Last-Mile Optimization with Truck and Drones

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Image Source: fortune.com

Agenda

01 **Introduction**

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.*

	speed	weight	capacity	range
drone	**high**	**light**	one	short
truck	low	heavy	**many**	**long**

Agatz, 2015

Introduction

Companies

Amazon

Google

DHL

Dominoes

UPS

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Problem Formulation

Problem

- Traveling Salesman Problem

Target Demographic

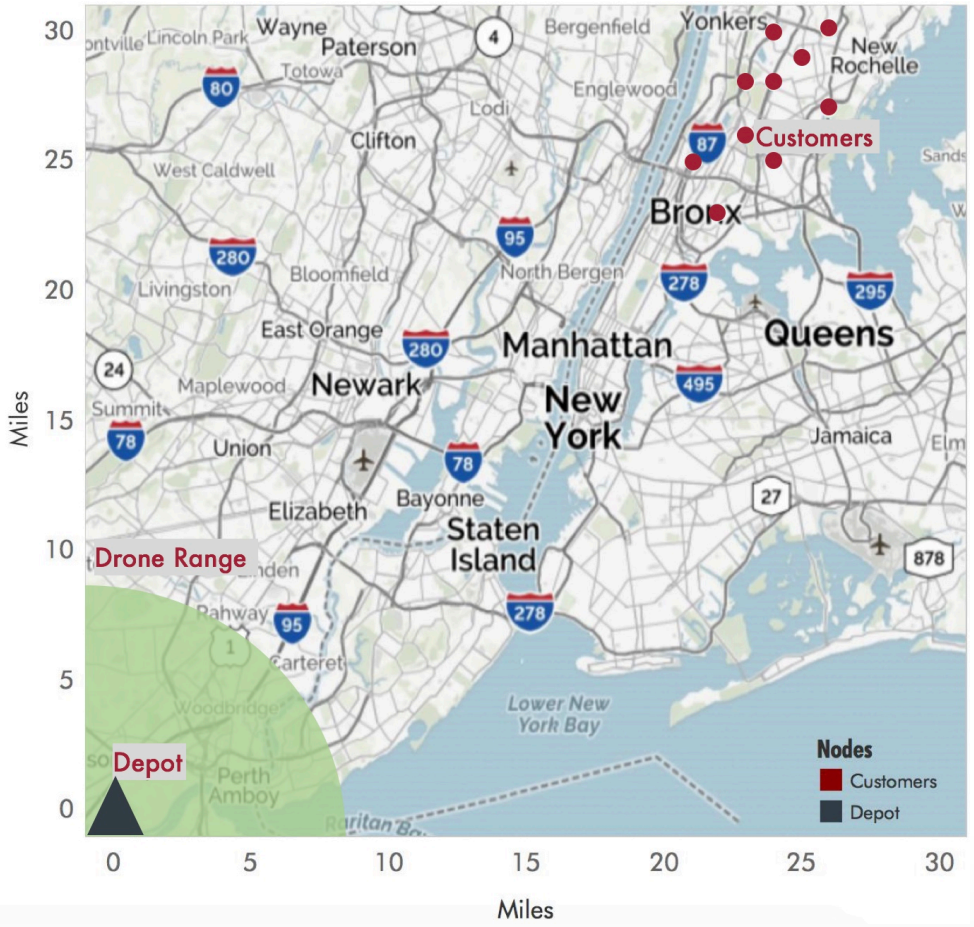
- Dense Urban Population

Objective

- Minimize Total Cost

Tools

- Python Programming
- Gurobi Optimizer



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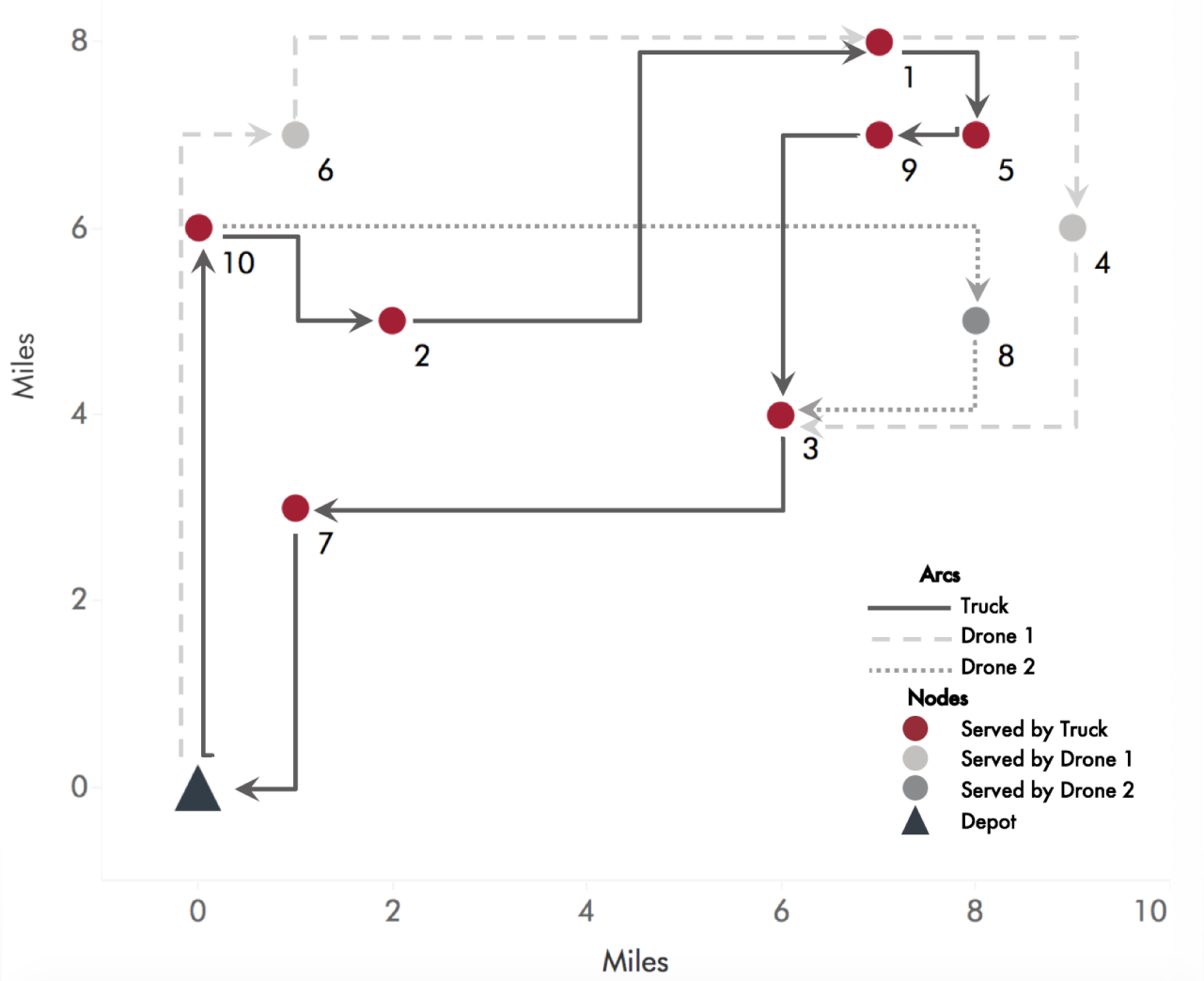
Methodology

