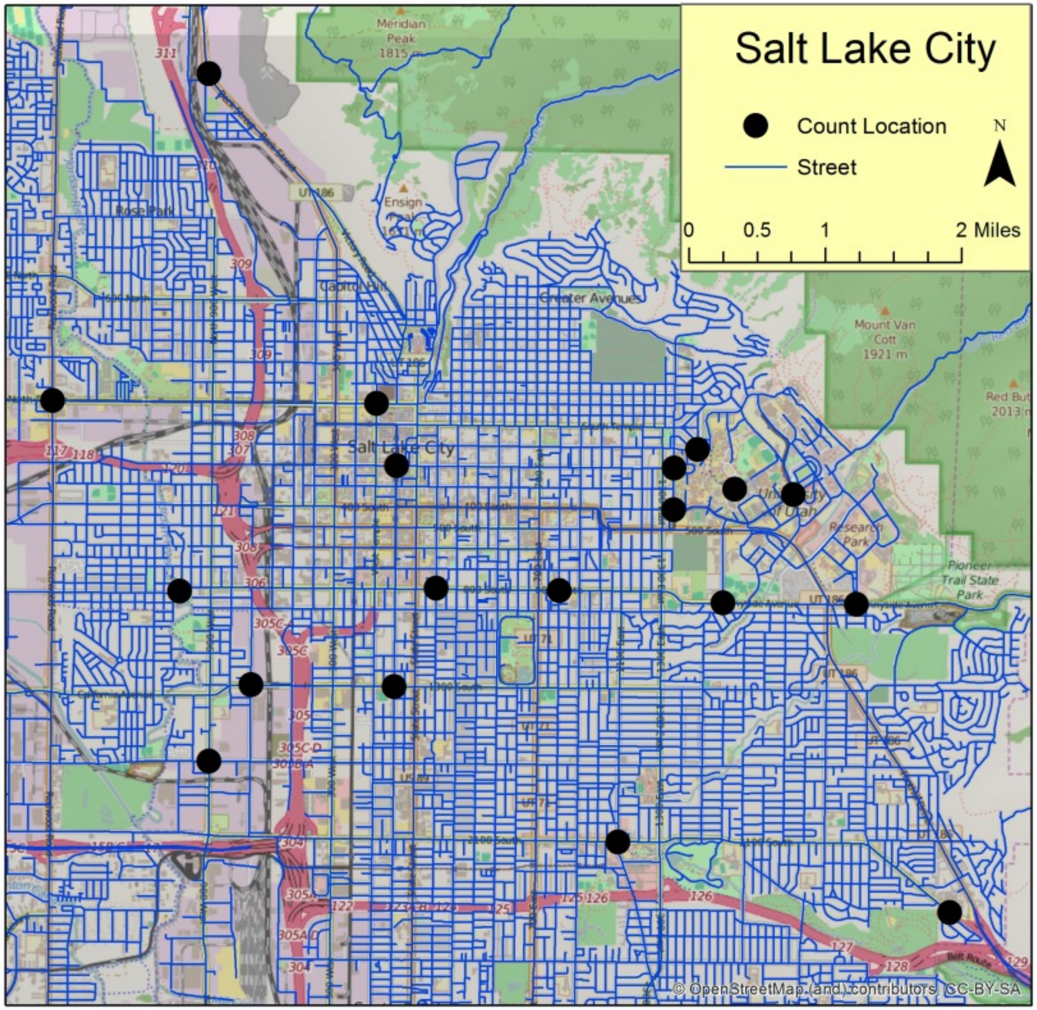
Bicycle Counts in Salt Lake City

- Date: Sep 15th(Tue), 16th(Wed), 17th(Thu), 19th(Sat), and 20th(Sun), 2015
- Location: 19 intersections
- Duration: 2 hours each day, 5-7 pm on weekdays, 12-2 pm on weekends

Summary Statistics for 2-hour Bicycle Counts

Statistic	All Counts	Weekday	Weekend
Number of counts	95	57	38
Minimum	2	7	2
Maximum	161	129	161
Median	47.0	47	42
Mean	54.8	54.1	55.9
Standard deviation	35.7	31.3	41.8

