Identification and Evaluation of Concepts of Operations for sUAS Package Delivery

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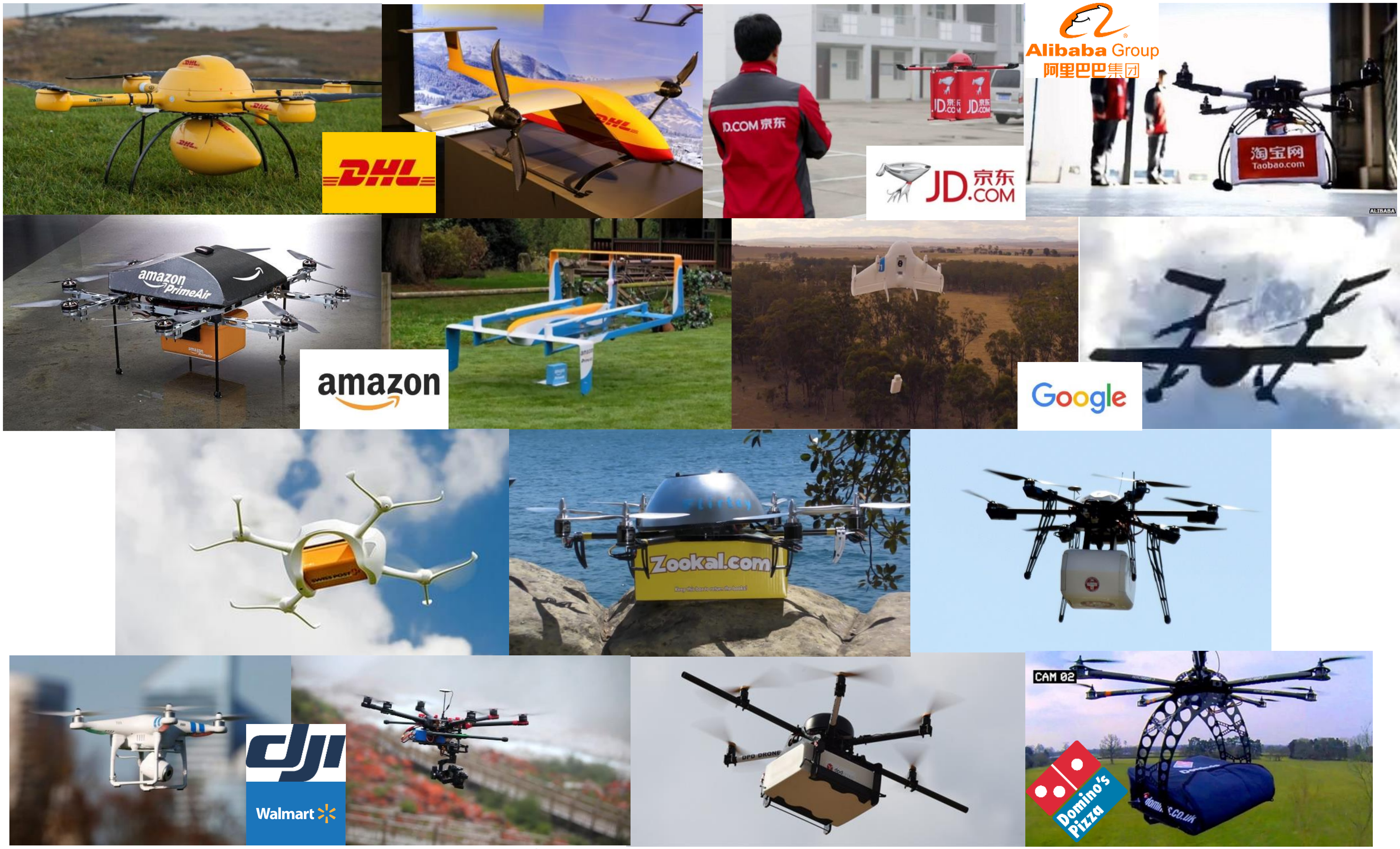
Industry Research



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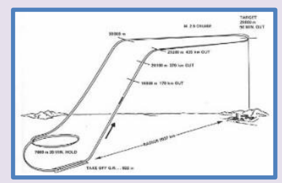
NASA

Delivery Process

Research Objectives

Investigate sUAS package delivery business cases for plausible near-term implementation

1. **Identify potential concepts of operations (CONOPs)**, with focus on:

Regulations	Economics	Safety	Vehicle	Mission	Package Security	Environment	Cyber Security
							
Evaluation of effects of regulations on feasibility	**Development of economics model**	Considered for CONOPs selection	Modeled via parametric performance	Considered for CONOPs selection	Considered for CONOPs selection	Considered for CONOPs selection	Important, but not considered in study

2. **Evaluate CONOPs**
   - Modeling and simulation to perform vehicle routing and economic analysis
   - Parametric vehicle architecture and performance
3. **Examine tradeoffs**
   - Differing airspace restrictions
   - Vehicle payload-range performance

