Driven by Time Windows: Predictive Strategies for Real-time Pick-up and Delivery Operations

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Industry Workshop: The Fight for the Last Mile
Northwestern University Transportation Center Oct 29th, 2013
Outline

• Part I: Background
  – Industry Overview
  – Innovations
  – Challenges

• Part II: Real Time Urban Freight Distribution
  – Research Problem
  – Modeling Framework
  – Large Network Application

• Part III: Closing Remarks
PART I: BACKGROUND
Growth Engine: E-Commerce

- Global ecommerce sales passed $1 trillion in 2012.

Top 5 Countries, Ranked by B2C Ecommerce Sales 2012-2013 ($ billions)

- **Japan**: 112.78 (2011), 127.82 (2012), 140.35 (2013)
- **Germany**: 38.08 (2011), 47.00 (2012), 53.00 (2013)

Source: eMarketer
Industries

- Amazon.com
- eBay
- Barnes & Noble
- Walmart
- Target
- Best Buy
- Apple
- Macy's
- Petco
- Gap
Frozen Vegetables
Handy, convenient and as nutritious as fresh.

Frozen Specials

Peapod Frozen Fruit
16 oz
On Sale: 2 for $5

Tyson Any'tizers & More
25 - 32 oz
On Sale: $8.99

Hot Buy! Blue Bunny Ice Cream
1.75 quart
On Sale: 2 for $7

Recommendations For You
## Delivery & Pick-up Times

**Service Fees**
- Delivery Fees
- Pick-up Fee

**Order for Delivery**

**Order for Pick-up**

### Your Delivery Address
Your Delivery Address will show up here once you check out and complete registration.

### Pick-up Fee
FREE No Pick-up Fee

**PICK UP YOUR GROCERIES FREE. NO MINIMUM.**

Pick-up your groceries in as little as 5 minutes.

- Learn More

### VALUE DAYS
Save You Money

**MON 28 October**

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<td>8:00 PM - 10:00 PM</td>
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Service Evolution I

Google Shopping Express

Get unlimited same-day delivery*

We're piloting in the San Francisco Bay Area

Sign up to become a tester

* Some restrictions may apply
Service Revolution II

How it works

Find what you need
Browse local stores online in one place

Select a delivery window
Provide delivery instructions for our couriers

Get it delivered today
Live life on your schedule

Brands:
- Target
- Raley's
- Walgreens
- Blue Bottle Coffee Co.
- American Eagle Outfitters
- Palo Alto Sport Shop & ToyWorld
- Staples
- Toys”R”Us
- Babies”R”Us
- Office Depot
Big Players’ Strategy

• Closely guarded: ahead of the curve vs. wait & see

• UPS and FedEx outsource part of their last mile delivery to USPS, allowing them to maximize the efficiency of their operations.
# Amazon Locker

## Amazon Locker Search Results

**Results for “Seattle”**

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<td>Amazon Locker - Aurora, 700 5th Ave, Located in Seattle Muni Tower, Seattle WA 98104-5056</td>
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<td>Amazon Locker - Spruce, 1201 1st Ave, Located in Harbor Steps NE TWR, Seattle WA 98101-2074</td>
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<td>4</td>
<td>Amazon Locker - Victor, 2121 6th Ave, Located in Via6, Seattle WA 98121-2513</td>
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<td>5</td>
<td>Amazon Locker - Pearl, 1522 E Madison St, Located in 7-Eleven, Seattle WA 98122-4014</td>
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<td>6</td>
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<td>Mon-Sun: 07:00 - 22:00</td>
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<tr>
<td>7</td>
<td>Amazon Locker - Ruby, 333 Boren Ave N, Located in Amazon Campus, Seattle WA 98109-5306</td>
<td>Mon-Fri: 07:00 - 00:30, Sat-Sun: 08:00 - 00:30</td>
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<tr>
<td>8</td>
<td>Amazon Locker - Morns, 103 15th Ave E, Located in 7-Eleven, Seattle WA 98112-5209</td>
<td>Open 24hrs</td>
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</table>

*Restricted Access*: This locker is available only to those with authorized access to this building.

- I confirm that I have access to this location [Learn more](Lea.../Access).

![Amazon Locker Image](image-url)
Innovative Delivery Services

Amsterdam

Berlin

UK

Zurich
Challenges

• Urban Congestion
• Disruptive Events on Road Network
• Vehicle size and Delivery Time
  Regulations
• Limited Physical Parking
• Loading and Vehicle Utilization
  Efficiency
• Customer Satisfaction
PART II:
REAL TIME URBAN FREIGHT DISTRIBUTION
Research Problem
Research Problem II
Research Problem III
Real-Time Urban Freight Distribution

- Customer Requests
  - All commodities are heterogeneous *(impossible to rearrange delivery requests once vehicles are out of depot)*
  - *A Priori* requests *(known before operation)*: a mixture of pickup and delivery requests
  - Intermediate Requests *(revealed during operation)*: pickup only
  - All pickup loads are *brought back to depot*

- Prevailing and anticipated traffic information
Key Features of the Problem

• **Multiple sources of uncertainty:**
  – Customer request arrival time;
  – Customer request location;
  – Customer request load (size and type).