Case Study


Salt Lake City
Count Location
Street
N
0 0.5 1 2 Miles
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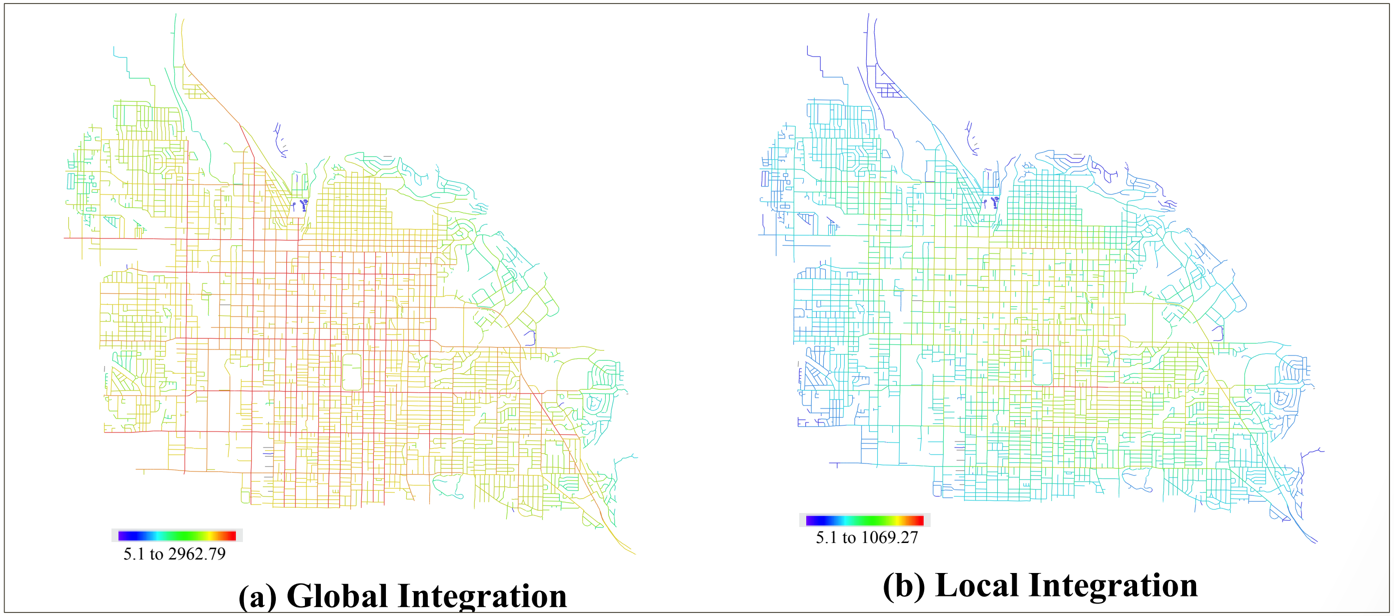
Case Study

Space Syntax Analysis

Global integration and local integration with a metric radius of 3 kilometers (1.86 miles) were calculated using segment analysis.



Case Study

Supplementary Data

- Motor vehicle volume: annual average daily traffic (AADT) data from UDOT.
- Data about speed limit and number of lanes: UDOT
- Bicycle lane data: Salt Lake Transportation Division
- Terrain slope data: digital elevation model (DEM) from Utah Automated Geographic Reference Center (AGRC)
- Other data: estimated based on HCM (2010)

Case Study

Regression Analysis

- Local integration is more appropriate in modeling bicycle traffic.

Model Variable	Coefficients	
	Global Integration Model	**Local Integration Model**
Constant	18.877 (0.325)	7.056 (0.332)
$IntG_a$	0.001 (0.617)	-
$IntL_a$	-	0.010 (0.005)
R-square	0.016	0.396
F-statistic	0.261 (0.617)	10.502 (0.005)

Case Study

Regression Analysis

- The combination of local integration and motor vehicle volumes provides a statistically significant model which has more explanatory power.
- Other models are either statistically non-significant or unreasonable.

	Model 1	Model 2	Model 3
Constant	264.884 (0.075)	137.917 (0.333)	18.200 (0.039)
$IntL_a$	0.014 (0.002)	0.012 (0.002)	0.013 (0.001)
$BSeg_a$	-20.242 (0.242)	-8.295 (0.648)	
$Motv_a$	-0.001 (0.497)	-0.001 (0.191)	-0.001 (0.041)
$PSeg_a$	-4526.53 (0.068)	-2107.57 (0.352)	
$BikeL_a$	0.298 (0.970)	-	
$Slope_a$	4.978 (0.034)	-	
R-square	0.731	0.588	0.547
F-statistic	4.986 (0.011)	4.635 (0.015)	9.055 (0.003)

Summary

- A real-world case study is conducted in Salt Lake City, Utah, to demonstrate the proposed methodology.
- The results show that a space syntax measurement (i.e., local integration) can explain the bicycle volume distribution fairly well.
- By incorporating another bicycle-related attribute (i.e., motor vehicle volume), the model improves significantly in describing bicycle movement.
- The combination of space syntax measurement and other bicycle-related attributes can improve the explanatory power of the regression model.

