APPENDIX A

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Table of Contents
An Overview of Methods in Transport Geography
Taxonomy of Transport Geography Methods

**Transport Related**
- Network Analysis (Graph Theory).
- Land Use / Transportation Interactions.
- Flow/Location Allocation Models.
- The Four-Stage Urban Transportation Model.
- Travel / Traffic Surveys.

**Multidisciplinary**
- Cartography / Geographic Information Systems.
- Descriptive Statistics, (e.g. Gini Coefficient).
- Questionnaires / Interviews.
- Big data.
- Graphs and Charts.
- Inferential Statistics.
- Impact Assessment.
- Risk Assessment.
- Policy Analysis.
Graph Theory: Definition and Properties
Graph Representation of a Real Network
Basic Graph Representation of a Transport Network

Vertex (Node)

Edge (Link)

Buckle
Planar and Non-Planar Graphs

A

Planar

B

Non-Planar
Simple and Multigraph

Simple Graphs

Road

Rail

Multigraph

Road & Rail
Connections and Paths

Connection

Path (1 to 3)
Length of a Link, Connection or Path

![Diagram of a network with distances labeled: 1 to 2: 5 km, 1 to 4: 2 km, 2 to 3: 4 km, 3 to 6: 2 km, 4 to 5: 2 km, 5 to 6: 3 km, 1 to 4: 7 km.](image-url)
Cycles and Circuits

1

2

3

4

5

6

Circuit

Cycle

Cycle
Ego Network
Connectivity in a Graph
Complementary Graph

Diagram:

- **G**
  - Nodes: 1, 2, 3, 4, 5
  - Connections: 1 to 2, 1 to 3, 1 to 4, 1 to 5, 2 to 3, 2 to 4, 2 to 5, 3 to 4, 3 to 5, 4 to 5

- **X**
  - Nodes: 1, 2, 3, 4, 5
  - Connections: 1 to 2, 1 to 3, 1 to 4, 1 to 5, 2 to 3, 2 to 4, 2 to 5, 3 to 4, 3 to 5, 4 to 5

- **Y**
  - Nodes: 1, 2, 3, 4, 5
  - Connections: 1 to 2, 1 to 3, 1 to 4, 1 to 5, 2 to 3, 2 to 4, 2 to 5, 3 to 4, 3 to 5, 4 to 5
Articulation Node

A

B (Connected)

C (Unconnected)

Removed

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Graph Theory: Indexes and Measures
Diameter of a Graph

Diameter = 4

<table>
<thead>
<tr>
<th>Shimbel Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>v</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>6</td>
</tr>
<tr>
<td>7</td>
</tr>
</tbody>
</table>
Changes in the Diameter of a Graph

A. $d = 2$

B. $d = 3$

C. $d = 4$

D. $d = 3$
Number of Cycles in a Graph

\[ u = e - v + p \]

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>e</td>
<td>v</td>
<td>p</td>
<td>u</td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>3</td>
<td>5</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>B</td>
<td>5</td>
<td>5</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>C</td>
<td>5</td>
<td>4</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>D</td>
<td>7</td>
<td>6</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>
Cost

A - Original network and weighted links

B - Minimum Spanning Tree (MST)

C - Greedy triangulation (GT)

<table>
<thead>
<tr>
<th></th>
<th>Cost (weight)</th>
<th>Cost (links)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>360</td>
<td>18</td>
</tr>
<tr>
<td>B</td>
<td>145</td>
<td>11</td>
</tr>
<tr>
<td>C</td>
<td>480</td>
<td>29</td>
</tr>
<tr>
<td>CostRel</td>
<td>0.642</td>
<td>0.389</td>
</tr>
</tbody>
</table>
### Order (degree) vs. Node (vertex) Frequency

<table>
<thead>
<tr>
<th>Order (degree)</th>
<th>Node (vertex) frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>48</td>
</tr>
<tr>
<td>2</td>
<td>20</td>
</tr>
<tr>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>9</td>
<td>1</td>
</tr>
<tr>
<td>30</td>
<td>1</td>
</tr>
</tbody>
</table>

The relationship between order and node frequency is described by the equation:

\[ y = 25.583x^{-1.209} \]
Transitivity

A

B

C

D

E

<table>
<thead>
<tr>
<th></th>
<th>Number of existing triplets (t₀)</th>
<th>Number of possible triplets (t₁)</th>
<th>Transitivity (t₀ / t₁)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>B</td>
<td>1</td>
<td>4</td>
<td>0.25</td>
</tr>
<tr>
<td>C</td>
<td>2</td>
<td>4</td>
<td>0.5</td>
</tr>
<tr>
<td>D</td>
<td>3</td>
<td>4</td>
<td>0.75</td>
</tr>
<tr>
<td>E</td>
<td>4</td>
<td>4</td>
<td>1</td>
</tr>
</tbody>
</table>
Order of a Node

A. Order (o)

B. Perfect spoke

C. Perfect hub

D.
Pi Index and the Shape of Transportation Networks

$\Pi = \frac{L(G)}{D(d)}$

Least developed (Low Pi)

Highly developed (High Pi)
The Eta Index is defined as:

$$\eta = \frac{L(G)}{e}$$

Table:

<table>
<thead>
<tr>
<th></th>
<th>L(G)</th>
<th>e</th>
<th>Eta</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>80 km</td>
<td>5</td>
<td>16.0</td>
</tr>
<tr>
<td>B</td>
<td>80 km</td>
<td>7</td>
<td>11.4</td>
</tr>
</tbody>
</table>
\[ \theta = \frac{Q(G)}{v} \]

