Last-Mile Logistics

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## TOP 3 CONSUMER WANTS

<table>
<thead>
<tr>
<th>Description</th>
<th>Percentage</th>
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<tbody>
<tr>
<td>More specific delivery time slots</td>
<td>45%</td>
</tr>
<tr>
<td>Sunday deliveries</td>
<td>23%</td>
</tr>
<tr>
<td>Same-day delivery</td>
<td>19%</td>
</tr>
</tbody>
</table>

Source: Mintel E-Commerce UK 2014

**Comment:** Retailers need to offer delivery choice to keep customers happy

Source: Retail Week

**Tesco takes on Amazon with same-day delivery across UK**

Source: BBC

**The Connected Business**

*Delivery charges cost online retailers dear*

Source: MarketWatch

**Amazon earnings fail to deliver because of delivery costs**

Published: Jan 29, 2015
Agenda

1. Methodological innovations
2. Technological innovations
3. Business model innovations
Methodological Innovations

Order booking  Order processing  Order delivery

Demand Management  Same-Day Routing
Demand Management – Problem Outline

Delivery Cost

Customer segments (e.g., by location)

What time would you like your delivery?
Please select a delivery slot from the calendar.

Time

Delivery Day

<table>
<thead>
<tr>
<th>May 2 – 8</th>
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<tbody>
<tr>
<td>Apr 28 - May 1</td>
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5
Optimal Control & Vehicle Routing Problem

\[ V_t(x_t) = \max_{d \in D} \sum_{j \in J} \lambda P_j(d) \left[ r + d_j - \left( V_{t+1}(x_t) - V_{t+1}(x_t + 1_j) \right) \right] + V_{t+1}(x_t) \quad \forall x_t, t \]

\[ V_{T+1}(x_T) = -C(x_T) \quad \forall x_T \]

- **Stage** \( t \): small time period
- **State** \( x_t \): accepted orders until time period \( t \)
- **Decision** \( d \): delivery charges, discounts and/or other incentives, or slot availability
- **\( J \)**: Set of delivery time slots
- **\( \lambda \)**: customer arrival rate
- **\( P_j(d) \)**: Probability of customer selecting delivery time slot \( j \)
- **\( r \)**: order profit before delivery cost
Optimal Control & Vehicle Routing Problem

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Opportunity cost
Optimal Control & Vehicle Routing Problem

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Delivery cost: Vehicle routing problem with time windows
Optimal Control & Vehicle Routing Problem

\[ V_t(x_t) = \max_{d \in D} \sum_{j \in J} \lambda P_j(d) \left[ r + d_j - \left( V_{t+1}(x_t) - V_{t+1}(x_t + 1_j) \right) \right] + V_{t+1}(x_t) \quad \forall x_t, t \]

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Curse of dimensionality
Optimal Control & Vehicle Routing Problem

Non-linear (choice-based) price optimization

\[ V_t(x_t) = \max_{d \in D} \sum_{j \in J} \lambda P_j(d) \left[ r + d_j - \left( V_{t+1}(x_t) - V_{t+1}(x_t + 1_j) \right) \right] + V_{t+1}(x_t) \quad \forall x_t, t \]

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NON-LINEAR (choice-based) PRICE OPTIMIZATION
Typical Solution Approach

\[
V_t(x_t) = \max_{d \in D} \sum_{j \in J} \lambda P_j(d) \left[ r + d_j - \left( V_{t+1}(x_t) - V_{t+1}(x_t + 1_j) \right) \right] + V_{t+1}(x_t) \quad \forall x_t, t
\]

\[
V_{T+1}(x_T) = -C(x_T) \quad \forall x_T
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Offline
\[
V_t(x) \approx \hat{V}_t(x)
\]

Opportunity cost estimates

Online
Control policy
Typical Solution Approach

\[ V_t(x_t) = \max_{d \in D} \sum_{j \in J} \lambda P_j(d) \left[ r + d_j - \left( V_{t+1}(x_t) - V_{t+1}(x_t + 1_j) \right) \right] + V_{t+1}(x_t) \quad \forall x_t, t \]

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**Offline**

\[ V_t(x) \approx \hat{V}_t(x) \]

**Online**

Opportunity cost estimates

Control policy
Online Problem: Choice-Based Pricing Policy

\[
\max \sum_{j \in J} P_j(d)[d_j + r - o_{jt}(x_t)] \\
\text{s.t. } d \in D
\]

Difficulty depends on choice model and feasible region \(D\)

Notation:

\(o_{jt}(x_t)\): opportunity cost of accepting order in time slot \(j\) given previously accepted orders \(x_t\) up to time \(t\)

\(D\): feasible controls
Example 1: Pricing Policy under MNL on Continuous Support

**Problem:**

\[
\max \sum_{j \in J} P_j(d) d_j
\]

s.t. \( d \in \{\mathbb{R} \cup \infty\}^{|J|} \)

where

\[
P_j(d) = \frac{\exp(\beta_j - \beta d j)}{\sum_{k \in J} \exp(\beta_k - \beta d k) + \exp(\beta_0)}
\]

