Economy of scale and the role of publicly available congestion information for local delivery industry: Agent-based simulation approach

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Outline

1. Background and motivation
2. Overview of study framework
3. Simulation approach
4. Findings
5. Challenges
Real-time/advanced travel information system

In the U.S.

• Travel time information collected from:
detectors, cameras, satellite imaging, cell phones, GPS, etc.

• Distributed via publicly accessible means (radio/TV, Internet, etc.) – direct provision by the government or outsourcing (e.g. Tele Atlas)

• Growth of customized travel information sent via text messages and e-mails (e.g. NAVTEQ-Traffic.com), Westwood One – SmartTraveler, etc.)

“predictive traffic trends, vehicle speeds, congestion levels, travel times, and delay times delivered via Web, wireless device, radio, television, and in-vehicle navigation systems.”
Motivation

Broad questions:
• Where is the travel information business heading?
• Is there a justification for non-exclusive ("public") provision of travel information?
• Are there positive externalities that are overlooked?

Hypothesis:
Publicly available travel information (or affordable equivalent in the private sector) benefits smaller goods delivery firms by lowering the market entry barrier.
“Peddle run" system commonly used in the U.S. by retail chains

- Supplier DC
- Distribution Center (DC)
- Supplier
- Supplier
- Urban Area
- Store
- Store
- Store
“Single-stage” system commonly used by parcel delivery/pick-up services
For each firm ...
Economy of scale at work
- Hypothesis w/o traffic info -

Exploratory examination of an entry into a hypothetical urban area by delivery service firms of different sizes
⇒ Compare efficiency for “with” vs. “without” information cases
Overview of Research

Expected outcomes:
Large firms have shorter learning period (lower entry cost) ⇒ smaller benefit from travel time information ⇒ publicly available traffic information lower entry barrier for smaller firms

However, magnitude of benefit may depend on various factors:
• Sizes of competing firms
• Environment (network configuration, congestion level, link travel time variation)

Build an exploratory simulation model of goods delivery to examine the hypothesis under different environment
Agent-based simulation

Agent-based model (ABM)

- Derived from complex systems perspective (i.e. emergence of pattern from behaviors and interactions of numerous intelligent agents)
- Behaviors are controlled by a set of rules defined for each agent.
- Generally, agents do not act according to global rules.
- Not necessarily suited for forecasting
- Flexible platform to simulate wide-ranging (especially emergent) phenomena
- Key components of simulation: agent, environment
Taxonomy of ABM

AGENT

<table>
<thead>
<tr>
<th>Designed</th>
<th>Analyzed</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Model description</td>
<td>- Model description</td>
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<tr>
<td></td>
<td>Experimental</td>
</tr>
<tr>
<td>- Purpose</td>
<td>- Purpose</td>
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<tr>
<td>Discovery of relationship</td>
<td>Laboratory experiment</td>
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<tr>
<td>- Verification</td>
<td>- Verification</td>
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<tr>
<td>Theoretical comparison</td>
<td>Repetition</td>
</tr>
</tbody>
</table>

Considerations:
- Data availability
- Resource limitations
- Level of complexity
- System required

- Model description
- Historical
- Purpose
- Explanation
- Verification
- Qualitative: goodness of fit

- Model description
- Empirical
- Purpose
- Prediction
- Verification
- Quantitative: goodness of fit

- Data availability
- Resource limitations
- Level of complexity
- System required
Simulation Environment

- City: 18 mile x 18 mile
- Land use: Road, commercial, residential located in 100mx100m Patches
- Land use: Houses & jobs randomly allocated
- Congestion from background traffic
Delivery tour simulation

- Customers are generated randomly across the city
- There is a product differentiation between small, medium, and large firms (i.e. no competition for customers)
- Each tour covers 4 customers
- Firms dispatch trucks from the terminal
  - Large: 6 tours/cycle
  - Medium: 4 tours/cycle
  - Small: 2 tours/cycle
- At the end of a cycle, firms update their knowledge of travel time for each link based on the mean of the sample (from the past deliveries)
NetLogo programming environment (Wilenski, 1999)
Background traffic