<table>
<thead>
<tr>
<th></th>
<th>Q(G)</th>
<th>v</th>
<th>Theta</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>3,500 t</td>
<td>6</td>
<td>583.3</td>
</tr>
<tr>
<td>B</td>
<td>3,500 t</td>
<td>8</td>
<td>437.5</td>
</tr>
</tbody>
</table>
\[ \iota = \frac{L(G)}{W(G)} \]

\[ W(G) = \begin{cases} 1, & \forall o = 1 \\ 2^o, & \forall o > 1 \end{cases} \]

<table>
<thead>
<tr>
<th></th>
<th>L(G)</th>
<th>W(G)</th>
<th>\iota</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>80</td>
<td>23</td>
<td>3.47</td>
</tr>
<tr>
<td>B</td>
<td>80</td>
<td>22</td>
<td>3.63</td>
</tr>
</tbody>
</table>
The Beta Index is defined as:

\[ \beta = \frac{e}{v} \]

where \( e \) is the number of edges and \( v \) is the number of vertices in a graph.

A 2 4 0.5
B 3 4 0.75
C 4 4 1.0
D 5 4 1.25
\[ \alpha = \frac{u}{2v - 5} \]

<table>
<thead>
<tr>
<th></th>
<th>( u ) (e-v+p)</th>
<th>( 2v-5 )</th>
<th>Alpha</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0</td>
<td>3</td>
<td>0.0</td>
</tr>
<tr>
<td>B</td>
<td>1</td>
<td>3</td>
<td>0.33</td>
</tr>
<tr>
<td>C</td>
<td>2</td>
<td>3</td>
<td>0.66</td>
</tr>
<tr>
<td>D</td>
<td>3</td>
<td>3</td>
<td>1.0</td>
</tr>
</tbody>
</table>
\[ \gamma = \frac{e}{3(v - 2)} \]

<table>
<thead>
<tr>
<th></th>
<th>3(v-2)</th>
<th>Gamma</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>9</td>
<td>0.44</td>
</tr>
<tr>
<td>B</td>
<td>9</td>
<td>0.66</td>
</tr>
<tr>
<td>C</td>
<td>9</td>
<td>0.88</td>
</tr>
<tr>
<td>D</td>
<td>9</td>
<td>1.0</td>
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</tr>
</tbody>
</table>
Geographic Information Systems and Transportation

Feature Classes / Layers

Transportation Network

Flows

Land Use Pattern

Components

Real World

Encoding

Representation model (space and data)

Management

Spatial – Thematic - Temporal

Analysis

Query – Operations - Modeling

Reporting

Visualization and Cartography

User

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GIS Data Models
## GIS in the Value Chain

<table>
<thead>
<tr>
<th>Inbound Logistics</th>
<th>Optimization of warehouse usage; logistics modeling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sales and Marketing</td>
<td>GIS as a market analysis tool; simulation of dispersion of new products; target marketing and advertising</td>
</tr>
<tr>
<td>Services</td>
<td>Route planning; dealer network maintenance; customer complaints; dispatch; maintenance forecasting</td>
</tr>
<tr>
<td>Operations</td>
<td>Enhancing the spatial content of process or product</td>
</tr>
<tr>
<td>Outbound Logistics</td>
<td>Route planning; fleet management; delivery assessment</td>
</tr>
</tbody>
</table>
Transportation and Accessibility
Relationship between Distance and Opportunities

Distance

Opportunities

High density
Medium density
Low density
Topological and Contiguous Accessibility

Topological

Contiguous

Least

Most

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Accessibility and Spatial Structure

[Diagram showing three scenarios labeled A, B, and C, with corresponding graphs on the right showing the number of locations against distance for different groups.]
Simple Connectivity Matrix

Network

Connectivity Matrix

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>B</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>C</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>D</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>E</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
More Complex Connectivity Matrix

Connectivity Matrix

<table>
<thead>
<tr>
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<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>B</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>C</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>D</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>E</td>
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<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
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<tr>
<td>F</td>
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<td>1</td>
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<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
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</tbody>
</table>
Total Accessibility Matrix (T-Matrix)

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>Σ</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>11</td>
</tr>
<tr>
<td>B</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>C</td>
<td>2</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>0</td>
<td>12</td>
</tr>
<tr>
<td>D</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>E</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Σ</td>
<td>11</td>
<td>9</td>
<td>12</td>
<td>9</td>
<td>5</td>
<td>46</td>
</tr>
</tbody>
</table>

\[ T = C_2 \]

\[ C_2 \]

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>B</td>
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<td>2</td>
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<tr>
<td>C</td>
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<td>4</td>
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<tr>
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<tr>
<td>E</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

\[ C_1 = C_2 \times \begin{pmatrix} 0 & 1 & 1 & 1 & 0 \\ 1 & 0 & 1 & 0 & 0 \\ 1 & 1 & 0 & 1 & 1 \\ 1 & 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \end{pmatrix} + \begin{pmatrix} 0 & 1 & 1 & 1 & 0 \\ 1 & 0 & 1 & 0 & 0 \\ 1 & 1 & 0 & 1 & 1 \\ 1 & 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \end{pmatrix} \]
Shimbel Distance (D-Matrix)