Regulatory Concerns

Commercial sUAS fall between existing regulations - FAA regulates navigable airspace, AMA oversees hobby aircraft

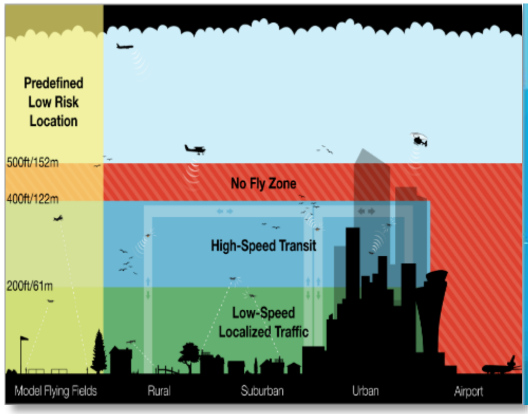
- United States v. Causby 328 U.S. 256 (1946) relating to FAR 91
  - "The airspace, apart from the immediate reaches above the land, is part of the public domain."
  - 500 ft. floor for civil aircraft in unpopulated areas, 1000 ft. from objects in 2000 ft. radius
- FAR 91.13 – aircraft may not be operated in a careless or reckless manner so as to endanger life or property of another
  - FAA v. Pirker (2011)
  - FAA v. SkyPan (2015)
- Congressional research on privacy issues in 2013 determined that more testing was required
- Boggs v. Merideth (2016) may provide further clarification
  - Man shot down small drone flying over his property

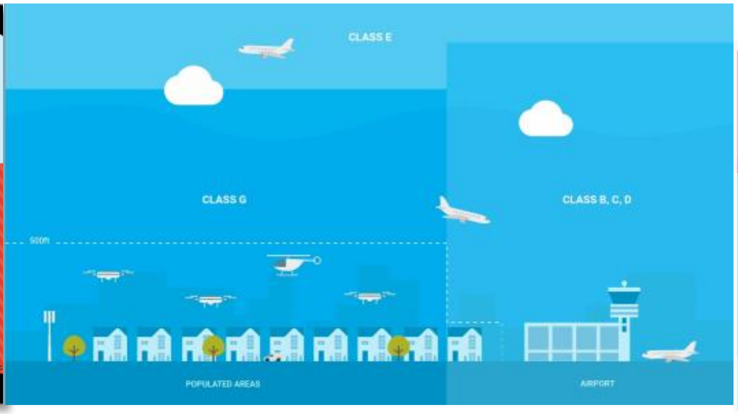
Proposed FAA Requirements – Part 107 Summary

- Flight ceiling – 500 feet
- Class G uncontrolled, B through E allowable with ATC permission, A not allowed
- Some controlled airspace – around airports, military bases, national parks
- Visual line-of-sight is required (VLOS)
- Vehicle weight – less than 55 lbs
- Vehicle speed limited to 100 MPH
- Daylight operations

FAA regulations are evolving from year to year – many legal gray areas

Airspace Proposals





Company Proposed Operations

Tradeoffs

- Warehouse size
- Customer convenience

- Number of customers
- Operations near and over persons
- Airspace restrictions and flight corridors
- Takeoff and Landing requirements

- Customer convenience
- Logistical ease

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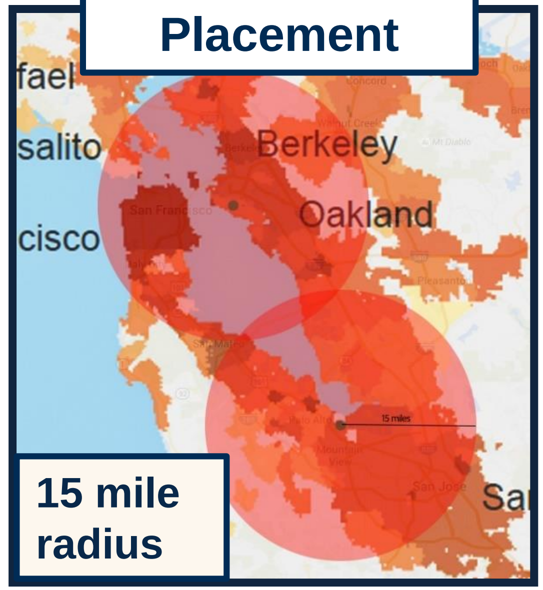
Initial CONOPs Investigated

