Same-Day Delivery: Operational and Tactical Analysis

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Motivation?
Motivation

Same Day Delivery in Manhattan

Order online by 11am. Get it by 7pm.
Outline

Introduction

Operations

Tactical Design

Conclusions
E-Retail

- E-retail is a large and growing sector of retail and overall economy.
  - About or above 10% of all US retail since 2013 (Forrester Research).
  - Average annual online spending will reach $2,000 per buyer this year (Forrester Research).
  - Amazon alone accounts for almost half of US e-retail (eMarketer).
  - Amazon now second to Walmart in terms of global employment numbers (566K vs. 2.3M); both very active in e-retail (Fortune).
- No longer the future – this is the present.
E-Retail

Amazon Retail Ecommerce Sales
US, 2016-2019

Source: eMarketer, June 2018
Same-Day Delivery

- Intense competition in e-retail, constant need for innovation – the customer wants it NOW.
- Same-day delivery (SDD) further erodes brick-and-mortar advantage. But...
Same-Day Delivery

- Intense competition in e-retail, constant need for innovation – the customer wants it NOW.

- Same-day delivery (SDD) further erodes brick-and-mortar advantage. But...
  - Extremely costly “last mile”.
  - Lower order numbers, fewer economies of scale.
  - Fewer than 1/4 of customers willing to pay, and then only small amount (McKinsey).
  - Flat fees (e.g. Amazon Prime) may help amortize costs.
Same-Day Delivery
What’s new?

- Traditional delivery: order acceptance, picking and packing *before* last-mile distribution.
  - Overnight/next-day delivery, two-day delivery, cheaper/free regular delivery.
Same-Day Delivery

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- Traditional delivery: order acceptance, picking and packing before last-mile distribution.
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- Same-day delivery: simultaneous order acceptance, picking, packing and last-mile distribution.
  - This talk: Delivery by end of day/common order deadline.
  - Food/grocery delivery: order-specific delivery times, 30 minutes to two hours (Amazon Restaurants, GrubHub, Uber Eats, pizza delivery).
Same-Day Delivery

What’s new?

Source: A. Erera
Basic Operational Model

• Single dispatching facility (local DC, retail store) with known service area, single delivery vehicle.

• Stochastic order arrivals throughout SDD horizon. All orders served, by delivery vehicle or third party (at higher cost).

• When vehicle is available, dispatcher chooses subset of open orders to serve; influences cost, *duration* of dispatch.

• Objective is minimizing total expected dispatch costs; can also be vehicle fill rate.
One-Dimensional Topology

- Restriction to one-dimensional geometry allows focus on dispatch trade-offs:
  - Dispatch now vs. dispatch later.
  - Long dispatch vs. short dispatch.

- Maximizes economies of scale.
  - If SDD is not cost-effective here, it certainly won’t be in general!
One-Dimensional Topology

\[(w, R, P) \rightarrow (w - 2, R \setminus S \cup F_2^w, P \setminus F_2^w)\]

\[\text{waves} \rightarrow \text{distance from DC}\]

\[\mathcal{R} \setminus \mathcal{S}\]

\[\mathcal{S}\]

\[\mathcal{F}_2^w\]

\[\mathcal{P} \setminus \mathcal{F}_2^w\]
One-Dimensional Topology

Deterministic analysis

- Assume order arrival times known with certainty.
- Still can’t serve order before arrival.
One-Dimensional Topology

Deterministic analysis

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One-Dimensional Topology

Deterministic analysis

• Takeaways:

1. Dispatches decrease in length – serve far customers early, but only nearby ones later.

2. All waiting is up front – once vehicle is dispatched, it operates continuously until end of day.

• Can use structure to solve the problem with dynamic programming (DP).
One-Dimensional Topology

Deterministic analysis – How do we leverage it?

\[ W \text{ dist.} \]

\[ 0 \]

\[ w \]
One-Dimensional Topology

Deterministic analysis – How do we leverage it?
One-Dimensional Topology
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One-Dimensional Topology
Deterministic analysis – How do we leverage it?

\[ \text{dist.} \]

\[ W \rightarrow 0 \]

\[ w \]
One-Dimensional Topology

Deterministic analysis – How do we leverage it?
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One-Dimensional Topology
Deterministic analysis – How do we leverage it?

- Replace probabilistic forecast with deterministic “copies” of orders, each discounted by its probability.
- Use same DP method to obtain a priori dispatch plan.
  - Can make simple updates as information is revealed.
One-Dimensional Topology

Deterministic analysis – How do we leverage it?

- Replace probabilistic forecast with deterministic “copies” of orders, each discounted by its probability.
- Use same DP method to obtain \textit{a priori} dispatch plan.
  - Can make simple updates as information is revealed.
- More powerful: “Roll out” the plan – recompute every time the vehicle returns to accommodate new info.
- Also helpful guidelines for general case.
General Topology

- Potential locations on a general (i.e. road) network.
General Topology

Deterministic analysis

- Example of operation plotted over time:

order 4: 
\[ \tau \]

order 3: 
\[ \tau \]

order 2: 
\[ \tau \]

order 1: 
\[ \tau \]

depot: 
\[ 8 \quad 7 \quad 6 \quad 5 \quad 4 \quad 3 \quad 2 \quad 1 \quad 0 \quad \rightarrow \text{waves} \]
General Topology

Deterministic analysis

- Example of operation plotted over time:

\[ S_7 = \{1, 2\} \quad S_3 = \{4, 3\} \]
General Topology
Deterministic analysis

- Example of operation plotted over time:

\[ S_6 = \{1, 2\} \quad S_3 = \{4, 3\} \]
General Topology

Deterministic analysis

- All waiting still up front, with continuous operations until end of day.
- Dispatch lengths might not be decreasing.
  - What about on average?..
- Solve with an integer programming (IP) model:

  Generalized prize-collecting TSP with multiple trips that cannot overlap in time, order release times, order pick-up at depot.
General Topology
Leveraging deterministic analysis

- Use multiple order “copies” as before to obtain a priori plan.
- Can “roll out” as in 1D case.
General Topology
Leveraging deterministic analysis

- Use multiple order “copies” as before to obtain a priori plan.
- Can “roll out” as in 1D case.
Use multiple order “copies” as before to obtain *a priori* plan.

