Last-Mile Optimization with Truck and Drones

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Agenda

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02 Problem Formulation
03 Methodology
04 Results & Discussion
05 Conclusion & Future Research
Introduction

Motivating the Research

• $82bn global parcel delivery market (McKinsey, 2016).
• Projected to double in next decade.
• Last mile ~50% of total parcel delivery costs.

Advantages and Limitations

+ Bypass congested roads.
+ Faster than trucks.
+ Significant cost reductions.
- Limited capacity (1 box @ 5 lbs).
- Limited range (10 mi @ 50 mph).
- Dependent on GPS Accuracy.

<table>
<thead>
<tr>
<th>speed</th>
<th>weight</th>
<th>capacity</th>
<th>range</th>
</tr>
</thead>
<tbody>
<tr>
<td>drone</td>
<td>high</td>
<td>light</td>
<td>one</td>
</tr>
<tr>
<td>truck</td>
<td>low</td>
<td>heavy</td>
<td>many</td>
</tr>
</tbody>
</table>

Agatz, 2015
Introduction

Companies
Amazon
Google
DHL
Dominoes
UPS
Agenda

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Problem Formulation

Problem
• Traveling Salesman Problem

Target Demographic
• Dense Urban Population

Objective
• Minimize Total Cost

Tools
• Python Programming
• Gurobi Optimizer
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Methodology

Key Assumptions

- Manhattan Distance
- One Truck, Multiple Drones
- Drones Serve One Customer per Dispatch
# Methodology

## Model Notation

- **Indexes**
- **Sets**
- **Parameters**
- **Variables**

<table>
<thead>
<tr>
<th>Indexes</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$h,i,j,k,l,m,o$:</td>
<td>Represents Node of Network, Total $c + 1$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$n$:</td>
<td>Represents Deployed Drones</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sets</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$N$:</td>
<td>${0,1,...,c+1}$: Set of all nodes in problem</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$N_o$:</td>
<td>${0,1,...,c}$: Set of all nodes that can be departed from</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$N_{t}$:</td>
<td>${1,2,...,c+1}$: Set of all nodes that can be arrived to</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$C$:</td>
<td>${1,2,...,c}$: Set of all customers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$D$:</td>
<td>${1,...,n}$: Set of available drones for deployment</td>
<td></td>
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</table>

<table>
<thead>
<tr>
<th>Parameters</th>
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</thead>
<tbody>
<tr>
<td>$min_D$:</td>
<td>Drone Endurance Time (min)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$mph_D$:</td>
<td>Drone Speed (mph)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$mph_T$:</td>
<td>Truck Speed (mph)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$s_L$:</td>
<td>Drone Launch Setup Time (min)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$s_R$:</td>
<td>Drone Retrieval Time (min)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$A$:</td>
<td>Customer Grid Area ($mi^2$)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$C_F$:</td>
<td>Variable Operating Cost for Truck Fuel ($USD/min$)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$C_L$:</td>
<td>Variable Operating Cost for Truck Labor ($USD/min$)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$C_E$:</td>
<td>Variable Operating Cost for Drone Electricity ($USD/min$)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$F_D$:</td>
<td>Fixed Cost of Deploying Unique Drone per Tour ($USD$)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$M$:</td>
<td>Linking Constraint</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Variables</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>$\tau$:</td>
<td>Travel Time</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$t$:</td>
<td>Arrival Time</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$x$:</td>
<td>Binary, Customer Served by Truck</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$y$:</td>
<td>Binary, Customer Served by Drone</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$z$:</td>
<td>Binary, Drone Deployed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$p$:</td>
<td>Binary, Tour Order Sequencing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$u$:</td>
<td>Binary, Sub-tour Elimination</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Methodology

Decision Variables
- Customer served by truck, \( x_{ij} \)
- Customer served by drone, \( y_{ijk} \)
- Number of drones deployed, \( z_n \)

Objective Function
- \( \text{MinCost} = t_{c+1}(C_F + C_L) + \sum_{i \in N_0} \sum_{j \in N} \sum_{k \in N_+} \sum_{n \in D} y_{ijkn} (\tau'_{ij} + \tau'_{jk}) * C_E + \sum_{n \in D} z_n * F_D \)

Key Constraints
- Subtour Elimination
- Each node visited only one time
- Truck and drones coordinate at launch and rendezvous
- Drone flight endurance limit
- Non-negativity constraint
Methodology

Base Case
- Drone Speed
- Drone Endurance
- Number of Drones Available
- Truck Speed
- Customer Grid

Sensitivity Analysis
- Speed/Endurance
- Available Drones
- Truck Speed
- Grid Area

<table>
<thead>
<tr>
<th>Parameter of Interest</th>
<th>available drones $D_n$</th>
<th>endurance $m_D$</th>
<th>drone speed $m_D$</th>
<th>truck speed $m_T$</th>
<th>grid area $A$</th>
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<tbody>
<tr>
<td>Speed/Endurance</td>
<td>2</td>
<td>20</td>
<td>25</td>
<td>25</td>
<td>100</td>
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<tr>
<td></td>
<td>3</td>
<td>30</td>
<td>35</td>
<td>25</td>
<td>100</td>
</tr>
<tr>
<td>Available Drones</td>
<td>1</td>
<td>30</td>
<td>35</td>
<td>25</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>30</td>
<td>35</td>
<td>25</td>
<td>100</td>
</tr>
<tr>
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<td>3</td>
<td>30</td>
<td>35</td>
<td>25</td>
<td>100</td>
</tr>
<tr>
<td>Truck Speed</td>
<td>2</td>
<td>30</td>
<td>35</td>
<td>5</td>
<td>100</td>
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<td>25</td>
<td>100</td>
</tr>
<tr>
<td>Grid Area</td>
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<td></td>
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<td>10</td>
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<td>15</td>
<td>400</td>
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</tbody>
</table>
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Results & Discussion

Drone Speed/Endurance

- Savings
Results & Discussion

Drone Speed/Endurance

- Savings
- Drone Usage
Results & Discussion

Number of Drones Available

• Savings
Results & Discussion

Number of Drones Available

- Savings
- Drone Usage
Results & Discussion

Truck Speed

- Savings
Results & Discussion

Truck Speed

- Savings
- Drone Usage
Results & Discussion

Customer Grid Area

• Savings
Results & Discussion

Customer Grid Area

• Savings
• Drone Usage
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Conclusion & Future Research

Conclusion
  • Savings over TSP
    • Base 30%
    • Worst 5%
    • Best 55%
  • Considerable Savings

Future Research
  • Heuristics
    • Genetic Algorithm
    • Ant Colony Algorithm
    • Simulated Annealing
  • Multiple Packages per Drone
  • En Route Drone Launch/Rendezvous