Location – San Francisco and San Jose Area

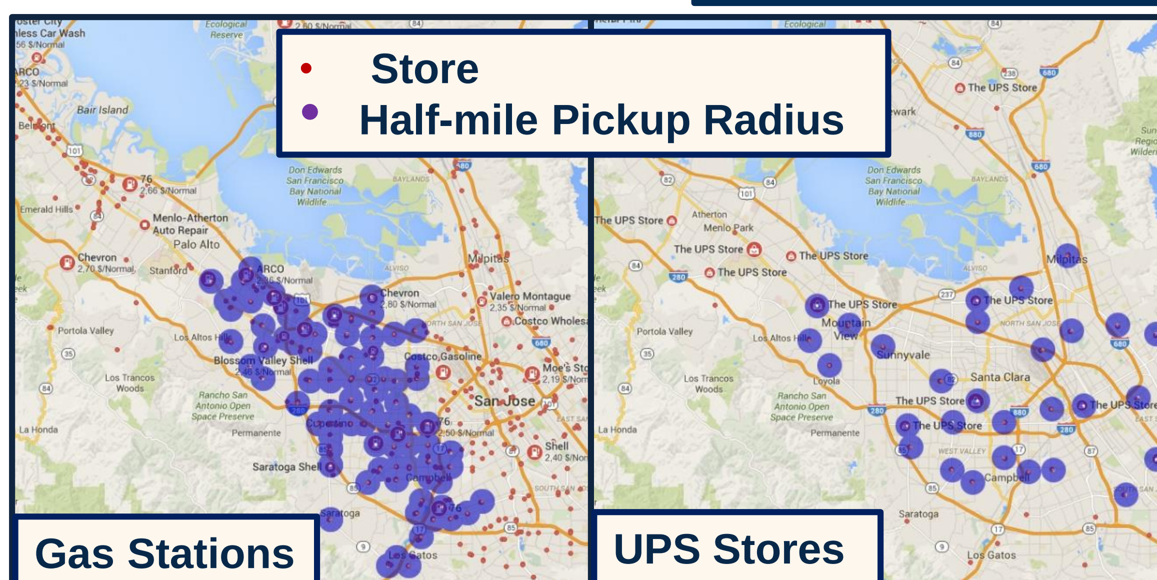
- Impassable Terrain
- High Traffic Volume
- High Population Density
- Choke Points

Warehouse Placement



15 mile radius

Pickup Locations



- Store
- Half-mile Pickup Radius

Gas Stations

UPS Stores

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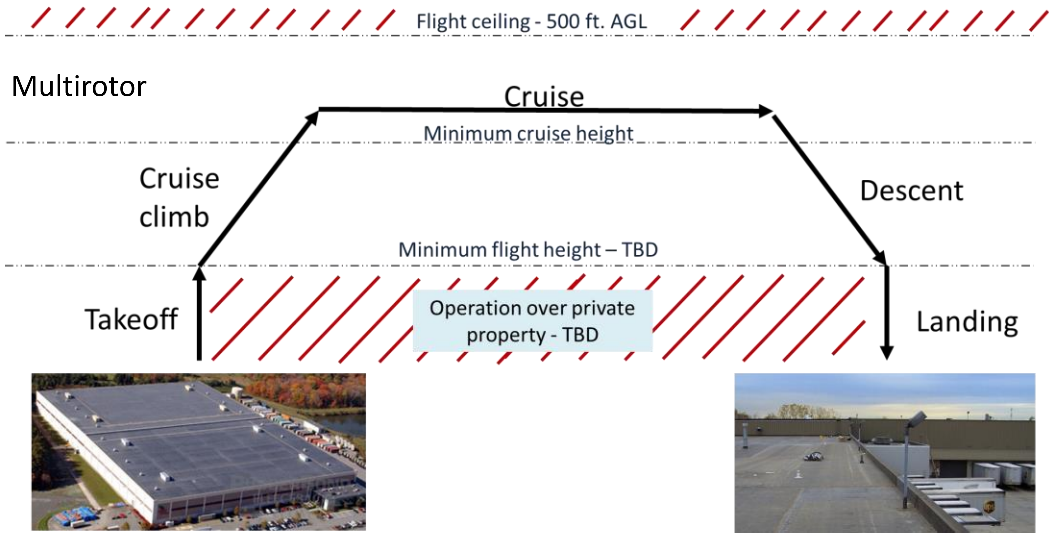
Sample Mission

Sample Mission Profile



sUAS Vehicle Architectures

Multirotor

- Small area required for takeoff and landing
- Precise takeoff and landing
- Poor endurance