Key Assumptions

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



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Methodology

Model Notation

- Indexes
- Sets
- Parameters
- Variables

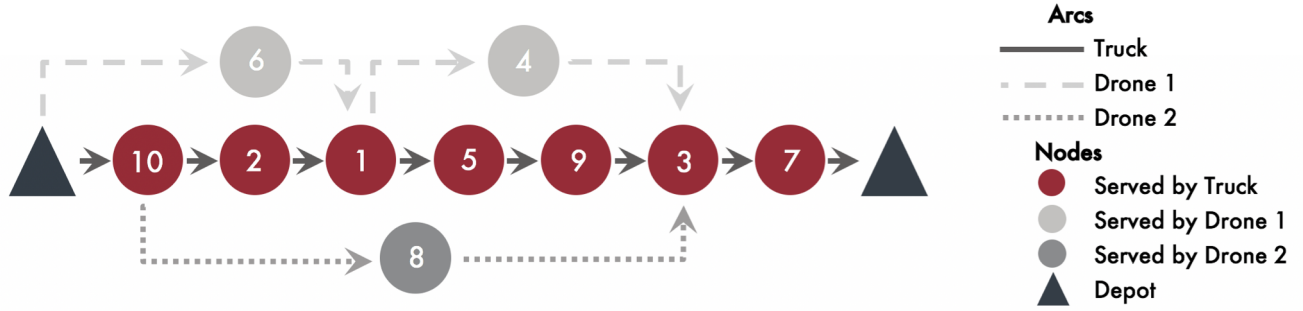
Indexes	
h, i, j, k, l, m, o:	Represents Node of Network, Total $c+1$
n:	Represents Deployed Drones
Sets	
N:	{0,1,...,c+1}: Set of all nodes in problem
N_0:	{0,1,...,c}: Set of all nodes that can be departed from
N_+:	{1,2,...,c+1}: Set of all nodes that can be arrived to
C:	{1,2,...,c}: Set of all customers
D:	{1,...,n}: Set of available drones for deployment

Parameters	
min_D:	Drone Endurance Time (min)
mph_D:	Drone Speed (mph)
mph_T:	Truck Speed (mph)
s_L:	Drone Launch Setup Time (min)
s_R:	Drone Retrieval Time (min)
A:	Customer Grid Area (mi^2)
C_F:	Variable Operating Cost for Truck Fuel (USD/min)
C_L:	Variable Operating Cost for Truck Labor (USD/min)
C_E:	Variable Operating Cost for Drone Electricity (USD/min)
F_D:	Fixed Cost of Deploying Unique Drone per Tour (USD)
M:	Linking Constraint
Variables	
τ:	Travel Time
t:	Arrival Time
x:	Binary, Customer Served by Truck
y:	Binary, Customer Served by Drone
z:	Binary, Drone Deployed
p:	Binary, Tour Order Sequencing
u:	Binary, Sub-tour Elimination

Methodology

Decision Variables

- Customer served by truck, x_{ij}
- Customer served by drone, y_{ijk}
- Number of drones deployed, z_n



Objective Function

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

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

Truck Variable Costs	
Labor Cost	0.124 $USD/minute$
Fuel Cost	0.418 $USD/minute$
Drone Variable Costs	
Electricity Cost	0.002 $USD/minute$
Drone Fixed Cost	
Deployment Cost	1.136 USD

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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

Parameter of Interest	available drones D_n	endurance (min_D)	drone speed (mph_D)	truck speed (mph_T)	grid area (A)
Speed/Endurance	2	20 30 40	25 35 45	25	100
Available Drones	1 2 3	30	35	25	100
Truck Speed	2	30	35	5 10 15 20 25	100
Grid Area	2	30	35	25	100 225 400