Network

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>Σ</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>B</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>C</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>D</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>E</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Σ</td>
<td>5</td>
<td>6</td>
<td>4</td>
<td>6</td>
<td>7</td>
</tr>
</tbody>
</table>

\[ D = \begin{bmatrix}
A & B & C & D & E \\
A & 0 & 1 & 1 & 1 & 0 \\
B & 1 & 0 & 1 & 0 & 0 \\
C & 1 & 1 & 0 & 1 & 1 \\
D & 1 & 0 & 1 & 0 & 0 \\
E & 0 & 0 & 1 & 0 & 0 \\
\end{bmatrix} \]

\[ C1 = \begin{bmatrix}
A & B & C & D & E \\
A & 0 & 1 & 1 & 1 & 0 \\
B & 1 & 0 & 1 & 0 & 0 \\
C & 1 & 1 & 0 & 1 & 1 \\
D & 1 & 0 & 1 & 0 & 0 \\
E & 0 & 0 & 1 & 0 & 0 \\
\end{bmatrix} \]

\[ D1 = \begin{bmatrix}
A & B & C & D & E \\
A & 0 & 1 & 1 & 1 & 0 \\
B & 1 & 0 & 1 & 1 & 0 \\
C & 1 & 1 & 0 & 1 & 1 \\
D & 1 & 1 & 0 & 1 & 0 \\
E & 1 & 1 & 0 & 0 & 0 \\
\end{bmatrix} \]

\[ C2 = \begin{bmatrix}
A & B & C & D & E \\
A & 3 & 1 & 2 & 1 & 1 \\
B & 1 & 2 & 1 & 2 & 1 \\
C & 2 & 1 & 4 & 1 & 0 \\
D & 1 & 2 & 1 & 0 & 2 \\
E & 1 & 1 & 0 & 1 & 1 \\
\end{bmatrix} \]

\[ D2 = \begin{bmatrix}
A & B & C & D & E \\
A & 0 & 1 & 1 & 1 & 2 \\
B & 1 & 0 & 1 & 2 & 2 \\
C & 1 & 1 & 0 & 1 & 1 \\
D & 1 & 2 & 1 & 0 & 2 \\
E & 2 & 2 & 1 & 2 & 0 \\
\end{bmatrix} \]
Valued Graph (L-Matrix)

Network

\[
\begin{array}{c|ccccc}
 & A & B & C & D & E \\
\hline
A & 0 & 10 & 7 & 12 & 14 & 43 \\
B & 10 & 0 & 5 & 16 & 12 & 43 \\
C & 7 & 5 & 0 & 11 & 7 & 30 \\
D & 12 & 16 & 11 & 0 & 18 & 57 \\
E & 14 & 12 & 7 & 18 & 0 & 51 \\
\hline
\Sigma & 43 & 43 & 30 & 57 & 51 & 194 \\
\end{array}
\]

\[
\begin{array}{c|ccccc}
 & A & B & C & D & E \\
\hline
A & 0 & 10 & 7 & 12 & \infty \\
B & 10 & 0 & 5 & \infty & \infty \\
C & 7 & 5 & 0 & 11 & 7 \\
D & 12 & \infty & 11 & 0 & \infty \\
E & \infty & \infty & 7 & \infty & 0 \\
\end{array}
\]

\[
\begin{array}{c|ccccc}
\sum & A & B & C & D & E \\
\hline
A & 0 & 10 & 7 & 12 & \infty \\
B & 10 & 0 & 5 & \infty & \infty \\
C & 7 & 5 & 0 & 11 & 7 \\
D & 12 & \infty & 11 & 0 & \infty \\
E & \infty & \infty & 7 & \infty & 0 \\
\end{array}
\]
Potential Accessibility

![Graph with nodes and edges]

<table>
<thead>
<tr>
<th>L</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0</td>
<td>8</td>
<td>4</td>
<td>9</td>
<td>15</td>
</tr>
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<td>B</td>
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<td>18</td>
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<tr>
<td>C</td>
<td>4</td>
<td>7</td>
<td>0</td>
<td>5</td>
<td>11</td>
</tr>
<tr>
<td>D</td>
<td>9</td>
<td>12</td>
<td>5</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>E</td>
<td>15</td>
<td>18</td>
<td>11</td>
<td>6</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>P</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1200</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>900</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>1500</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>600</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>E</td>
<td>800</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>i(i)j</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>(\Sigma i)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1200.0</td>
<td>150.0</td>
<td>300.0</td>
<td>133.3</td>
<td>80.0</td>
<td>1863.3</td>
</tr>
<tr>
<td>B</td>
<td>112.5</td>
<td>900.0</td>
<td>128.6</td>
<td>75.0</td>
<td>50.0</td>
<td>1266.1</td>
</tr>
<tr>
<td>C</td>
<td>375.0</td>
<td>214.3</td>
<td>1500.0</td>
<td>300.0</td>
<td>136.4</td>
<td>2525.7</td>
</tr>
<tr>
<td>D</td>
<td>66.6</td>
<td>50.0</td>
<td>120.0</td>
<td>600.0</td>
<td>100.0</td>
<td>936.6</td>
</tr>
<tr>
<td>E</td>
<td>53.3</td>
<td>44.4</td>
<td>72.7</td>
<td>133.3</td>
<td>800.0</td>
<td>1103.7</td>
</tr>
<tr>
<td>(\Sigma j)</td>
<td>1807.4</td>
<td>1358.7</td>
<td>2121.3</td>
<td>1241.6</td>
<td>1166.4</td>
<td>7695.4</td>
</tr>
</tbody>
</table>
The Traveling Salesperson Problem

A

1
2
3
4
5
6

Total = 62 km

B

1
2
3
4
5
6

Total = 48 km

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Effect of Topography on Route Selection
Effect of Transport Costs on Route Selection