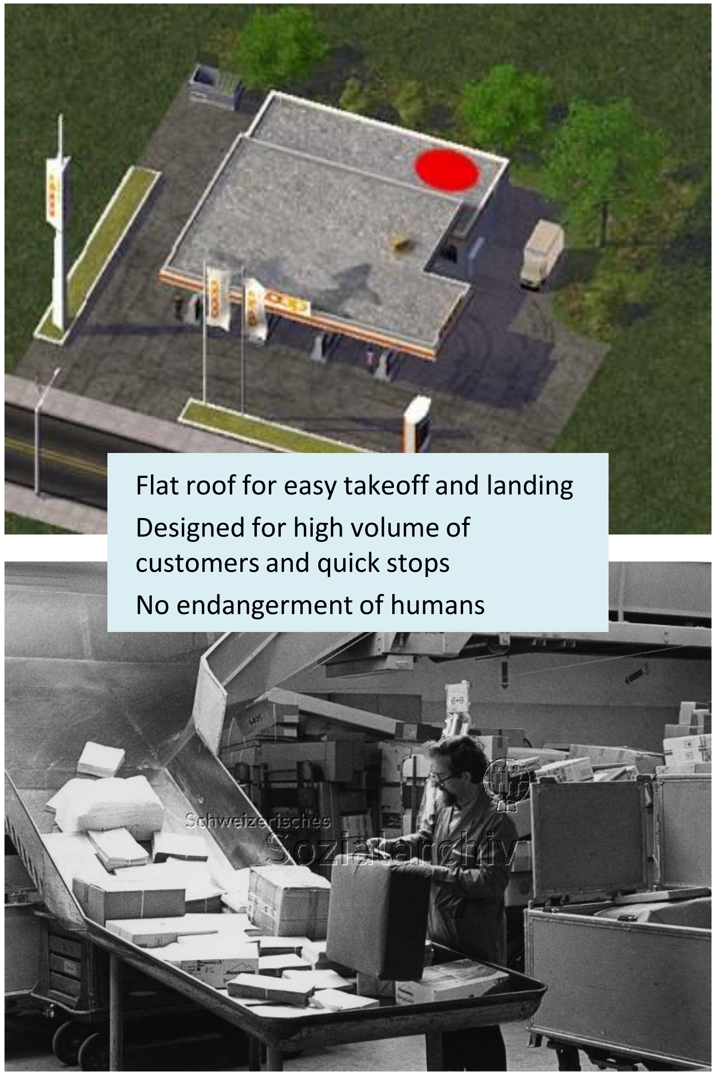
VTOL Fixed Wing

- Provides good takeoff and landing characteristics and better endurance, but increases technical complexity

Conventional Fixed Wing

- Large area required for takeoff and landing
- Imprecise takeoff and landing
- Good endurance

Gas Station Operation



Flat roof for easy takeoff and landing

Designed for high volume of customers and quick stops

No endangerment of humans

Trade Study Environment

CONOPs
- Regulations
- Safety
- Mission
- Vehicle

Modeling and Simulation

Vehicle Routing Model → Economic Analysis

Explore CONOPs Tradeoffs and Suggest Business Case

Vehicle Routing Model

Parametric Study

- UAS speed
- Number of packages
- Number of vehicles
- Number of warehouses
- Delivery radius