Thank You!

Applications in Transportation

The procedure of travel demand estimation with space syntax:

1) Represent the network with a graph by so-called axial analysis
2) Measure configuration through topological distance in the graph, without metric weighting
3) Predict traffic flow distribution based on the configurational measurements

Accessibility of Unit Space: Integration

1. Mean Depth (MD)

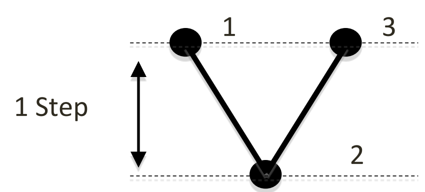
Space Syntax typically describe the topological connections of unit space through the notion of depth analysis.

When moving from one space to its connected space, there is a transition of space. In space syntax, the transition of space, which is also called step or turn, is the unit of measurement of "distance".

The distance from one space to another space is called depth. The mean depth from one space to all other space can represent the connectivity of the space in the system.

$$MD_k = \frac{\sum_{i \neq k} d(i,k)}{k-1}$$

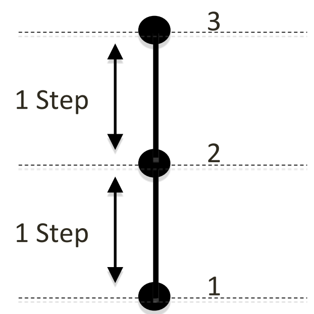
$d(i,k)$ = the steps between space i and k



$d(2,1) = 1$

$d(2,3) = 1$

$MD_2 = \frac{1+1}{2} = 1$



$d(1,2) = 1$

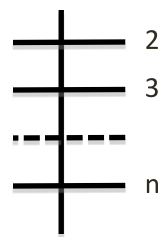
$d(1,3) = 2$

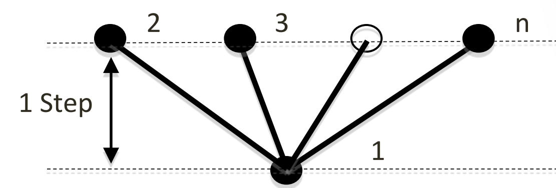
$MD_1 = \frac{1+2}{2} = 1.5$

Accessibility of Unit Space: Integration

2. Relative Asymmetry (RA)

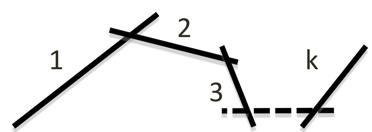
When a space is directly connected to all other spaces, it has the lowest mean depth.
In space syntax, we consider this space has the highest symmetricity.

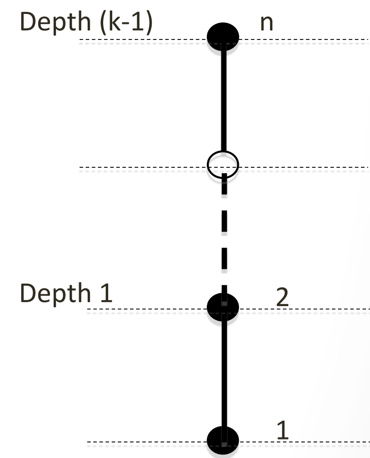




$$MD(lowest) = \frac{1(n-1)}{n-1} = 1$$

When a space need to travel the longest topological distant to reach other spaces, it has the highest mean depth.
In space syntax, it has the lowest symmetricity.





$$RA_k = \frac{MD_k - MD(lowest)}{MD(highest) - MD(lowest)}$$

$$= \frac{MD_k - 1}{n/2 - 1} = \frac{2(MD_k - 1)}{n-2}$$

$$MD(highest) = \frac{1(1) + 2(1) + \cdots + (n-1)(1)}{n-1} = \frac{n}{2}$$

Accessibility of Unit Space: Integration

3. Real Relative Asymmetry (RRA)

The relative asymmetries (of unit spaces) of two different system cannot be compared, because the size of a system (n value) also influences the accessibility of the unit spaces. Thus (Hillier et al. 1984) proposed a factor *Dn* to relativise the RA.

$$D_n = \frac{2\left(n\left(\log_2\left(\frac{n+2}{3}\right)-1\right)+1\right)}{(n-1)(n-2)}$$

$$RRA_k = \frac{RA_k}{D_n}$$

Accessibility of Unit Space: Integration

4. Integration

$$Integration_k = \frac{1}{RRA}$$

It describes how closely (or distantly) the space is topologically accessible from all other spaces within a given system addressing its symmetricity and size.