1. \( R \{ C(\text{sea}) = C(\text{land}) \} \)
   - Sea
   - R (sea)
   - \( p_1 \)
   - \( p_2 \)
   - \( p_3 \)
   - \( p_4 \)
   - \( a \)

2. \( R \{ C(\text{sea}) > C(\text{land}) \} \)
   - R (land)
   - \( p_1 \)
   - \( a \)
   - \( p_2 \)
   - \( p_3 \)
   - \( p_4 \)

3. \( R \{ \Delta C(\text{land}) > \Delta C(\text{sea}) \} \)
   - R (sea)
   - \( p_2 \)
   - \( a \)

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Cost Minimization and Efficiency Maximization in Route Selection
Network Data Models
The ESRI Shapefile Model

Main file (*.shp)

Index file (*.shx)

dBase table (*.dbf)

Predefined fields

<table>
<thead>
<tr>
<th>geom</th>
<th>id</th>
<th>shp_len</th>
<th>type</th>
<th>surface</th>
<th>width</th>
<th>lanes</th>
<th>name</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>101</td>
<td>4507.4</td>
<td>2</td>
<td>asphalt</td>
<td>85.3</td>
<td>4</td>
<td>I95</td>
</tr>
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<td></td>
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<td>45.1</td>
<td>2</td>
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<td>104</td>
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<td>35.2</td>
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<td>Ridge</td>
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<tr>
<td></td>
<td>105</td>
<td>1279.1</td>
<td>4</td>
<td>asphalt</td>
<td>60.3</td>
<td>4</td>
<td>Main</td>
</tr>
</tbody>
</table>

custom fields
Topology of a Network Data Model

Node

Bi-directional Link

Directional Link
Geocoding in a Network Data Model
Routing in a Network Data Model
Nodes

<table>
<thead>
<tr>
<th>ID</th>
<th>Lat</th>
<th>Long</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>40.42345</td>
<td>-75.1245</td>
</tr>
<tr>
<td>B</td>
<td>40.31021</td>
<td>-75.2510</td>
</tr>
<tr>
<td>C</td>
<td>40.41882</td>
<td>-74.9124</td>
</tr>
<tr>
<td>D</td>
<td>40.25908</td>
<td>-75.0031</td>
</tr>
<tr>
<td>E</td>
<td>40.28990</td>
<td>-74.7893</td>
</tr>
</tbody>
</table>

Links

<table>
<thead>
<tr>
<th>ID</th>
<th>From</th>
<th>To</th>
<th>One_Way</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A</td>
<td>C</td>
<td>Yes</td>
</tr>
<tr>
<td>2</td>
<td>B</td>
<td>A</td>
<td>Yes</td>
</tr>
<tr>
<td>3</td>
<td>D</td>
<td>B</td>
<td>Yes</td>
</tr>
<tr>
<td>4</td>
<td>D</td>
<td>C</td>
<td>No</td>
</tr>
<tr>
<td>5</td>
<td>D</td>
<td>E</td>
<td>No</td>
</tr>
<tr>
<td>6</td>
<td>C</td>
<td>E</td>
<td>No</td>
</tr>
</tbody>
</table>
Creation of a Connectivity Matrix with a Link Table

### Links

<table>
<thead>
<tr>
<th>ID</th>
<th>From</th>
<th>To</th>
<th>One Way</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>C</td>
<td>A</td>
<td>Yes</td>
</tr>
<tr>
<td>2</td>
<td>B</td>
<td>A</td>
<td>Yes</td>
</tr>
<tr>
<td>3</td>
<td>D</td>
<td>B</td>
<td>Yes</td>
</tr>
<tr>
<td>4</td>
<td>D</td>
<td>C</td>
<td>No</td>
</tr>
<tr>
<td>5</td>
<td>D</td>
<td>E</td>
<td>No</td>
</tr>
<tr>
<td>6</td>
<td>C</td>
<td>E</td>
<td>No</td>
</tr>
</tbody>
</table>

### Connectivity Matrix (C)

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>B</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>C</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>D</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>E</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

\[ C_{ij} = 0 \ \forall i, j \]

\[ \forall ID[i], C_{From[i], To[i]} = 1 \]

\[ \forall One\_Way[i] = "No", C_{To[i], From[i]} = 1 \]
Turn Penalties at an Intersection

**Turn Penalty Table – Node A**

<table>
<thead>
<tr>
<th>From</th>
<th>To</th>
<th>Penalty</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
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<tr>
<td>3</td>
<td>4</td>
<td>-1</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>1</td>
</tr>
</tbody>
</table>
Object-Oriented Network Model

Transport Network

Link
- ID
- Length
- Capacity
...

Node
- ID
- Capacity
- Impedance
...