• Congestion generated by (shortest-path) home-to-work trips made by the population

• Degree of congestion = f(population, network size, link capacity)
### Environment

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Values tested</th>
</tr>
</thead>
<tbody>
<tr>
<td>Network size</td>
<td>8x8, 15x15, 20x20</td>
</tr>
<tr>
<td>Population</td>
<td>6000, 7000, 8000, 9000, 10000</td>
</tr>
<tr>
<td>Freeway orientation</td>
<td>Diagonal, parallel</td>
</tr>
<tr>
<td>Spacing between ramps</td>
<td>10, 16, 20</td>
</tr>
<tr>
<td>Freeway link capacity</td>
<td>400, 500, 600, 700, 800</td>
</tr>
<tr>
<td>Street link capacity</td>
<td>75, 100, 125, 150</td>
</tr>
<tr>
<td>Stops per delivery tour</td>
<td>3, 4</td>
</tr>
</tbody>
</table>

Selection criteria:
- Link V/C ratio must be realistic
- Effect on simulation outcome
- Computation time

Values eventually used in scenario simulations
Simulation scenarios

Variables: Congestion level, travel time variation, real-time traffic information

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Population</th>
<th>Expwy capacity</th>
<th>Local capacity</th>
<th>Travel time variation factor</th>
<th>w/ traffic info?</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7000</td>
<td>500</td>
<td>100</td>
<td>0.5</td>
<td>Y</td>
</tr>
<tr>
<td>2</td>
<td>7000</td>
<td>500</td>
<td>100</td>
<td>0.5</td>
<td>N</td>
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<tr>
<td>3</td>
<td>7000</td>
<td>500</td>
<td>100</td>
<td>0.3</td>
<td>Y</td>
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<tr>
<td>4</td>
<td>7000</td>
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<tr>
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<td>8000</td>
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<td>N</td>
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<tr>
<td>7</td>
<td>6000</td>
<td>500</td>
<td>100</td>
<td>0.3</td>
<td>Y</td>
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<tr>
<td>8</td>
<td>6000</td>
<td>500</td>
<td>100</td>
<td>0.3</td>
<td>N</td>
</tr>
</tbody>
</table>
Adding random delay to link travel time

• For a link $i$,

$$TT_i = \max (\text{Variable congested time}, \text{Free-flow time})$$

Variable congested time $= \sim N(\mu = \text{Loaded travel time}, \sigma = \text{variability factor} \times \text{loaded travel time})$

*Variability factors of 0.3 and 0.5 were used*

e.g. For a link with loaded travel time $= 5$ min

$$\text{Variable congested time} = \sim N(5, 0.3 \times 5)$$
Simulation flow chart

Setup Environment

Create background traffic

Add random delay to each link

Call a truck company

Generate customers

Delivery tour

Store traffic information

5 runs each for 8 scenarios

70 cycles

More delivery to simulate?

Yes

No
Scenario 1 (Moderate congestion, 0.5 variability factor, \textit{with info.})

![Graph showing cumulative no. of cycles vs. total travel time per tour for different simulations.]

**Small firm**
Scenario 2 (Moderate congestion, 0.5 variability factor, without info.)

Total travel time per tour (5pt. Moving avg.)

Cumulative no. of cycles

Equilibrium condition

40 cycles

Small firm
Scenario 1 (Moderate congestion, 0.5 variability factor, **with info.**)
Scenario 2 (Moderate congestion, 0.5 variability factor, **without info**)

Total travel time per tour (5pt. Moving avg.)