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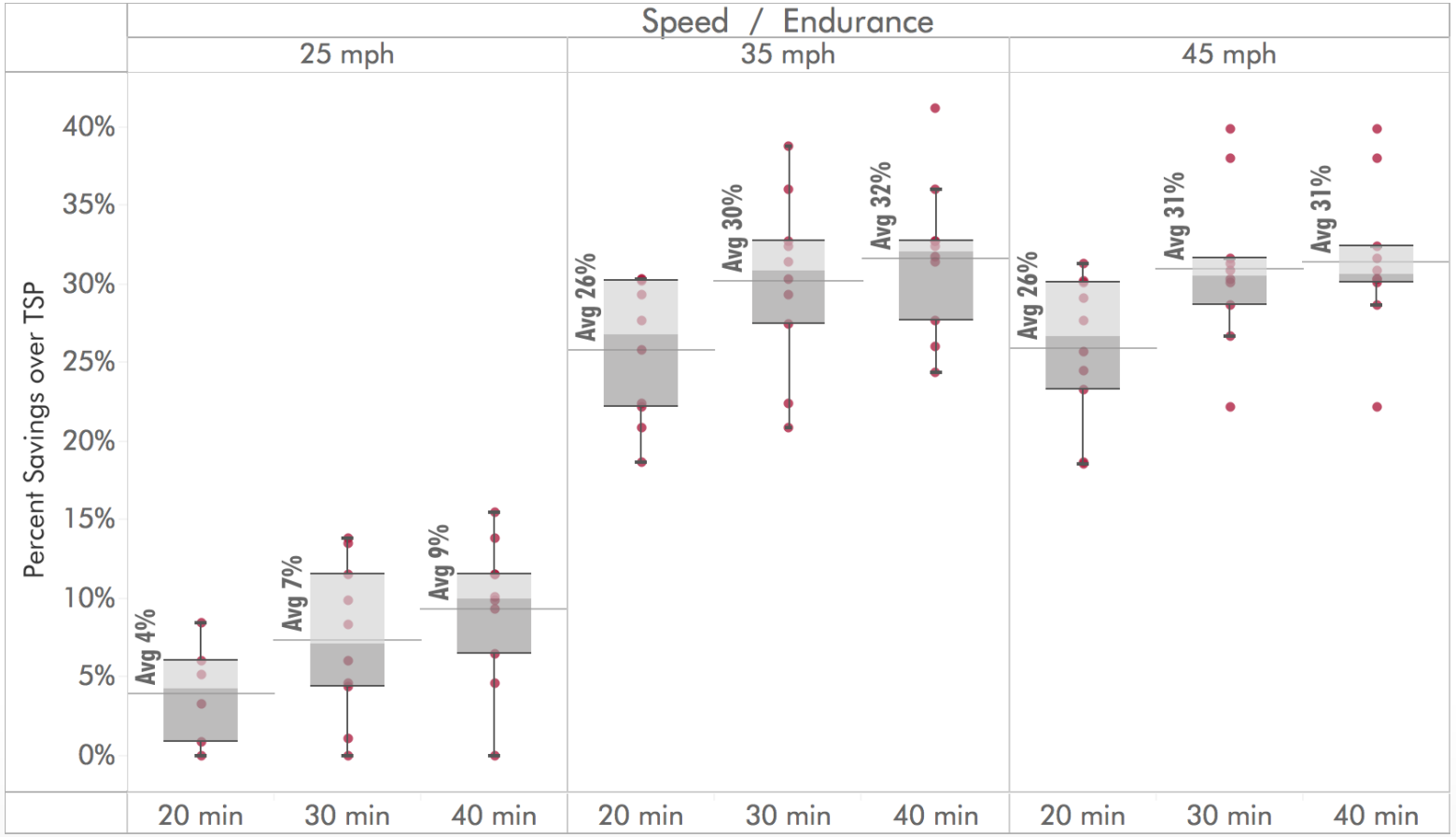
Results & Discussion

Drone Speed/Endurance

- Savings



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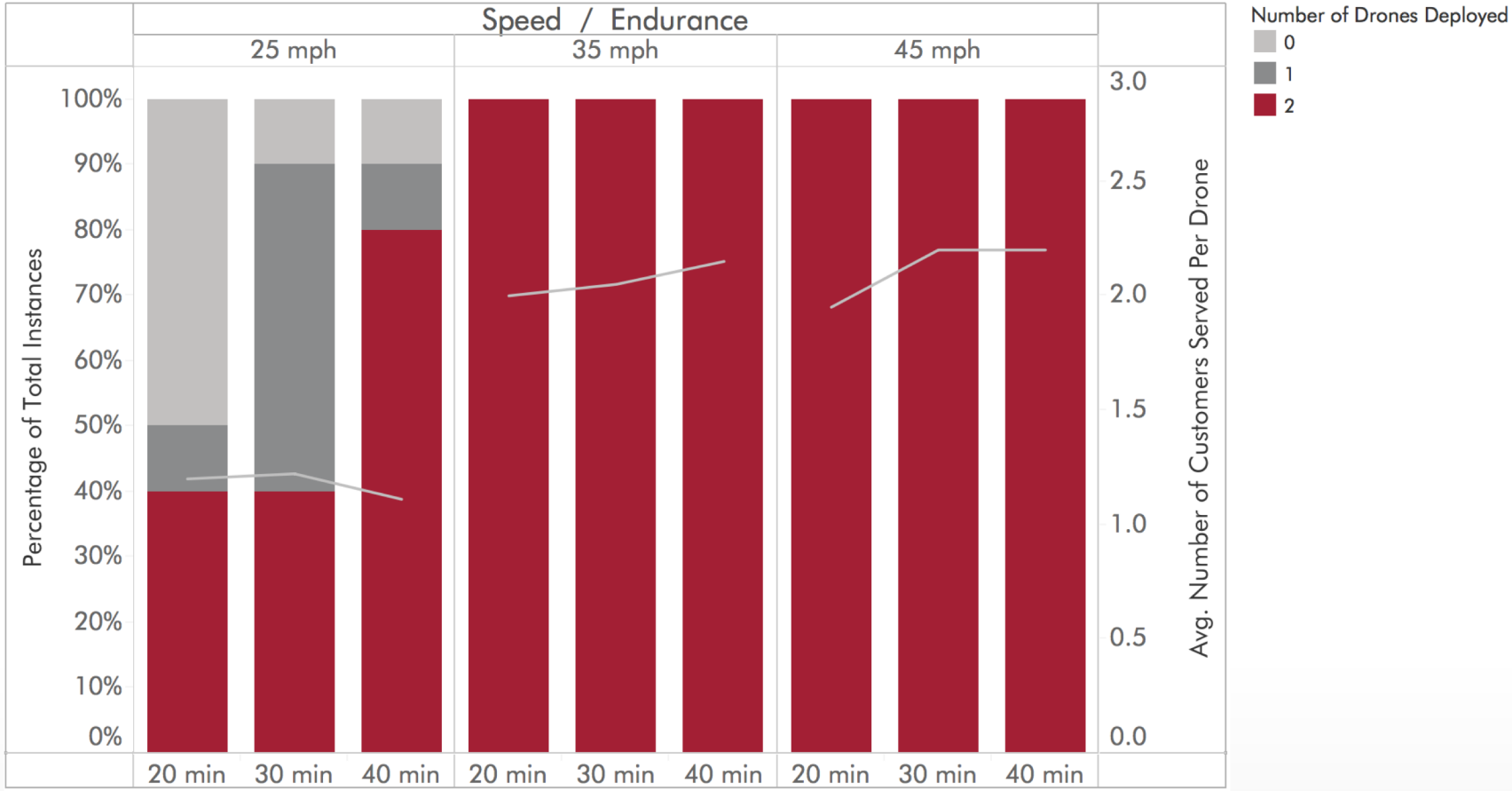
Results & Discussion