Connection
Inheritance

Class

Properties

A
B

a
Symbolization of Transport Features in a GIS
Visual Resources

Color

Hue
Texture
Intensity

Geometry

Shape
Size
Orientation
Category Ranges

Gray Scale

Pattern

Hue

Intensity
Visual Resources

Cartographic Representation

<table>
<thead>
<tr>
<th>Point representation</th>
<th>Line representation</th>
<th>Area representation</th>
<th>Volumetric representation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tree</td>
<td>Phone line</td>
<td>Animal range</td>
<td>Housing density</td>
</tr>
<tr>
<td>Point objects</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tree</td>
<td>X</td>
<td>Administrative division</td>
<td>Road density</td>
</tr>
<tr>
<td>Line objects</td>
<td>Highway</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phone line</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Point objects</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chemical spill</td>
<td>Right of way</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Area objects</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chemical spill</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volumetric objects</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Open-pit mine</td>
<td>Valley</td>
<td>Mountain range</td>
<td>Proportional symbol</td>
</tr>
<tr>
<td>Volumetric objects</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Real World Phenomena

- Point objects: Tree, Chemical spill, Open-pit mine
- Line objects: Airport, Highway, Tel. poles, Right of way
- Area objects: Animal range, Administrative division, Housing density
- Volumetric objects: Housing density, Road density, Forest cover

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Major Map Elements

Continental United States

Title

Locator Map

Inset Frame

Scale
1:20,000,000

Inset

North Arrow

Projection
Albers Equal Area Conic Projection

Credits
Cartography: Dr. Jean-Paul Rodrigue

Inset

Long Island

Credits

Cartography: Dr. Jean-Paul Rodrigue
Symbolization of Transport Features

Nominal Classification

- Interstate
- US Highway
- State Highway

Ordinal Classification

- Low
- Average
- High

Interval Classification

- Less than 0.7
- 0.7 to 0.9
- More than 0.9

Proportional Symbols

- Less than 75,000
- 75,000 to 150,000
- More than 150,000

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Traffic Assignment
Traffic Assignment Problem
Spatial Interactions and Traffic Assignment

Origin / Destination

Traffic in a Network
Two Perspectives for Considering Traffic

Traffic Maximization

- Increase in travel time with demand
- Point 1

Cost Minimization

- Decrease in transport costs with assignment
- Point 2
Heuristic Method for Traffic Maximization

Maximum Possible Traffic between A and F

Possible paths between A and F:
- A-B-D-F, A-B-E-F, and A-C-E-F

**Step 1**
- A-B-D-F path (maximum traffic assignment = 20)

**Step 2**
- A-B-D-F path (maximum traffic assignment = 20)

**Step 3**
- A-B-E-F path (maximum traffic assignment = 10)

**Step 4**
- A-C-E-F path (maximum traffic assignment = 20)
- Maximum traffic between A and F = 50 units.
Possible paths between A and B ordered by cost (least to most):
1) A-B-E-F, 2) A-C-E-F, and 3) A-B-D-F

Assignment on path 1 (A-B-E-F) = 15 units

Assignment on path 2 (A-C-E-F) = 15 units

Assignment on path 3 (A-B-D-F) = 5 units

Minimal cost = 130. Average cost = 3.7 per unit.
Types of Traffic Costs

![Graph showing types of traffic costs](image_url)

- **Demand**
- **Global cost**

Marginal cost:
- (a-b)
- (c-d)
Traffic Cost Functions

\[ g(Q(a,b)) \]

Non-linear cost function

Linear cost function

\[ c = 5 \]
Traffic assignment

\[
q_{ij} = f(d_{ij})
\]

\[
\min \sum g(q_{ij})
\]

Transport strategies

Spatial strategies

Optimization

Transport Costs

Traffic assignment
Technical Performance Indicators
<table>
<thead>
<tr>
<th>Indicator</th>
<th>Passenger</th>
<th>Freight</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger / freight density</td>
<td>passenger-km / km</td>
<td>ton-km / km</td>
<td>A standard measure of transport efficiency.</td>
</tr>
<tr>
<td>Mean distance traveled</td>
<td>passenger-km / passenger</td>
<td>ton-km / ton</td>
<td>A measure of the ground covering capacity of networks and different transport modes.</td>
</tr>
<tr>
<td>Mean per capita ton output (freight)</td>
<td>passengers / population</td>
<td>tons / population</td>
<td>Used to measure the relative performance of transport modes.</td>
</tr>
<tr>
<td>Mean number of trips per capita</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(passenger)</td>
<td></td>
<td></td>
<td>Particularly useful with increasing complexity of logistics associated with containerization of freight (i.e. of empty returns). Can also be used to measure transit ridership.</td>
</tr>
<tr>
<td>Mean load factor</td>
<td>number of passengers aboard / total carrying capacity (%)</td>
<td>actual load (ton) / overall load capacity (ton) (%)</td>
<td></td>
</tr>
</tbody>
</table>
### Common Economic Impact Indicators

<table>
<thead>
<tr>
<th>Factors of production</th>
<th>Scale-specific indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Micro</td>
</tr>
<tr>
<td>Output / Capital</td>
<td>Transport sector income / Local income</td>
</tr>
<tr>
<td>Output / Labor</td>
<td>Output / Local income</td>
</tr>
<tr>
<td>Capital / Labor</td>
<td>Output / GDP</td>
</tr>
</tbody>
</table>
Continuous and Discontinuous Traffic
### Levels of Service for Road Transportation (Vehicle per Lane per Hour)

**Volume to Capacity Ratio**

\[ S = \frac{sf}{1 + a(v/c)^b} \]

<table>
<thead>
<tr>
<th>Speed</th>
<th>Volume to Capacity Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>600</td>
<td>0.0 to 0.2</td>
</tr>
<tr>
<td>960</td>
<td>0.2 to 0.4</td>
</tr>
<tr>
<td>1440</td>
<td>0.4 to 0.7</td>
</tr>
<tr>
<td>1824</td>
<td>0.7 to 0.8</td>
</tr>
<tr>
<td>2200</td>
<td>0.8 to 1.0</td>
</tr>
<tr>
<td>&gt;2200</td>
<td>&gt;1.0</td>
</tr>
</tbody>
</table>