Cumulative no. of cycles

Large firm
Scenario 4 (Moderate congestion, 0.3 variability factor, without info)
Scenario 4 (Moderate congestion, 0.3 variability factor, without info)

Large firm
Scenario 6 (Severe congestion, 0.3 variability factor, without info)

Small firm
Scenario 6 (Severe congestion, 0.3 variability factor, without info)

Large firm
Scenario 8 (Light congestion, 0.3 variability factor, without info)

Small firm
Scenario 8 (Light congestion, 0.3 variability factor, without info)
Equilibrium time/tour

Scenario 1&2 (Moderate congestion, 0.5 variability factor)
Scenario 3&4 (Moderate congestion, 0.3 variability factor)
Scenario 5&6 (Severe congestion, 0.3 variability factor)
Scenario 7&8 (Light congestion, 0.3 variability factor)
Comparison of “without info” scenarios
- Small firm -

**SC 2**
- Moderate congestion
- High variability

**SC 4**
- Moderate congestion
- Low variability

**SC 6**
- High congestion
- Low variability

**SC 8**
- Low congestion
- Low variability
Calculation of costs

<table>
<thead>
<tr>
<th>Cost of no info.</th>
<th>40</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of simulation cycles</td>
<td></td>
</tr>
</tbody>
</table>

Cost of delivery per cycle

- Learning cost
- W/O info. cost
- W/ info. cost
- Equilibrium cost

$ per mile data from Transport Canada, fuel prices, fuel economy for 2-axle, single unit van
### Benefit of Travel Time Information (per tour)

**(Avg. of 5 simulation runs)**

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Median V/C</th>
<th>Var. Factor</th>
<th>Learning cost</th>
<th>Permanent</th>
<th>Learning cost</th>
<th>Permanent</th>
<th>Learning cost</th>
<th>Permanent</th>
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<tbody>
<tr>
<td>1 &amp; 2</td>
<td>0.97</td>
<td>0.5</td>
<td>5.7</td>
<td>13.4</td>
<td>1.7</td>
<td>14.1</td>
<td>2.3</td>
<td>10.0</td>
</tr>
<tr>
<td>3 &amp; 4</td>
<td>0.97</td>
<td>0.3</td>
<td>4.0</td>
<td>5.9</td>
<td>1.3</td>
<td>8.3</td>
<td>1.2</td>
<td>7.9</td>
</tr>
<tr>
<td>5 &amp; 6</td>
<td>1.21</td>
<td>0.3</td>
<td>7.0</td>
<td>9.8</td>
<td>3.4</td>
<td>6.4</td>
<td>1.1</td>
<td>10.5</td>
</tr>
<tr>
<td>7 &amp; 8</td>
<td>0.76</td>
<td>0.3</td>
<td>3.8</td>
<td>11.1</td>
<td>1.6</td>
<td>4.9</td>
<td>1.8</td>
<td>5.8</td>
</tr>
</tbody>
</table>

Scenario 1 & 2 (Moderate congestion, 0.5 variability factor)
Scenario 3 & 4 (Moderate congestion, 0.3 variability factor)
Scenario 5 & 6 (Severe congestion, 0.3 variability factor)
Scenario 7 & 8 (Light congestion, 0.3 variability factor)
Learning Costs Comparisons

Scenario 1&2 (Moderate congestion, 0.5 variability factor)
Scenario 3&4 (Moderate congestion, 0.3 variability factor)
Scenario 5&6 (Severe congestion, 0.3 variability factor)
Scenario 7&8 (Light congestion, 0.3 variability factor)
Conclusions

- Simulation of “learning” traffic conditions was conducted
- Benefit of traffic information increases with the level of congestion & variability
- Savings from knowing real link travel time (as opposed to estimating) is often greater than the saving in learning cost
- Without publicly available traffic information…
  - For medium or large firms, learning cost is negligible
  - For small firm, learning cost can be an issue (up to 4.5% of total cost)
- Simulation-to-simulation variability in the benefit is large in some cases
Future work

- Stochastic decision by the trucks
- More simulation runs
- Variations in terminal locations
- Better optimization algorithm
- Simulation of congestion caused by incident
- Larger network
- Real-time (during the tour) updating of traffic data