Drone Speed/Endurance

- Savings
- Drone Usage



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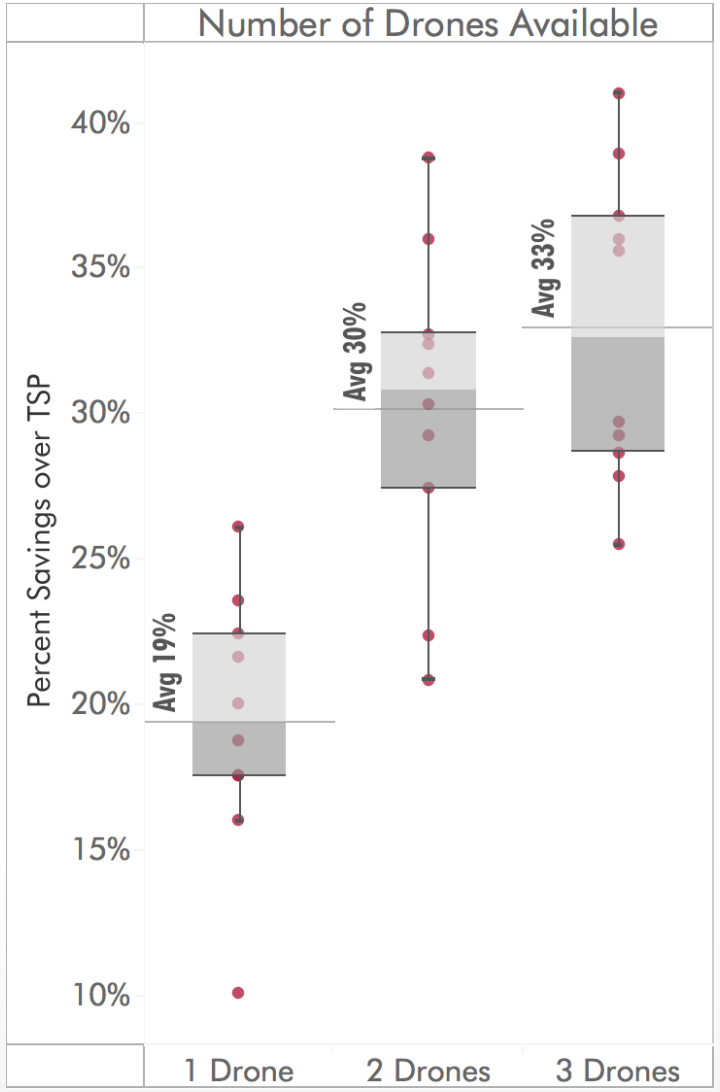
Results & Discussion

Number of Drones Available

- Savings



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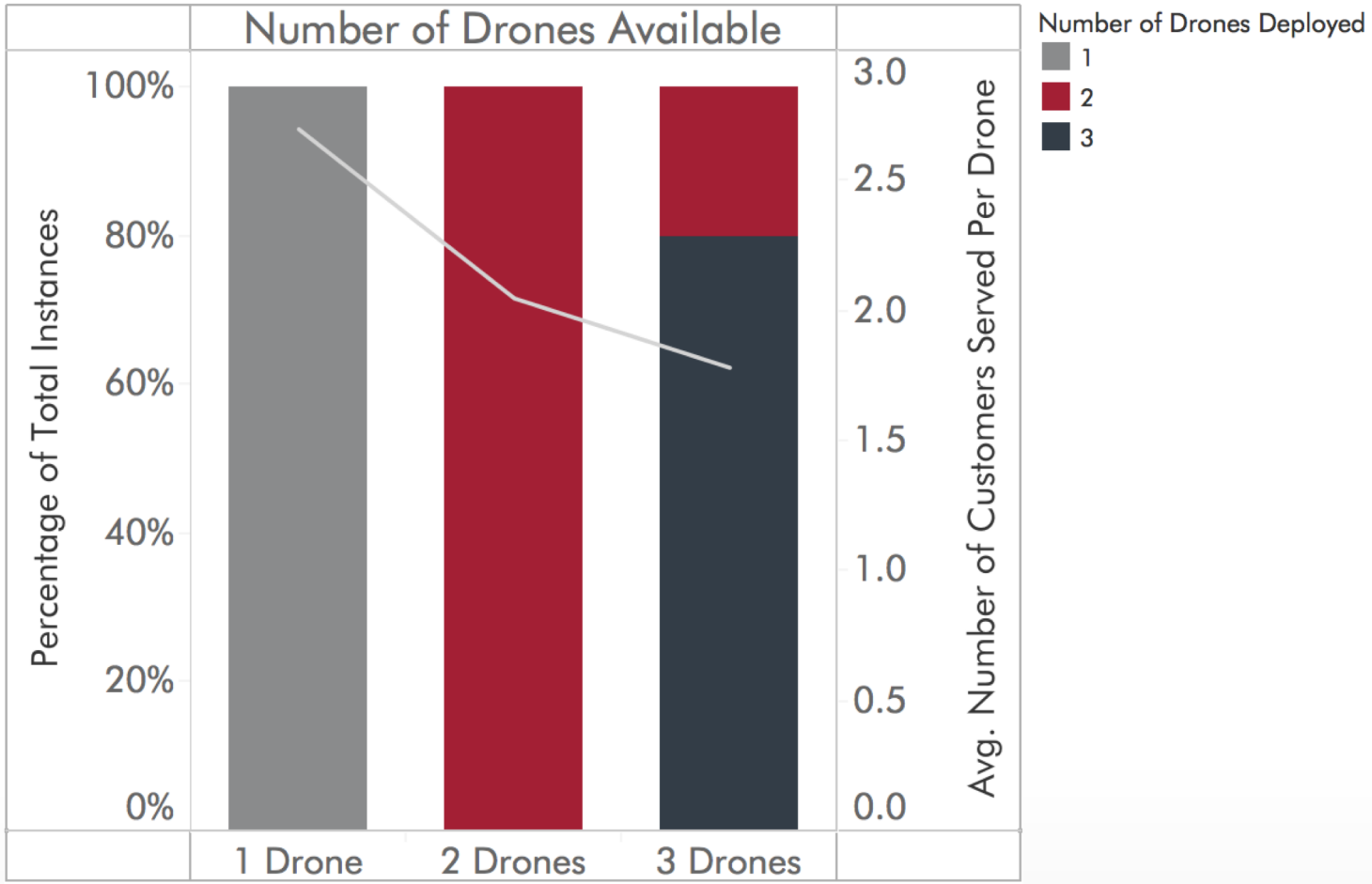
Results & Discussion