**Level of Service**

- A
- B
- C
- D
- E
- F

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Causes of Road Transportation Bottlenecks

- Traffic interruption
- Lane reduction
- Merging
- Distraction
Critical Density and Critical Speed

![Graph showing capacity, density, and speed relationship](image-url)
The Gini Coefficient
The Lorenz Curve

Perfect inequality line

Lorenz curve

Perfect equality line

Gini = A/(A+B)
Traffic Concentration and Lorenz Curves

No concentration

A

LAND

SEA

Port

Some concentration

B

High concentration

C

Cumulative Traffic

Cumulative facilities

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Lorenz Curves of the World’s 50 Largest Container Ports, Passenger Airports and Freight Airports, 2010
Lorenz Curves of the World's 50 Largest Container Ports, Passenger Airports and Freight Airports, 2010 (Greyscale)
World’s 50 Largest Container Ports, Passenger Airports and Freight Airports, 2010

[Map showing the locations of the 50 largest container ports, passenger airports, and freight airports worldwide, with markers indicating their size and activity levels.]
Calculation of the Index of Dissimilarity

\[ ID = 0.5 \sum_{i=1}^{N} |X_i - Y_i| = 0.325 \]

| X (% of terminals) | Y (% of traffic) | |X – Y| |
|--------------------|------------------|----------------|
| 0.10               | 0.25             | 0.15           |
| 0.10               | 0.20             | 0.15           |
| 0.10               | 0.15             | 0.05           |
| 0.10               | 0.10             | 0.00           |
| 0.10               | 0.08             | 0.02           |
| 0.10               | 0.07             | 0.03           |
| 0.10               | 0.05             | 0.05           |
| 0.10               | 0.05             | 0.05           |
| 0.10               | 0.03             | 0.07           |
| 0.10               | 0.02             | 0.08           |
| 1.0                | 1.0              | 0.65           |
### Calculation of the Gini Coefficient

The Gini coefficient is calculated as:

\[
G = 1 - \sum_{i=1}^{N} (\sigma Y_{i-1})(\sigma X_{i-1} - \sigma X_i) = 0.392
\]

<table>
<thead>
<tr>
<th>Y</th>
<th>(\sigma X) (Cumulative)</th>
<th>(\sigma Y) (Cumulative)</th>
<th>(\sigma Y_{i-1} + \sigma Y_i) (A)</th>
<th>(\sigma X_{i-1} - \sigma X_i) (B)</th>
<th>A*B</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.25</td>
<td>0.10</td>
<td>0.25</td>
<td>0.25</td>
<td>0.10</td>
<td>0.025</td>
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<tr>
<td>0.20</td>
<td>0.20</td>
<td>0.45</td>
<td>0.70</td>
<td>0.10</td>
<td>0.070</td>
</tr>
<tr>
<td>0.15</td>
<td>0.30</td>
<td>0.60</td>
<td>1.05</td>
<td>0.10</td>
<td>0.105</td>
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<tr>
<td>0.10</td>
<td>0.40</td>
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<td>1.30</td>
<td>0.10</td>
<td>0.130</td>
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<td>0.10</td>
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<td>0.07</td>
<td>0.60</td>
<td>0.85</td>
<td>1.63</td>
<td>0.10</td>
<td>0.163</td>
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<tr>
<td>0.05</td>
<td>0.70</td>
<td>0.90</td>
<td>1.75</td>
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<td>0.175</td>
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<tr>
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<td>1.85</td>
<td>0.10</td>
<td>0.185</td>
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<tr>
<td>0.03</td>
<td>0.90</td>
<td>0.98</td>
<td>1.93</td>
<td>0.10</td>
<td>0.193</td>
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<tr>
<td>0.02</td>
<td>1.00</td>
<td>1.00</td>
<td>1.98</td>
<td>0.10</td>
<td>0.198</td>
</tr>
<tr>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.392</td>
</tr>
</tbody>
</table>
Linear Programming
Basic Linear Programming Objective Function

\[ \text{Min: } \sum \sum g(Q(a,b)) \text{ subject to } Q(a,b) \geq 0 \]
Graphic Formulation of the Distribution Problem

Factories (Unit Supply)

W 700
X 600
Y 1000
Z 500

Distribution Costs

20 40 60 70 30 200

Distributors (Demand)
Graphic Solution of the Distribution Problem

Factories (Unit Supply)

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>400</td>
<td>1500</td>
<td>900</td>
</tr>
</tbody>
</table>

Distributors (Demand)

<table>
<thead>
<tr>
<th>W</th>
<th>X</th>
<th>Y</th>
<th>Z</th>
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</thead>
<tbody>
<tr>
<td>700</td>
<td>600</td>
<td>1000</td>
<td>500</td>
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</table>

Assignment

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>A to X</td>
<td>600</td>
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<tr>
<td>A to Y</td>
<td>400</td>
</tr>
<tr>
<td>A to Z</td>
<td>300</td>
</tr>
<tr>
<td>B to X</td>
<td>600</td>
</tr>
<tr>
<td>B to Y</td>
<td>400</td>
</tr>
<tr>
<td>B to Z</td>
<td>500</td>
</tr>
<tr>
<td>C to X</td>
<td>500</td>
</tr>
<tr>
<td>C to Y</td>
<td>600</td>
</tr>
<tr>
<td>C to Z</td>
<td>600</td>
</tr>
</tbody>
</table>
Spatial Interactions and the Gravity Model
Conditions for the Realization of a Spatial Interaction

Complementarity

Demand
Supply

Intervening Opportunity

Transferability

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Representation of a Movement as a Spatial Interaction

