Optimization of Last Mile Delivery Using Shared Locker Systems

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Introduction

E-commerce Growth

• Global urban population increase
• Growth of business-to-consumer (B2C) e-commerce

- In the US:
  • 16 Billion+ packages
  • 16% of US retail sale is on-line
  • 82% of Americans are e-shoppers
Introduction

Package Delivery Growth and Challenges

- Online transactions boom the economy, but also challenge the urban logistics:
  - 70% increase in goods delivery vehicles in the UK
  - Steady increase of goods delivery vehicles kilometers
  - Greater occupation of curbside space/lane and disturbance of (especially nonmotorized) traffic
  - $1.1 Billion market loss
Introduction

High cost associated with home deliveries

• Home is the most preferred delivery mode (67% in 2015 by UPS)
• Home-attended deliveries are associated with high operational cost (due to failed deliveries)
• Innovative delivery modes:
  – collection and delivery point (CDP)
  – shared lockers (SL)
  – delivery with robots/drones
Introduction

Problem Description

• Given
  – Customers demand points
  – Network
  – Candidate shared lockers

• Determine
  – Optimal locations of shared lockers
  – Optimal delivery truck routes (dedicated and/or blended)
  – Optimal customer–locker assignment

• Objective- minimizing total system cost
Optimization Method

Objective Function

- Customers pick-up trip cost discounted using parameter $\gamma$

\[
\text{minimize} \quad \text{Company's Delivery Cost} + (\gamma - 1) \sum \text{Customer's Pick-up Cost} \quad \text{"Saving"} + \text{Company's Lockers Cost}
\]

- First Term: Delivery truck cost (including virtual visits)
- Second Term: Customer pick-up cost savings
- Third Term: Shared lockers’ capital cost
Optimization Method

Constraints

Flow conservation constraints
\[
\sum_{i \in \mathcal{E}} x_{ijv} = \sum_{j \in \mathcal{C}} x_{dju} = 1, \quad \forall v \in \mathcal{V}
\]

Sub-tour elimination constraints
\[
\sum_{i \in S} x_{ijv} - \sum_{j \in S} y_{ijv} \leq |S| - 1, \quad \forall S \subseteq \mathcal{E}, \forall v \in \mathcal{V}
\]

Truck capacity constraints
\[
\sum_{i \in \mathcal{E}} x_{ijv} + \sum_{j \in \mathcal{C}} y_{ijv} \leq \sum_{k \in \mathcal{S}} D_k y_{kju} \leq C_k, \quad \forall v \in \mathcal{V}, \forall k \in \mathcal{S}
\]

Locker capacity constraints
\[
\sum_{i \in \mathcal{C}} y_{ijv} \leq \sum_{j \in \mathcal{S}} y_{ijv} \leq |\mathcal{C}|, \quad \forall v \in \mathcal{V}
\]

Variable definitions
\[
\begin{align*}
& x_{ijv} \in \{0, 1\}, \quad \forall i \in \mathcal{C}, j \in \mathcal{S}, v \in \mathcal{V} \\
& y_{ijv} \in \{0, 1\}, \quad \forall i \in \mathcal{C}, j \in \mathcal{S}, v \in \mathcal{V} \\
& z_{k} \in \{0, 1\}, \quad \forall k \in \mathcal{S}
\end{align*}
\]
Case Study

Test Network and Parameter Settings

- Downtown Minneapolis Network
  - One-way streets
  - 74 demands sites at block corners (random demand values)
  - 2 delivery trucks with $3.0/mile operating cost
  - 12 candidate lockers with $300 capital cost amortized to 5 years
  - Customer pick-up cost parameter $\gamma$ ranging from 0.25 to 0.5
Case Study

Results from Fours Scenarios

$\gamma = 0.5$  Opt. Cost=27.2

$\gamma = 0.4$  Opt. Cost=26.9

$\gamma = 0.3$  Opt. Cost=25.0

$\gamma = 0.25$  Opt. Cost=22.1
Case Study

System Cost Savings w.r.t. Customer Pick-up Cost
Case Study

Varying Customers Scenario

\( \gamma = 0.15 \) for less than 500m distance
\( \gamma = 0.3 \) for 500-1000m distance
\( \gamma = 0.5 \) for 1000-2000m distance
\( \gamma = 0.75 \) for more than 2000m distance

Optimal cost = 12.3
Case Study
System Cost Savings w.r.t. Capital Cost

\[ \gamma = 0.25 \]

- Total Cost
- Relative Saving

<table>
<thead>
<tr>
<th>Unit Capital Investment</th>
<th>Total Cost</th>
<th>Relative Saving</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>27.8%</td>
<td>24.24</td>
</tr>
<tr>
<td>250</td>
<td>21.52</td>
<td></td>
</tr>
<tr>
<td>300</td>
<td>22.27</td>
<td></td>
</tr>
<tr>
<td>350</td>
<td>15.2%</td>
<td></td>
</tr>
<tr>
<td>400</td>
<td>10.9%</td>
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</tr>
</tbody>
</table>
Conclusions

• Jointly optimized 1)shared lockers location, 2)delivery trucks routing, and 3)customers assignment to minimize the total system cost.

• Novel formulation reduces the computational time for real-size network applications.

• The last mile delivery using the shared lockers can save the system cost up to 19-28%, relative to the traditional home delivery.

• The shared locker system benefits from the economy of scale.
Future Work

• Extending the model:
  – Incorporating uncertain demand
  – Incorporating customers choices
  – Incentivizing customers to use lockers

• Informing practice and policy:
  – Understanding customers choices
  – Package delivery demand data
  – Curbside implications of increased last mile delivery
Acknowledgments

Yufeng Zhang, PhD Candidate
Questions?

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Multi-echelon distribution network

- Logistic hub/DC
- Intermediate depots
- Shared lockers
- PODs

First-echelon distribution

Traditional home deliveries

Shared Lockers

First-echelon route

Last-mile delivery

Last-mile delivery route

Customer pick-up