Number of Drones Available

- Savings
- Drone Usage



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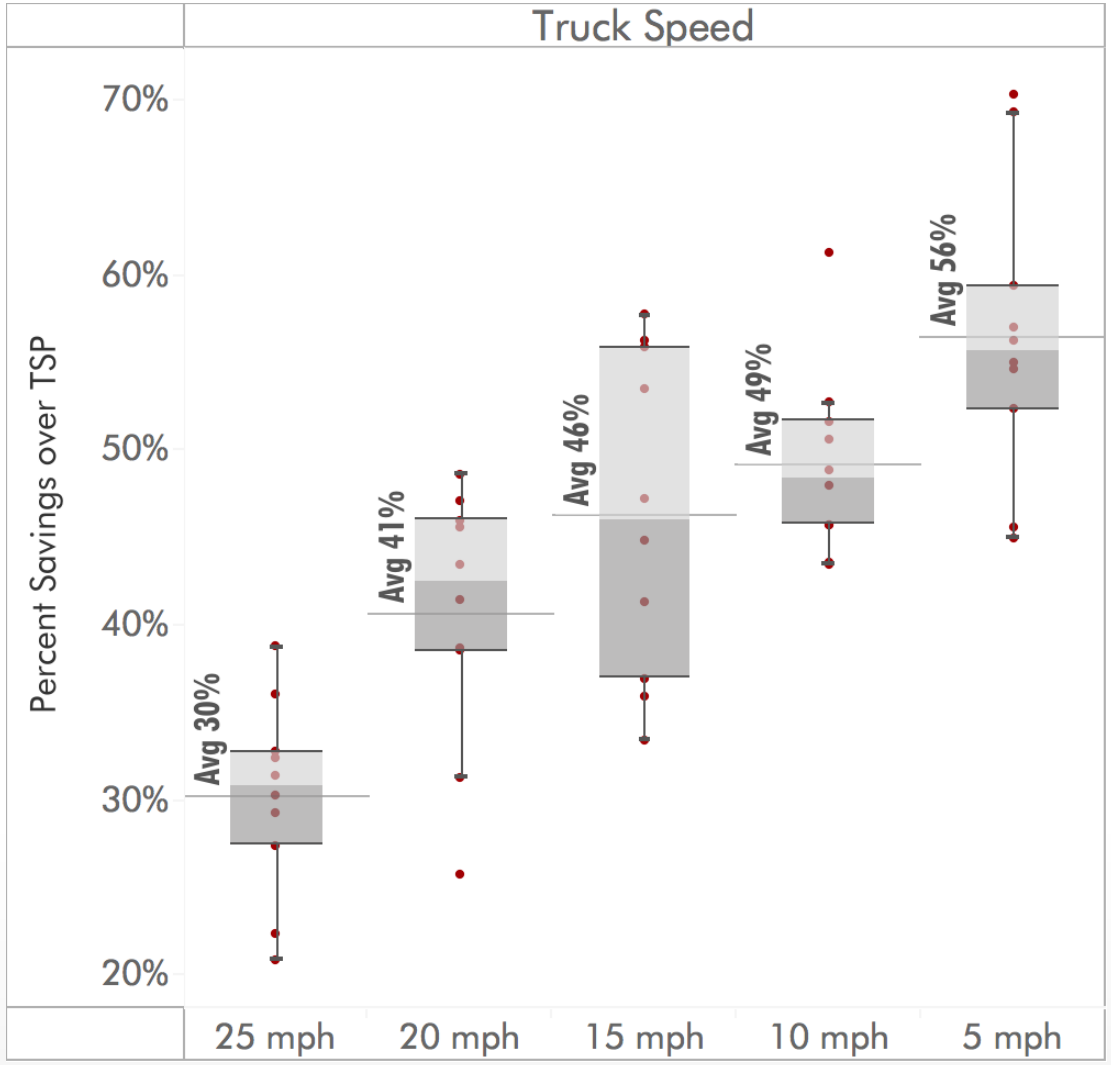
Results & Discussion