• **Information**
  – Detailed urban road networks (signals, one-way streets, etc.);
  – Prevailing traffic information;
  – Predicted traffic information.
Modeling Framework

A Priori Information:
- Urban Road Network
- Historical Time-Dependent Travel Time
- Vehicle Fleet Information
- A priori Customer Requests

A Priori Routing Planner

Initial Routing Plan

DTA Simulator: DYNASMART

State Estimation Module
State Prediction Module

Dynamic Service Network
- Vehicle location and status;
- All unserved customer locations;
- Time-dependent shortest paths between all unserved customer sites and path costs

Real-Time Information:
- Intermediate Requests
- Traffic Events: work zones, weather, incidents, etc.

Online Booking Processor

Online Re-Routing Planner

Updated Routing Plan
DTA Model & Simulator

• Emulates the actual traffic flow propagation and provides predicted traffic conditions.
• Models various traffic events, e.g. accidents, lane closures, etc.
• Loads, simulates and tracks individual vehicle tour on a realistic representation of road network to assist evaluating the routing designs.
Online Re-Routing: arrival of new loads

Historical Travel Time Data Base

New Pickup: 6 & 7

Route 3

Route 2

Route 1

Deliver Request

Pickup Request
Online Re-Routing: arrival of new information

Updated Travel Time Data Base

Anticipated Traffic Information

Route 3

Route 2

Route 1

Deliver Request

Pickup Request
Online Re-Routing: combination of the two

Updated Travel Time Data Base

Anticipated Traffic Information
New Pickup: 6 & 7

Route 3
Route 2
Route 1

Deliver Request
Pickup Request
Chicago Network and Settings

Network Size:
- Nodes: 1,578
- Links: 4,805
- TAZs: 218
- OD: 1.16 million vehicles (6am-8pm)

General Settings:
- Operational Hour: 8am – 6pm
- Customer Base: 500
- Time Window: 3hrs
- TD Travel Time Info.: 10min resolution

<table>
<thead>
<tr>
<th>Instances</th>
<th># of A Priori Requests</th>
<th># of Intermediate Requests</th>
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<td>250</td>
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<tr>
<td>25aPriori</td>
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## Results: Normal Day Operations

<table>
<thead>
<tr>
<th></th>
<th>totDuration ¹ (hr)</th>
<th>totTravelTime (hr)</th>
<th>totDistance (mile)</th>
<th>#. Of Veh</th>
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<tr>
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<td>38.13</td>
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<td>75aPriori</td>
<td>171.44</td>
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<td>25aPriori</td>
<td>173.70</td>
<td>56.87</td>
<td>2150.21</td>
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</table>

¹: totDuration includes travel time, service time and waiting time for all routes.
Vehicle Utilization: Normal Day

- Work Hour per Vehicle = \( \text{totDuration} / \text{no. of Vehicle} \)
- Number of Customer per Vehicle = \( \text{totCustomer} / \text{no. of Vehicle} \)
Evaluation under Snowy Day

• Weather Data: Chicago, Feb. 26th, 2013
• Performance Measures from the Simulator:
  – Simulated total travel time;
  – Planned travel time (normal day);
  – Planned number of customers (normal day);
  – Number of unserved customers under snow;
  – Number of violations of time window;
  – Total late penalty due to time-window violations.
75a Priori: Heavy Snow

- Planned # of Customers: 309
- Unserved Customers: 95
- # of Time Window Violations: 79
- Late Penalties (min): 9,430

- Planned # of Customers: 191
- # of Time Window Violations: 34
- Late Penalties (min): 2,072.48

Graph showing:
- Travel Time (min) for Simulated vs. Planned
- Returned Vehicles
- On-Route Vehicles
50a Priori: Heavy Snow

Planned # of Customers: 388
Unserved Customers: 60
# of Time Window Violations: 162
Late Penalties (min): 13968.7

# of Veh. Returned Depot: 6
# of Veh. Still On-Route: 19

Planned # of Customers: 112
# of Time Window Violations: 38
Late Penalties (min): 1906.36

Travel Time (min)

simulated Travel Time
Planned Travel Time

Returned Vehicles
On-Route Vehicles
25a Priori: Heavy Snow

- Planned # of Customers: 330
- Unserved Customers: 98
- # of Time Window Violations: 98
- Late Penalties (min): 8396.80

- Planned # of Customers: 170
- # of Time Window Violations: 88
- Late Penalties (min): 7815.45

Diagram:
- # of Veh. Returned Depot: 9
- # of Veh. Still On-Route: 17

Graph:
- Travel Time (min)
  - Simulated Travel Time
  - Planned Travel Time
  - Returned Vehicles
  - On-Route Vehicles
Solutions with Perfect Predicted Information

**Total Duration (hour)**

- **25aPriori**
- **50aPriori**
- **75aPriori**

**Total Travel Time (hour)**

- **25aPriori**
- **50aPriori**
- **75aPriori**
Solutions with Perfect Predicted Information I

### Total Travel Distance (mile)

- **25aPriori**: 2300, 2450, 2600
- **50aPriori**: 2300, 2450, 2600
- **75aPriori**: 2300, 2450, 2600

### Number of Vehicles

- **25aPriori**: 23, 25, 26
- **50aPriori**: 23, 25, 26
- **75aPriori**: 23, 25, 26
Potential Benefits

• Improve information utilization.
• Reduce operation cost.
• Increase customer satisfaction.
• Evaluate the efficiency and effectiveness of city logistics services.
PART III:
CLOSING REMARKS
Closing Remarks

• Showcases value of predictive analytics in urban routing for time-sensitive pick-up and delivery
  – Traffic prediction unique feature
  – New effective real-time routing procedures with new demands and information

• Efficiency tool as competitive pressures increase in fight for last mile

• Next:
  – Focus on acceptance/rejection decision; revenue management and pricing
  – Field test with actual data