Statistical Simulation

Delivery Coordinate
Start and end time

OPEN DOOR LOGISTICS

Operating time, distance traveled

Average total operating time and distance traveled

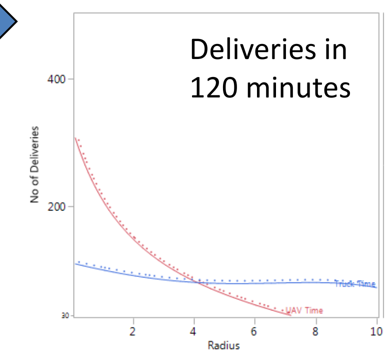
Economic Analysis

Parametric Study

- Cost/distance
- Cost/vehicle
- Cost/time

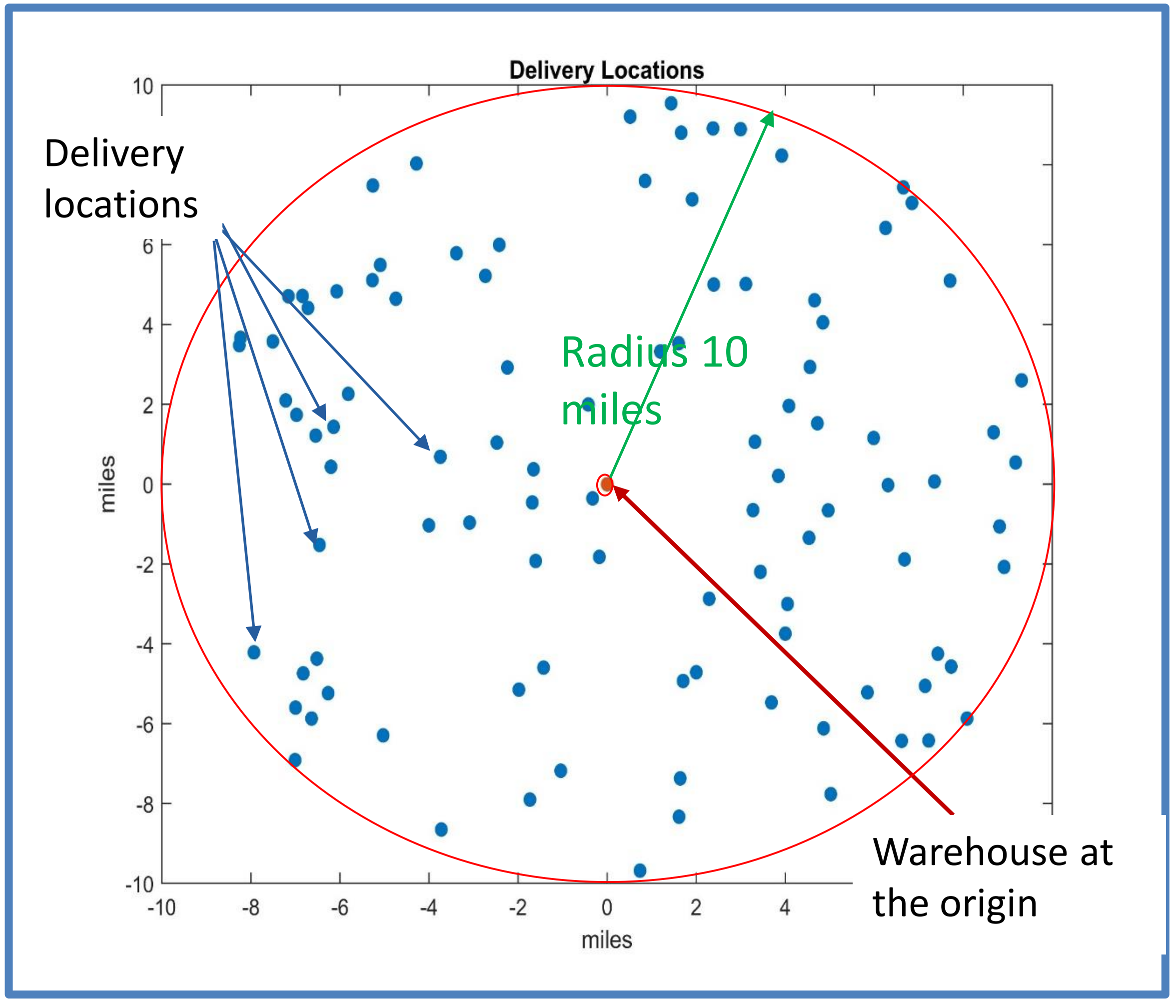
- \$/kWh
- \$/gallon
- \$/labor-hr
- Vehicle Acq. \$
- Vehicle Maint. \$