Truck Speed

- Savings



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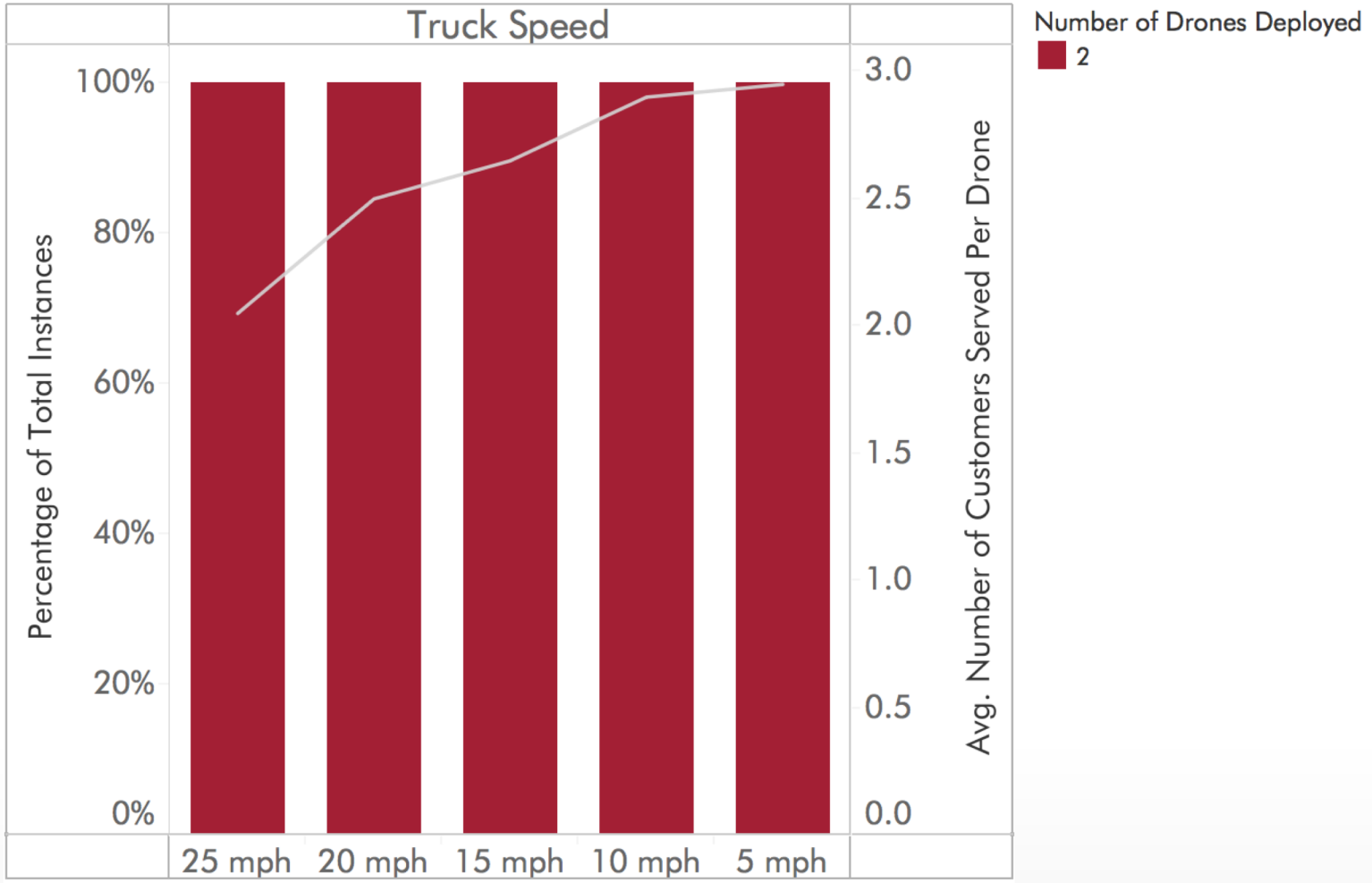
Results & Discussion

Truck Speed

- Savings
- Drone Usage



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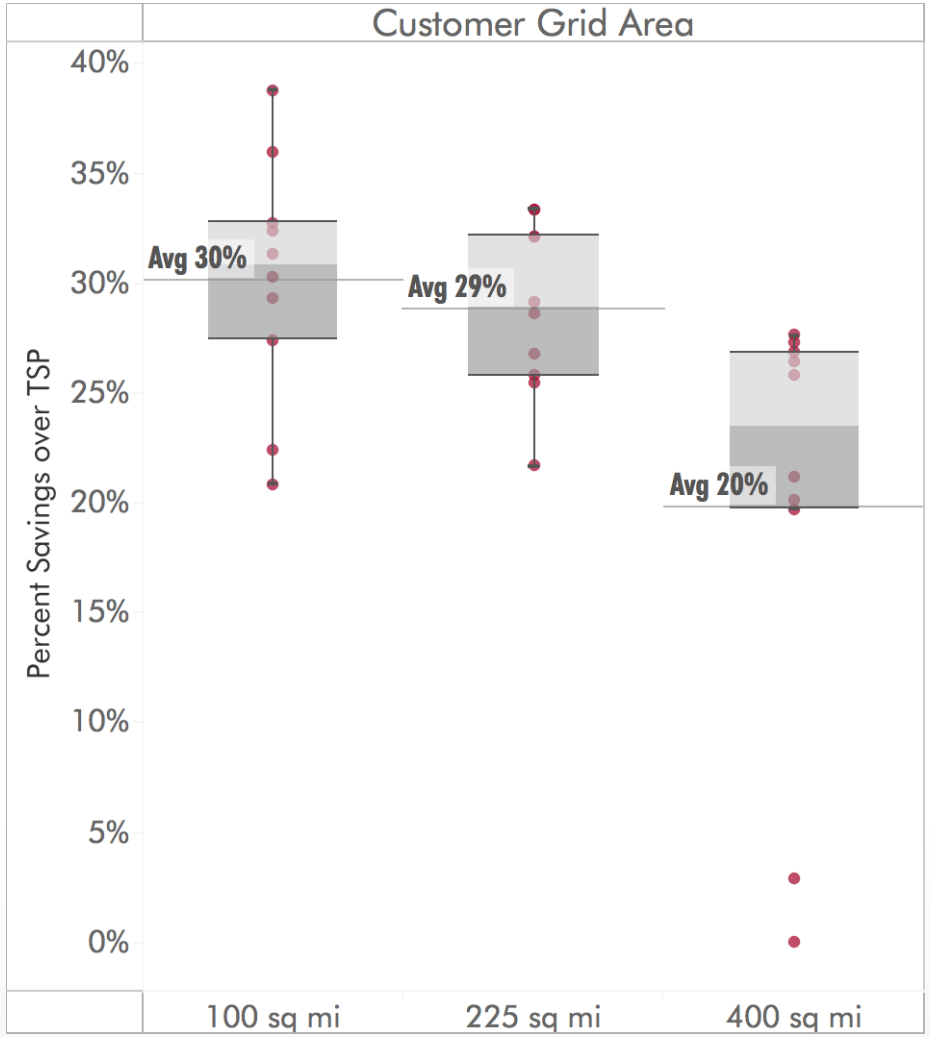
Results & Discussion