**Result:**

- 1-1 mapping between price space and sales probability space

- Objective in terms of probabilities is concave

- Obtain optimal prices by standard Newton root search

Example 2: Pricing under MNL on Finite Price Set

**Problem:**

\[
\max \sum_{j \in S} P_j(S)d_j \\
\text{s.t.} \quad S \in \left\{ S' \subset J : \sum_{j \in J} a_{ij} 1_{j \in S'} \leq b_i \ \forall i \right\} \\
\text{where } A = [a_{ij}]_{i,j} \text{ unimodular,}
\]

\[
P_j(S) = \frac{v_j}{\sum_{k \in S} v_k + v_0}.
\]

**Result:** Equivalent LP

\[
\max \sum_{j \in J} P_jd_j \\
\text{s.t.} \quad \sum_{j \in J} P_j + P_0 = 1 \\
\sum_{j \in J} a_{ij} \frac{P_j}{v_j} - b_i \frac{P_0}{v_0} \leq 0 \quad \forall i \\
0 \leq \frac{P_j}{v_j} \leq P_0 \quad \forall j
\]

Example 2: Pricing under MNL on Finite Price Set

**Problem:**
\[
\max_{S} \sum_{j \in S} P_j(S) d_j \\
\text{s.t. } S \in \left\{ \sum_{j \in S} \sum_{i \in J} a_{ij} } \right\} \\
\text{where } A = (a_{ij})_{ij} \\
\]

\[
P_j(S) = \frac{v_j}{\sum_{k \in S} v_k + v_0}.
\]

**Result:** Equivalent LP
\[
\max_{p} \sum_{j \in J} P_j d_j \\
\text{s.t. } \sum_{j \in J} S_j = 1, \forall j \\
0 \leq \frac{P_j}{v_j} \leq P_0, \forall j
\]

**Further info:**
Strauss, Klein and Steinhardt.
*A Review of Choice-Based Revenue Management: Theory and Models*
Working paper, University of Warwick, August 2017

**Source:** Davis J, Gallego G and Topaloglu H. Assortment Planning under the Multinomial Logit Model with Totally Unimodular Constraint Structures.
Cornell University, Working Paper (April 2013)
Offline Problem: Opportunity Cost Estimation

Example: Approximate Dynamic Programming Approach

- Decompose delivery area using continuous clustering-first, routing-second approach

- Optimize parameters $\gamma$ and $\theta$ of value function approximation for each area independently:

  $$V_t(x) \approx \hat{V}_t(x) = \gamma_0 - \sum_{j} \gamma_j x_j + (T + 1 - t)\theta$$

Then, opportunity cost estimates are given by

$$V_{t+1}(x_t) - V_{t+1}(x_t + 1_j) \approx \gamma_j$$

Current State-of-the-Art: Order in Advance

Focus on demand management

- Low
  - Slot availability control
  - Slot price control
  - Accept/deny requests

Focus on vehicle routing

- High
  - Agatz et al. (2011)
  - Campbell & Campbell (2014)
  - Ehmke & Campbell (2014)
  - Campbell & Savelsbergh (2006)

- Low
  - Klein et al. (2016b)
  - Klein et al. (2016a)
  - Yang et al. (2016)
  - Yang & Strauss (2017)
  - Asdemir et al. (2009)

Opportunity?

Asdemir et al. (2009)
Current State-of-the-Art: Same-Day

<table>
<thead>
<tr>
<th>Focus on vehicle routing</th>
<th>Focus on demand management</th>
</tr>
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<tbody>
<tr>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>High</td>
<td>High</td>
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- Arslan et al. (2017), Voccia et al. (2017), Ulmer et al. (2016), Klapp et al. (2016a,b), Reyes et al. (2016), Cattaruzza et al. (2016), Archetti et al. (2015), Azi et al. (2012)
- Ulmer (2017)
Agenda

1. Methodological innovations

2. Technological innovations

3. Business model innovations
Technological Innovations

Trucks & Drones

Basic trade-off:
- Speed: drone >> truck
- Capacity & range: drone << truck

Problem designs:
- Single/multiple drones per truck
- Drones departing from truck and/or depots
- Various restrictions on launch, landing and recover locations
- Same-day delivery
- Discrete TSP-based/continuous approximation

Agenda

1. Methodological innovations

2. Technological innovations

3. Business model innovations
business model innovations & research opportunities

flexible (crowdsourced) drivers

sharing economy (shipping alliance)
Selected Literature – Demand Management for the Last Mile

Selected Literature – Same-Day Deliveries

- Ulmer, MW (2017). Dynamic Pricing for Same-Day Delivery Routing, TU Braunschweig, Germany
Selected Literature – Truck & Drone


Selected Literature – Crowdshipping/Shipping Alliances


- Devari et al. (2017) Crowdsourcing the last mile delivery of online orders by exploiting the social networks of retail store customers, Transportation Research Part E 105 (2017) 105-122


THANK YOU

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