Measuring the Structure of Transport Networks: Beyond Density, Diversity, and Design

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Objective

Research to test for the existence and measure the relationship between network structure and travel behavior.

If the relationship exists:

Does it hold steady across different regions and scales?
Conceptual Model

Network Structure

Investments in Infrastructure

Congestion

Mobility

Accessibility

Travel Behavior

Land Patterns

Demand for particular land uses
What is Network Structure (Topology)?

Refers to layout of the network - arrangement and characteristics of the individual elements in the network.

A successful measure of network structure provides an overall understanding of the network, a detailed analysis of the individual elements and their contribution to network performance.
Connection Patterns

Identify the existing patterns in a roadway and quantify the relative importance of each pattern.

Two basic structures in planar transportation networks:

Circuit networks - Networks distinguished by closed circuits.

Tree networks - Networks distinguished by a tree shaped structure.
Trees vs. Circuits

Circuit - A closed path, with no less than three links, that begin and end at the same vertex.

Tree - Set of connected links without any complete circuits.
Treeness = \frac{\text{Length of arterials in tree network}}{\text{Total length of arterials}}
Circuity

Spatial distribution of the network and the choices available to the traveler.

\[
\text{Circuity} = \frac{\text{Shortest path network distance}}{\text{Euclidean distance}}
\]

Network distance - realistic representation of actual distance between origin and destination.

Euclidean distance - straight line distance between origin and destination.

Source: Geneidy & Levinson (2007)
Hess (1997)
Ballou et al. (2002)
Directness = 1/Circuity.

Directness = Euclidean distance
Shortest path network distance
Network Distance = 6.9 mi
Euclidean Distance = 5.5 mi
Circuity = 6.9/5.5 = 1.3
On Manhattan Grid, Maximum Circuity is

\[ \frac{2}{1.414} = 1.414 \]

Typical worst case for regular network patterns though irregular networks may have higher circuity.
Typical values from random samples of urban networks about 1.2 (Newell 1980)

1.21 - 1.23 at Transit station catchment areas (O’Sullivan and Morral)

Higher for pedestrian and bike travel than auto (Dill 2004)

Actual routes from GPS measurements higher than would be expected from shortest path analysis (Axhausen 2004)
Preliminary Results

Exploratory analysis conducted to analyze the relationship between network structure and travel behavior

Data sources:

Travel behavior data from year 2000
Travel Behavior Inventory (TBI)

Network structure variables estimated using the roadway network in the Twin Cities regional model
Statistical model developed to predict travel behavior (trip distance) as a function of socio-demographic and network structure variables

Analysis restricted to home to work trips in the TBI
2-km buffers around the home to work trip
| Variable                              | Coefficient | t     | P>|t| | Elasticity (% change) |
|--------------------------------------|-------------|-------|------|----------------------|
| Circuity                             | -1.9E+04    | -14.26| 0.00 | -1.41                |
| Treeness in buffer                   | 3.8E+04     | 2.37  | 0.02 | 0.01                 |
| Roadway density in buffer            | -1.6E+06    | -13.01| 0.00 | -0.44                |
| Constant                             | 4.8E+04     | 15.01 | 0.00 |                      |
| Number of observations               | 2204        |       |      |                      |
| R-squared                            | 0.2424      |       |      |                      |
| Adj R-squared                        | 0.2319      |       |      |                      |

Roadway density and Treeness as expected. Circuity requires explanation. Networks are more circuitous at shorter distances than longer distances, the sign reflects that. (correlation is not causality)
Hypotheses:

We posit that individuals would like to have the most space available at the least travel and monetary cost.

This implies that, all else equal, residence and work locations will be chosen where the network circuity is at a minimum.

We expect to find that circuity is lower for actual home and work pairs than for the random set of home and work pairs that have been used in previous research (e.g. Newell 1980), as people can select how to arrange their activities on the network.
While cities are not strictly monocentric, there is still a strong attraction of jobs at center and large dispersal of houses to suburbs.

Density gradient (higher residential densities in center than periphery) still exists.

Average size of US home over time (proportional to distance from center)

Source: National Association of Home Builders, This Old House Magazine (May, 2003)
Home and Work Locations in Twin Cities in study
<table>
<thead>
<tr>
<th>Euclidean Distances</th>
<th>Fixed to Observation</th>
<th>Random</th>
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<tbody>
<tr>
<td>Network Distances</td>
<td>Case 1: (Observed)</td>
<td>Case 4</td>
</tr>
<tr>
<td>Fixed to Observation</td>
<td>Case 3</td>
<td>Case 2: (Literature)</td>
</tr>
<tr>
<td>Case</td>
<td>Relationship</td>
<td>Average Network Distance</td>
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<td>------</td>
<td>--------------</td>
<td>--------------------------</td>
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<td>1</td>
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<tr>
<td>2</td>
<td>Random</td>
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<tr>
<td>3</td>
<td>Euclidean Distance Matched</td>
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<tr>
<td>4</td>
<td>Network Distance Matched</td>
<td>18,134</td>
</tr>
</tbody>
</table>
Circuity Ratio by Euclidean distance between home and work for random points
People are selecting network circuity ratios that are 0.056 smaller than random, while controlling all other factors affecting the selection of home locations.

While that number may not sound large, this is 0.056 better than the 1.22 (case 3) random result.

Overall this is about 25% better (since the best possible ratio would be 1.0).

Given all of the other constraints individuals face when finding housing and jobs in a multi-worker context and on inefficient networks, we conclude that maximizing land while minimizing commute remains an important factor in urban location decisions.

An important corollary of these findings is that the efficiency of the network cannot be assessed independently of how travelers use it.

The circuity that users face depends on what they do.
The chart displays the comparison between Observed HW Circuity and Random Circuity for various cities across different regions. The x-axis represents different cities including Greater Los Angeles, Dallas, Philadelphia, Houston, Miami, Atlanta, Detroit, San Francisco, Inland Empire, Seattle, Minneapolis, San Diego, Tampa Bay Area, Baltimore, Denver-Aurora, Pittsburgh, Portland, Sacramento, Greater Orlando, Kansas City, Las Vegas, and Seattle. The y-axis measures the circuity values, with a range from 1.0 to 1.9. The bars indicate the observed circuity (yellow) and random circuity (gray) for each city.
Summary

This research considers the influence of network structure on travel behavior, which hasn’t been done previously.

The empirical analysis of this relationship across different regions and at different levels will provide a clearer understanding of the presence and magnitude of this relationship.

The relationship is complex. Simple “common sense” heuristics may be wrong.
Policy Implications

The models developed in this analysis can be used to

Analyze the impacts of network changes on travel, e.g. addition of a new roadway

Design more efficient networks that maximize the net benefit of infrastructure.
Planning for Place and Plexus

The Transportation Experience

Access to Destinations

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