Customer Grid Area

- Savings



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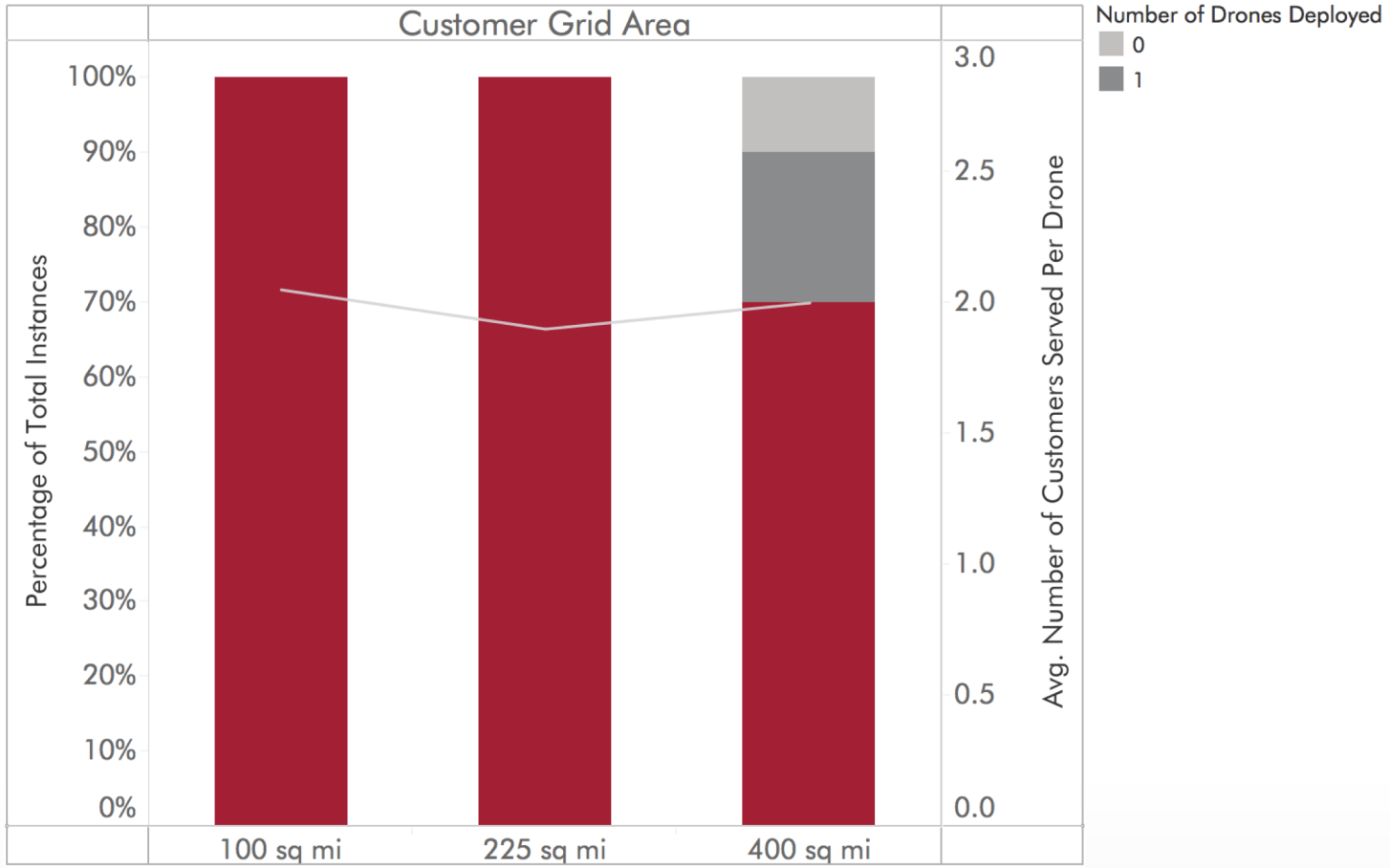
Results & Discussion