Movement

Centroid

Spatial Interaction

Centroid

$i \rightarrow j$

$T_{ij} = 50$

$\text{Vector}$

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Constructing an O/D Matrix

Spatial Interactions

O/D Matrix

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>Ti</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0</td>
<td>0</td>
<td>50</td>
<td>0</td>
<td>0</td>
<td>50</td>
</tr>
<tr>
<td>B</td>
<td>0</td>
<td>0</td>
<td>60</td>
<td>0</td>
<td>30</td>
<td>90</td>
</tr>
<tr>
<td>C</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>30</td>
<td>0</td>
<td>30</td>
</tr>
<tr>
<td>D</td>
<td>20</td>
<td>0</td>
<td>80</td>
<td>0</td>
<td>20</td>
<td>120</td>
</tr>
<tr>
<td>E</td>
<td>0</td>
<td>0</td>
<td>90</td>
<td>10</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>Tj</td>
<td>20</td>
<td>0</td>
<td>280</td>
<td>40</td>
<td>50</td>
<td>390</td>
</tr>
</tbody>
</table>
Relationship between Distance and Interactions

Distance (friction of)

T(B-A)  A → B  1
T(C-A)  A → C  2
T(D-A)  A → D  3

Interaction

Distance (friction of)
Three Basic Interaction Models

**General Formulation**

\[ T_{ij} = f \left( V_i, W_j, S_{ij} \right) \]

- **Gravity Model**
  \[ T_{ij} = \frac{V_i \times W_j}{S_{ij}^2} \]
  \[ T_{ji} = 10.9 \]
  \[ T_{ij} = 10.9 \]
  \[ S_{ij} = 8 \]

- **Potential Model**
  \[ T_i = \sum_j \frac{W_j}{S_{ij}^2} \]
  \[ T_i = 3.8 \]
  \[ 2.2 \]
  \[ 3 \]
  \[ 20 \]

- **Retail Model**
  \[ B_{ij} = \frac{S_{ij}}{1 + \frac{W_j}{V_i}} \]
  \[ B_{ij} = 4.9 \]
  \[ B_{ik} = 2.8 \]

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Application of an Elementary Spatial Interaction Equation

Elementary Formulation

\[ T_{ij} = k \frac{P_i P_j}{D_{ij}} \]

<table>
<thead>
<tr>
<th>W</th>
<th>X</th>
<th>Y</th>
<th>Z</th>
<th>Tj</th>
</tr>
</thead>
<tbody>
<tr>
<td>W</td>
<td>100,000</td>
<td>100,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>100,000</td>
<td>50,000</td>
<td>25,000</td>
<td>175,000</td>
</tr>
<tr>
<td>Y</td>
<td>50,000</td>
<td>25,000</td>
<td>25,000</td>
<td>50,000</td>
</tr>
<tr>
<td>Z</td>
<td>25,000</td>
<td>25,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tj</td>
<td>100,000</td>
<td>175,000</td>
<td>50,000</td>
<td>25,000</td>
</tr>
</tbody>
</table>

Centroid (i)  | Distance (D)  | Interaction (T) |
---|---|---|
Weight (P)  | Constant (k)  |
Application of a Simple Spatial Interaction Equation

Simple Formulation

$$T_{ij} = k \frac{P_i^{\alpha} P_j^{\beta}}{D_{ij}^\lambda}$$

<table>
<thead>
<tr>
<th></th>
<th>W</th>
<th>X</th>
<th>Y</th>
<th>Z</th>
<th>Ti</th>
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<tbody>
<tr>
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<td>71,378</td>
<td></td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>6,059</td>
<td>2,203</td>
<td>36</td>
<td>8,298</td>
<td></td>
</tr>
<tr>
<td>Y</td>
<td></td>
<td>19,420</td>
<td>19,420</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Z</td>
<td>153,893</td>
<td>153,893</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tj</td>
<td>6,059</td>
<td>244,692</td>
<td>2,203</td>
<td>36</td>
<td>252,990</td>
</tr>
</tbody>
</table>
Effects of beta, alpha and lambda on Spatial Interactions

Beta

- Distance vs. Interaction Level
- Lines represent different values of beta: 0.25, 0.5, 1, 1.5, 2

Alpha and Lambda

- Population vs. Interaction Level
- Curves show the relationship between population and interaction level for different values of alpha and lambda

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Chicago’s Beta Values for Air Transportation, 1949-1989
Modeling Transportation / Land Use Relationships (under construction)

Static Modeling

\[ p_i \]

\[ D_{ij} \]

Accessibility

System Modeling

Spatial Interactions

Origin

Destination

Distance decay

Modeling Interactions between Systems

Land Use

Spatial Interaction

Transport Network

Modeling in a Decision-taking Environment
Components of the Transportation / Land Use System

Transportation Network
- Traffic assignment models
- Transport capacity

Spatial Interactions
- Spatial interaction models
- Distance decay parameters
- Modal split

Land Use
- Economic base theory
- Location theory
- Traffic generation and attraction models

- Traffic generation and attraction models
- Economic base theory
- Location theory

Components of the Transportation / Land Use System

Transportation Network
- Traffic assignment models
- Transport capacity
Integrated Land Use and Transportation Package

Trip Generation

Trip Distribution

Modal Split

Traffic Assignment

Household location

Employment location

DRAM

EMPAL

Economic forecast

Friction of distance

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The Lowry Model
The Lowry Model

A. Basic employment by zone
B. Residential attractor; travel cost matrix
C. Population - employment ratios
D. Service activity rates
E. Service attractor weights; travel cost matrix

Input Data

1. Population
2. Employment
3. Work trips
4. Service demands

Output Data

Constraints

Convergence criterion met?