Can “roll out” as in 1D case.
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General Topology
Leveraging deterministic analysis

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- Can “roll out” as in 1D case.
• Use multiple order “copies” as before to obtain *a priori* plan.
• Can “roll out” as in 1D case.
Sample Results

- Average results of policies over all instances

<table>
<thead>
<tr>
<th>policy</th>
<th>% gap</th>
<th>cost reduction</th>
<th>fill rate</th>
<th>dist/order</th>
<th>dispatches</th>
</tr>
</thead>
<tbody>
<tr>
<td>AP</td>
<td>23.1%</td>
<td></td>
<td>81.6%</td>
<td>11.0</td>
<td>2.5</td>
</tr>
<tr>
<td>GP</td>
<td>16.1%</td>
<td>5.8%</td>
<td>85.0%</td>
<td>11.2</td>
<td>2.5</td>
</tr>
<tr>
<td>RRP</td>
<td>12.1%</td>
<td>9.1%</td>
<td>86.2%</td>
<td>11.2</td>
<td>2.6</td>
</tr>
<tr>
<td>RP</td>
<td>12.1%</td>
<td>9.1%</td>
<td>86.6%</td>
<td>11.4</td>
<td>2.7</td>
</tr>
</tbody>
</table>

- Distribution of gap over all instances
What About Maximizing Fill Rate?

<table>
<thead>
<tr>
<th>metric</th>
<th>$\alpha = 1$</th>
<th>$\alpha = 2$</th>
<th>$\alpha = 100$</th>
</tr>
</thead>
<tbody>
<tr>
<td>travel</td>
<td>305</td>
<td>352</td>
<td>448</td>
</tr>
<tr>
<td>travel/order</td>
<td>11.4</td>
<td>13.1</td>
<td>16.8</td>
</tr>
<tr>
<td>fr (fill rate)</td>
<td>86.0%</td>
<td>88.5%</td>
<td>90.7%</td>
</tr>
<tr>
<td>Routes</td>
<td>2.60</td>
<td>3.40</td>
<td>4.80</td>
</tr>
<tr>
<td>Waves/route</td>
<td>1.36</td>
<td>1.22</td>
<td>1.13</td>
</tr>
<tr>
<td>initialWait</td>
<td>2.60</td>
<td>1.97</td>
<td>0.58</td>
</tr>
</tbody>
</table>

- marginal $fr$ improvements require increasing sacrifices in $travel/order$.
- structural difference in solutions!
- $\alpha = 100$: more returns to depot (recourse), short routes, longer operation.
- $\alpha = 2$: fewer & longer routes, compressed operation.
What About Maximizing Fill Rate?

Minimize total cost

Minimize total penalties

- On right, sacrifice $\approx 50\%$ in route efficiency to increase order coverage by one.
Tactical Design

• What does the “average” SDD operating day look like?

• Still interested in single dispatch facility and its service region, still minimizing total dispatch cost.

• Make some simplifications to examine big picture:

1. Orders arrive at constant rate over service horizon, uniformly random location in region, must all be served.

2. A dispatch to serve $n$ orders takes $f(n) = an + b\sqrt{n}$ time, where $a, b$ are calibrated based on road network, service time.
Many Vehicles

- Optimal Dispatch Plan: Each vehicle leaves when it can return right at deadline.
- Each planned dispatch time calculated by finding a quadratic root.
- Decreasing dispatch lengths...
A Single Vehicle

- Optimal Dispatch Plan:
  1. Each dispatch takes all available orders at departure time.
  2. Once it starts, the vehicle never waits until end of day.

- Planned dispatch times still found by (more complex) root finding algorithm.

- Decreasing dispatch lengths again!
Tactical Design

An example: How many vehicles to use?

- 8 mile × 8 mile region, 75 orders arrive over 10-hour service window.
- Dispatcher has 2 hours after end of window to deliver, 12 hours total.
- Dispatch time equivalent to Manhattan distances traveled at 25 mph, plus 1 minute service time per order.
Tactical Design

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• Many Vehicle Plan: Two dispatches, 64 and 11 orders.

• Single Vehicle Plan: Two dispatches, 55 and 20 orders. Dispatch time increase of only 4%!
Conclusions

- E-retail is here to stay. SDD growing as means to further compete with brick-and-mortar stores.
- Last-mile home delivery logistics costly due to poor scale economies, SDD makes it worse.
- Fundamental trade-offs:
  1. Dispatch now (sure) vs. later (know more, lose some orders).
  2. Short dispatch (flexible) vs. long dispatch (efficient).
Conclusions

• Operations:
  • Deterministic analysis can reveal useful dispatch plan structure.
  • Need dynamic, adaptive dispatch policies to keep costs low.

• Tactical Design:
  • “Average” behavior reflects intuitive properties.
  • Economies of scale lead to unbalanced expected dispatch lengths.

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