Customer Grid Area

- Savings
- Drone Usage



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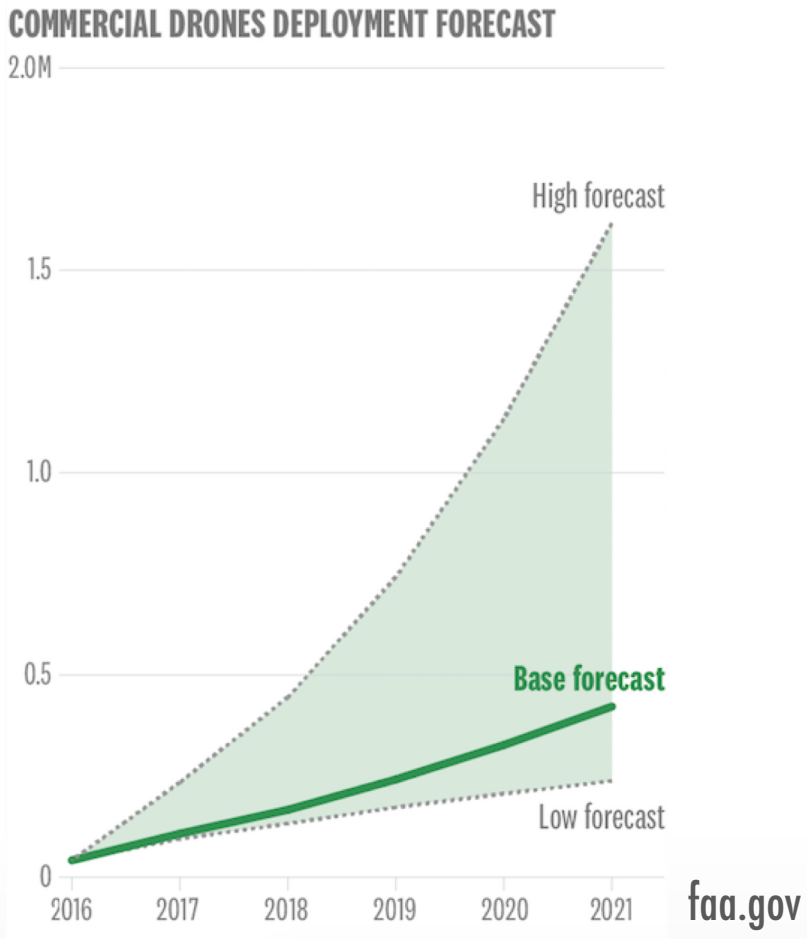
Conclusion & Future Research

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



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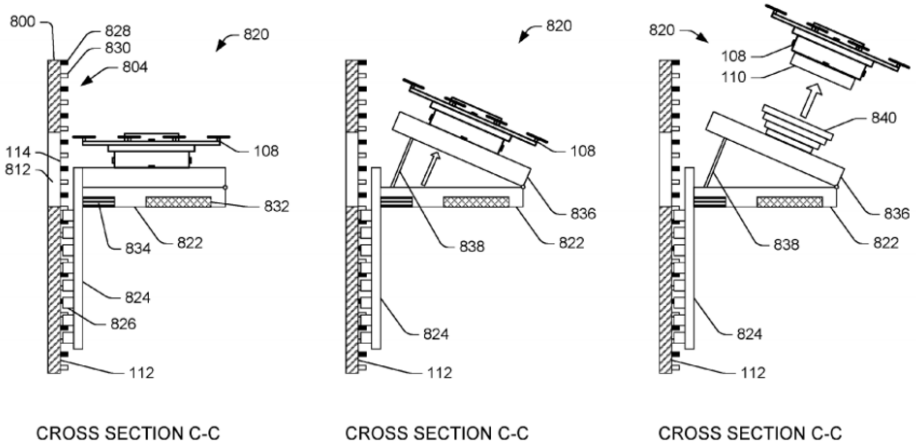
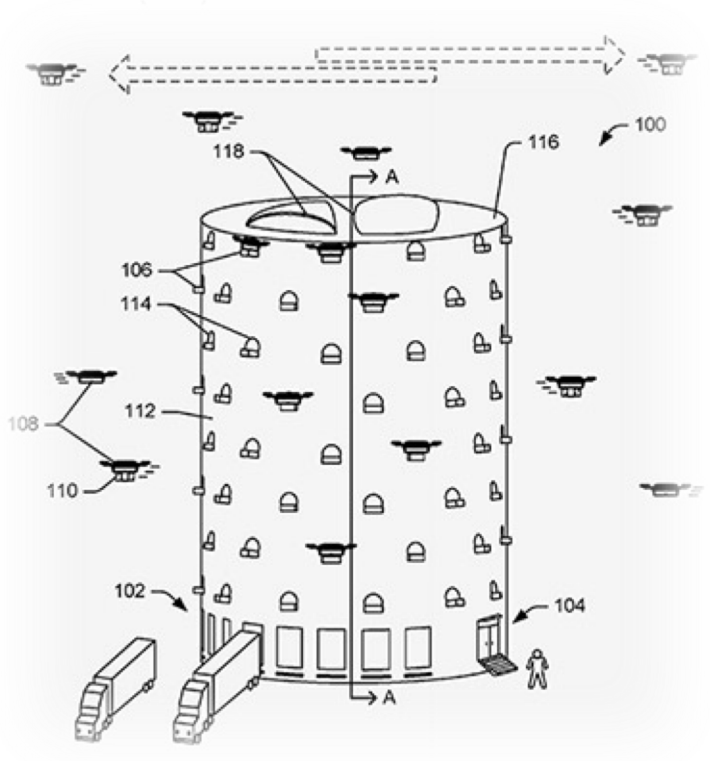
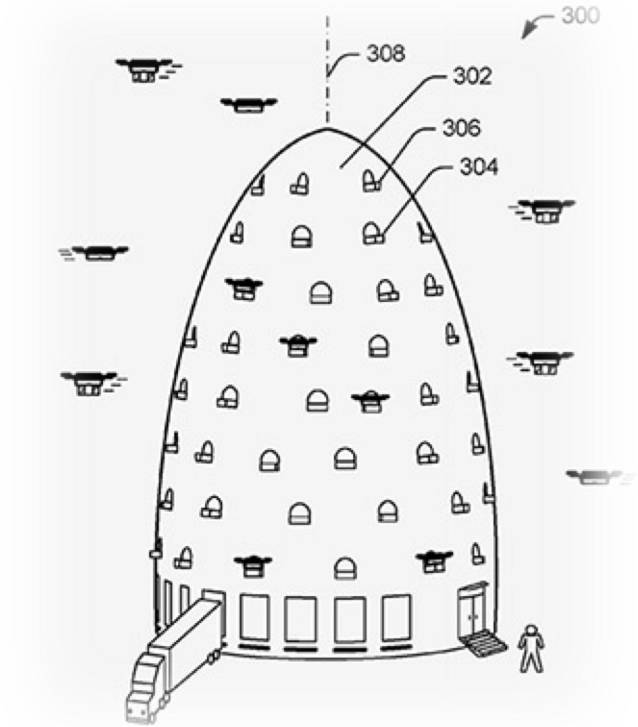
Questions?







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