Is population density within allowable limits?

Are increments of service employment and population within limits?

Allocate increment of employees to zones of residence
Allocate increment of service employment to zones of workplace

Calculate increment of residential population
Calculate increment of population serving employment

Allocate increment of employees to zones of residence
Allocate increment of service employment to zones of workplace

1. Population
2. Employment
3. Work trips
4. Service demands
Evaluating Urban Transportation Quality
Maximum Traffic Volumes Per Level of Service (Passenger Cars Per Hour Per Lane)
Components of the MOBILE Emission Model

- Fleet Characteristics
- Driving Characteristics
- Atmospheric Conditions
- Fuel Characteristics
- Emissions
Market Areas Analysis
Market Profitability

A. **Threshold**

- **Range**
- **P** → **R(A)**

B. **Threshold**

- **Range**
- **P** → **R(B)**

© GTS
The Optimal Shape of a Market Area

A. 10 km
B. 20 km
C. 20 km
D. 17 km
E. © GTS
Non-Isotropic Conditions and the Shape of Market Areas

Isotropic Condition

Non-Isotropic Conditions

Modified Market Areas

Low
Average
High
Density
Road

© GTS
Supply, Demand and Equilibrium Price

Demand Curve

Supply Curve

Equilibrium Price

Price

Demand

Price

Supply

© GTS
Derivation of a Market Area from a Supply / Demand Equilibrium
Demand Cone
Conventional Distance Decay Curves for Retail Activities

Distance

Customers

Department Store / Superstore

Grocery Store

Convenience Store

E-commerce

Distance

© GTS
Hotelling’s Principle of Market Competition
Reilly’s Law

\[ M_{ab} = \frac{D_{ab}}{1 + \sqrt{P_b / P_a}} \]

\[ M_{ab} = \frac{75}{1 + \sqrt{100,000 / 250,000}} \]

\[ M_{ab} = 45.9 \]
### Reilly’s Law and Market Areas

- **Graph:**
  - Nodes: a, b, c, d, e
  - Distances:
    - a: 35 km
    - b: 30 km
    - c: 15 km
    - d: 20 km
    - e: 30 km

- **Table:**

<table>
<thead>
<tr>
<th>km</th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>d</th>
<th>e</th>
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<tbody>
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<td>21.4</td>
<td>19.7</td>
<td>9.4</td>
<td>17.3</td>
</tr>
<tr>
<td>b</td>
<td>14.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>c</td>
<td>10.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>d</td>
<td>5.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>e</td>
<td>12.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Huff’s Law

\[ P(C_a) = \frac{P_a}{D_a} \]

\[ P(C_b) = \frac{P_b}{D_b} \]

\[ P(C_a) = 0.71 \]

\[ P(C_b) = 0.29 \]

\[ P(C_a) = \frac{250,000}{37.5} \]

\[ P(C_a) = \frac{100,000}{37.5} \]

\[ P(C_a) = 0.71 \]
Reilly’s Law

\[ M_{ab} = \frac{D_{ab}}{1 + \sqrt{\frac{P_b}{P_a}}} \]

Huff’s Law

\[ P(C_a) = \frac{P_b}{\Sigma_a^n \frac{P_a}{D_{ab}}} \]

\[ P(C_a) = \frac{250,000/37.5}{250,000/37.5 + 100,000/37.5} = 0.71 \]
Location of Distribution Centers and Market Areas According to Response Time

- **7 days**
- **5 days**
- **3 days**
- **Next Day**
GIS Methods to Estimate Market Areas

**Concentric Circles**

Store

- 5 min.
- 10 min.
- 15 min.

**Share by Polygon**

- 5 min.
- 10 min.
- 15 min.
- 20 min.

**Star Map**

**Spatial Smoothing**

**Transport Distance**

- 5 min.
- 10 min.
- 15 min.
- 20 min.

**Manual Polygon**
Cost / Benefit Analysis
Inaccuracy of Transportation Project Cost Estimates by Type of Project

- Rail: 38.4%
- Bridges and tunnels: 62.4%
- Roads: 29.9%
**Environmental Practices**

- **Match activities with environmental components**
  - What are the environmental components the logistics activities of the firm?

- **Link environmental components with regulations**
  - What is the regulatory standing of each environmental component?

- **Assess risks, impacts and responsibilities**
  - What are the risks of doing nothing? What are the rewards of improvements?

- **Identify environmental issues to be addressed**
  - What are the most important issues to be addressed and their priority?

- **Develop commercial strategies**
  - Which improvements can be implemented in management and operations?

- **Introduce best practices**
  - How improvements can be implemented?

- **Undertake monitoring and auditing**
  - What is the effectiveness of the best practices and which adjustments are required?
The Implementation of an Environmental Management System

### Direct Environmental Aspects
- Air emissions
- Water emissions
- Waste
- Material use (resources and raw materials)
- Local emissions (noise, odors, vibrations)
- Land use
- Risks of environmental accidents

### Indirect Environmental Aspects
- Product life cycle
- Capital investments
- Insurance
- Management and planning process
- Environmental management of suppliers

### Process
- General requirements
- Environmental policy
- Planning
- Implementation and operation

### Internal Audit and Review

### Environmental Statement

### Verification and Validation

### Registration
Environmental Management System for Ports and Maritime Shipping