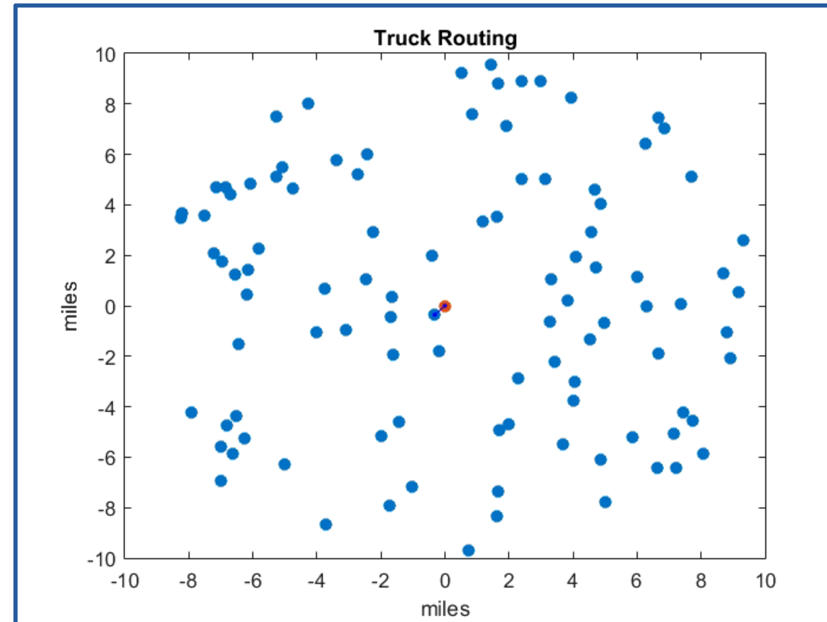
Examine Economically Feasible Space

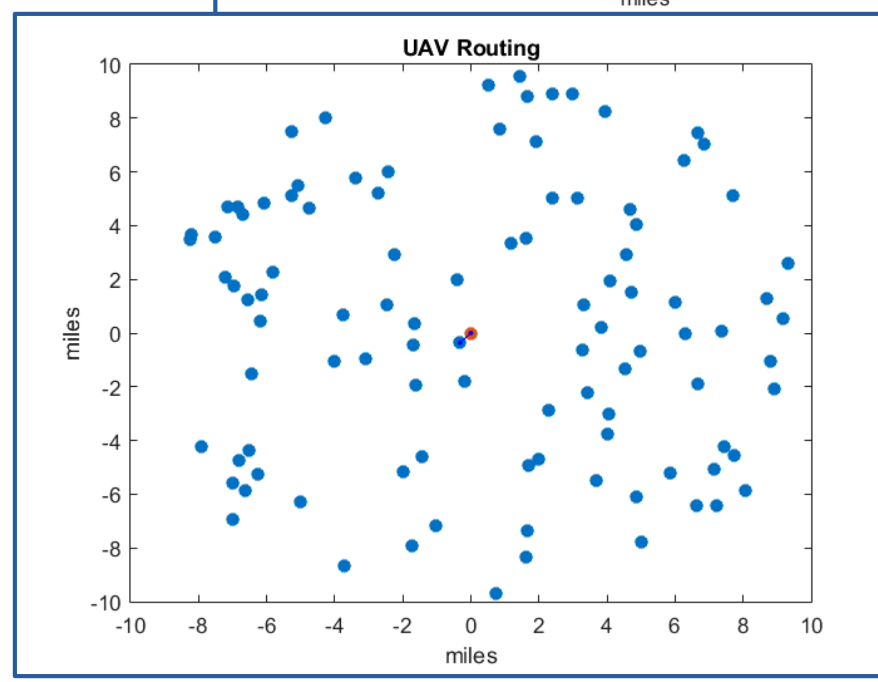


Preliminary Greedy Routing Model

- Assigns closest vehicle to package
- All deliveries known at start of day







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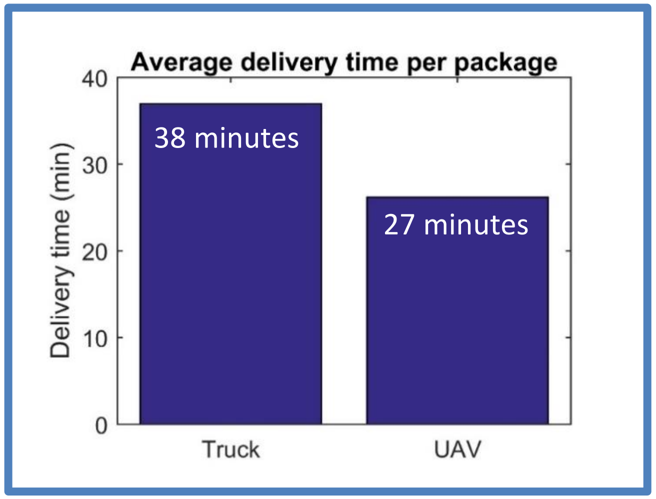
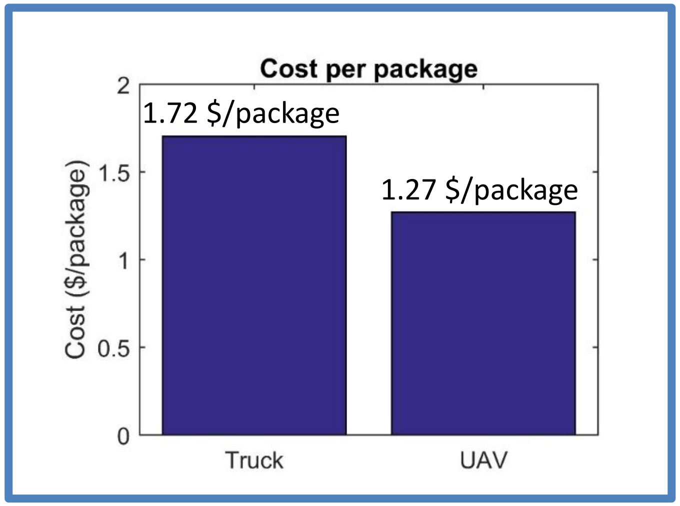
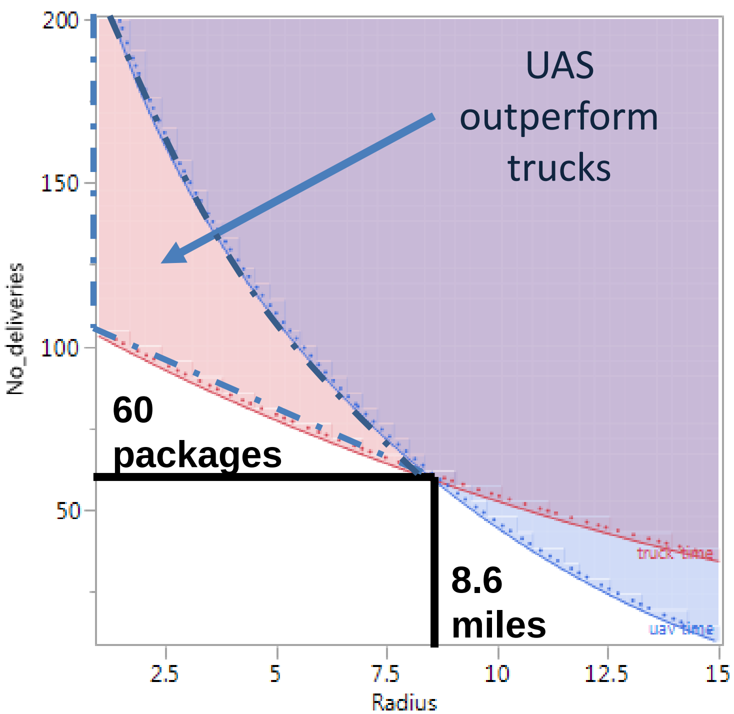
Preliminary Truck vs. UAS Study

- Parametric study varying number of packages and delivery radius
- As time window is decreased, feasibility point shifts in favor of UAS

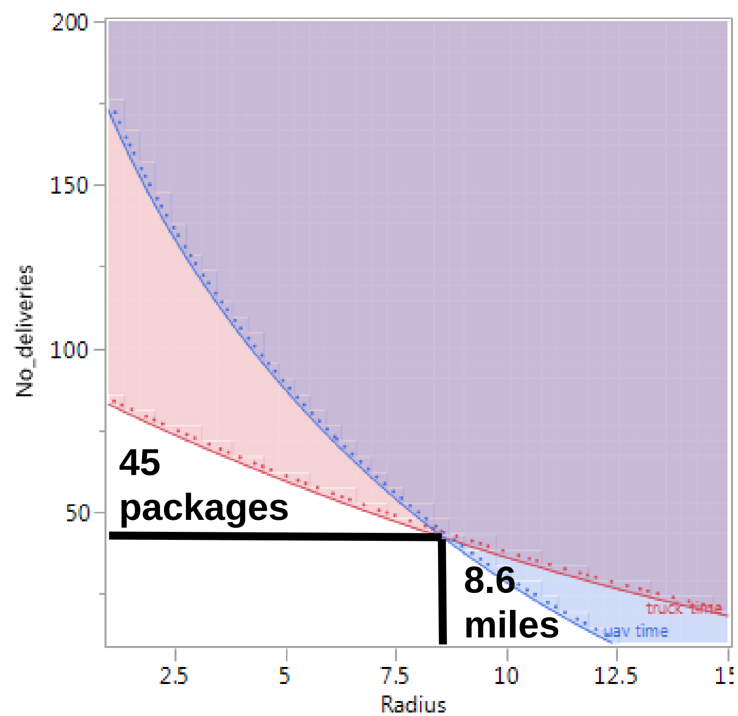




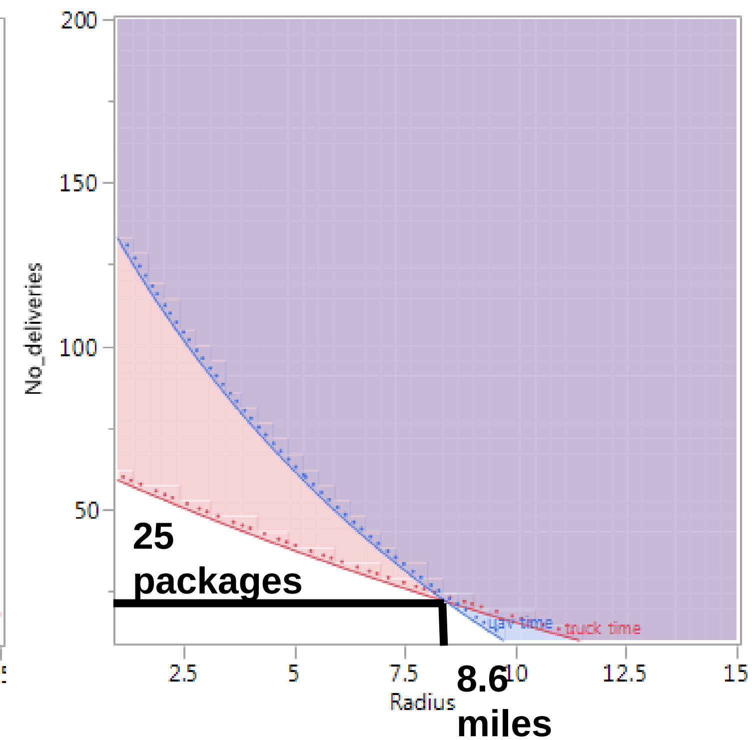
120 min



90 min



60 min



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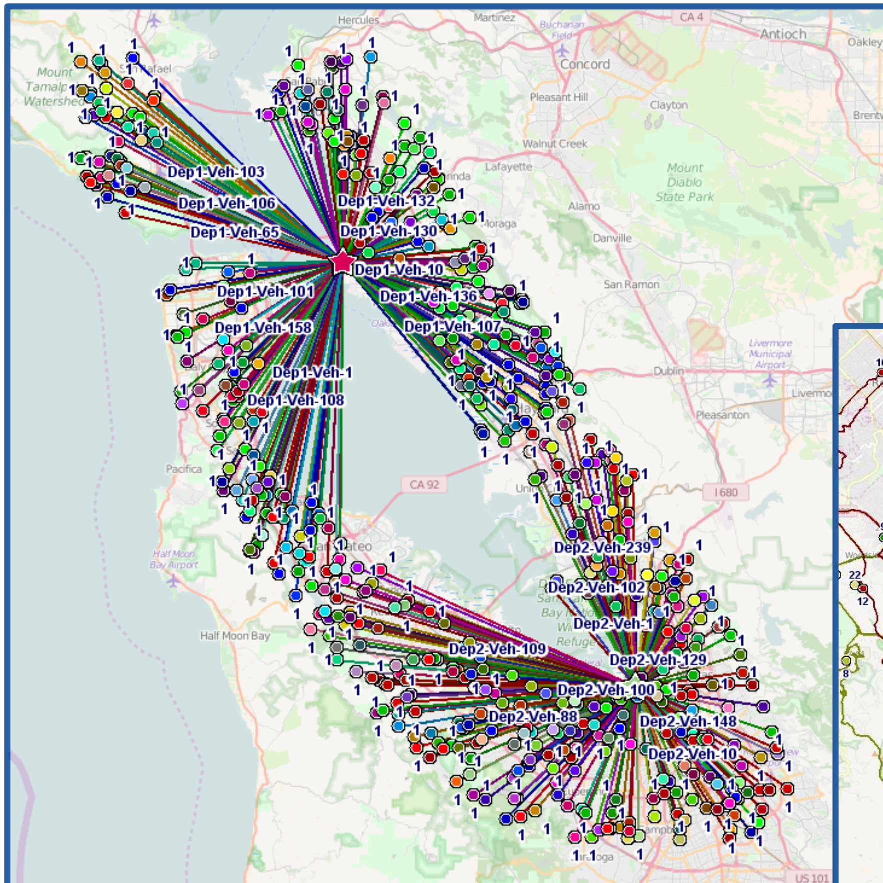
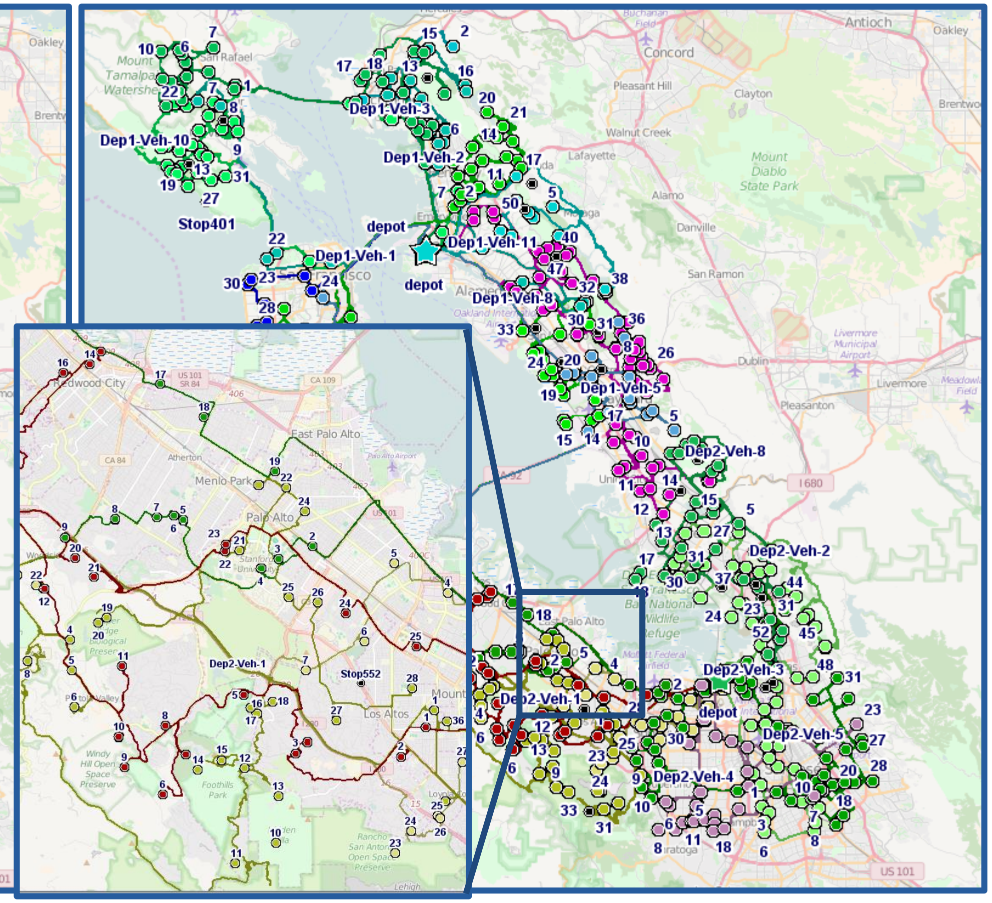
Higher Fidelity Routing Model

UAS With 1 Package



Trucks



- Utilizing an open-source toolset integrating Jsprit/Graphhopper and OpenStreetMaps to find global optimum and integrate road networks
- Plan to explore the impacts of UAS routing, delivery radius, delivery density, number of warehouses, delivery windows, vehicle speeds…
- Will then use the same framework to evaluate additional scenarios

Conclusions

- Goal is to explore plausible business cases
- First phase of work will end in May and will continue as a funded study
- Presenting work at AIAA Aviation 2016
- We encourage any interested parties to collaborate!

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