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A Framework for Using Drones After a Tornado

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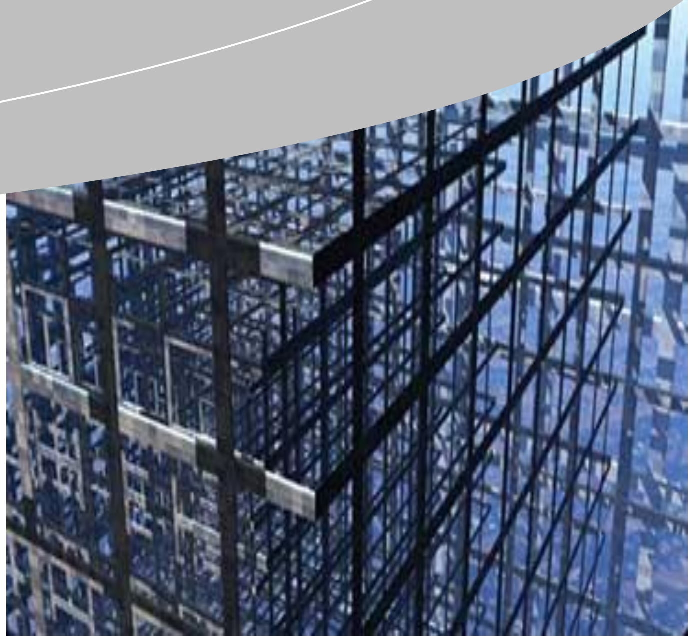
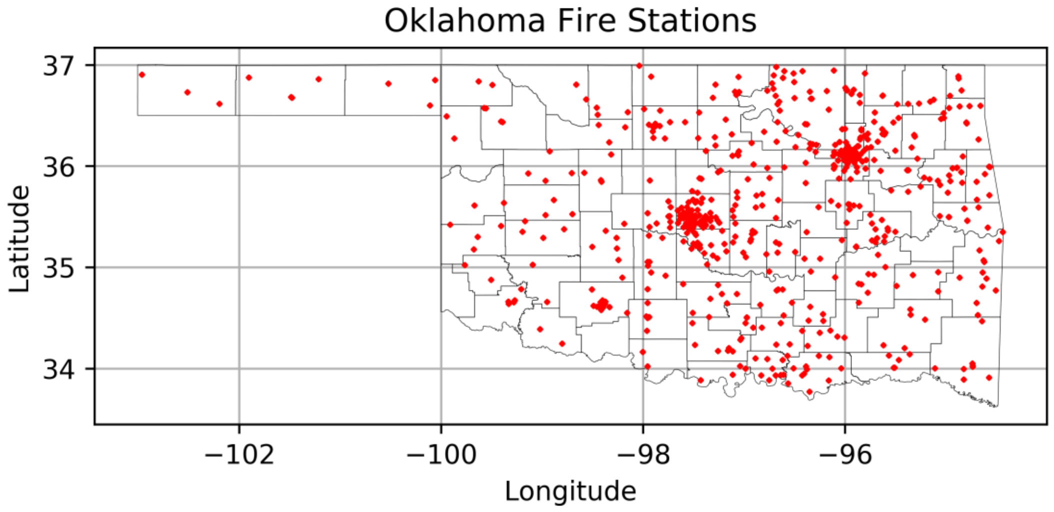


Outline



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- Introduction and literature overview
- Introduction to tornadoes
- Problem description and formulation
- Framework and application
- Concluding remarks

Drones in disaster response

- Some organizations and research institutions are adding a new dimension to their search and rescue operations by using UAVs and drones
- Proliferation of cell phones provides a detection opportunity
- Key study from Beck, et al (2018) where the authors propose a system for assisting in locating people after the Haitian earthquake in 2010

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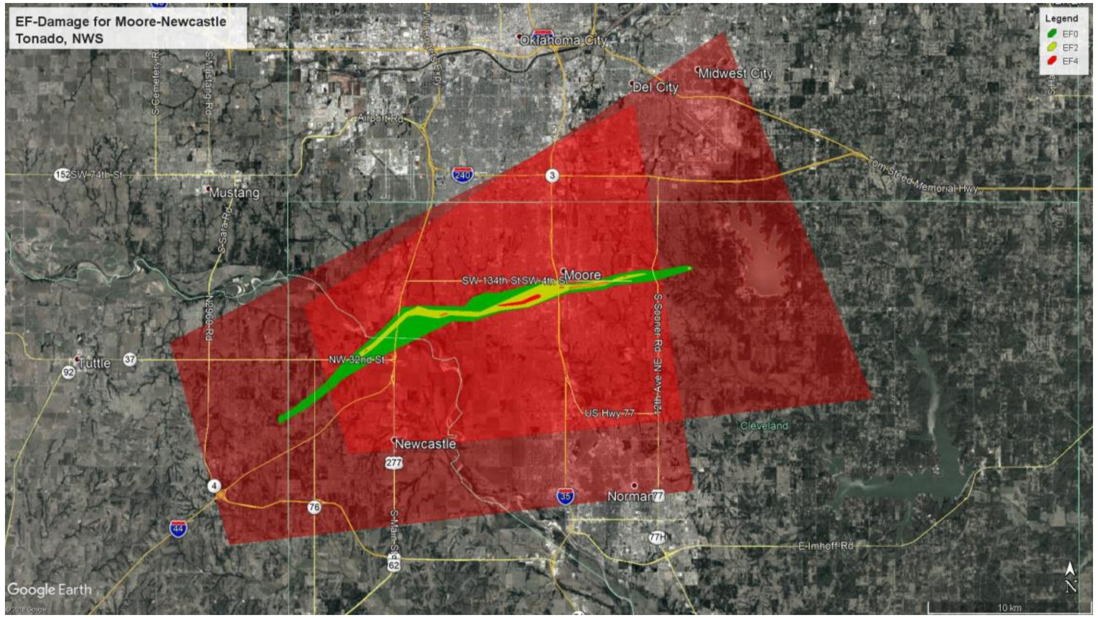
Beck, Zoltan, et al. “Collaborative Online Planning for Automated Victim Search in Disaster Response.” *Robotics and Autonomous Systems*, vol. 100, 2018, pp. 251–266., doi:[10.1016/j.robot.2017.09.014](https://doi.org/10.1016/j.robot.2017.09.014).

What is a tornado?

- A violently rotating column of air in contact with the ground
- Usually causes damage to structures near the column of air
- The Enhanced Fujita (EF-*n*) scale is used to *asses damage*
  - *n* can take a value of 1 to 5, inclusive



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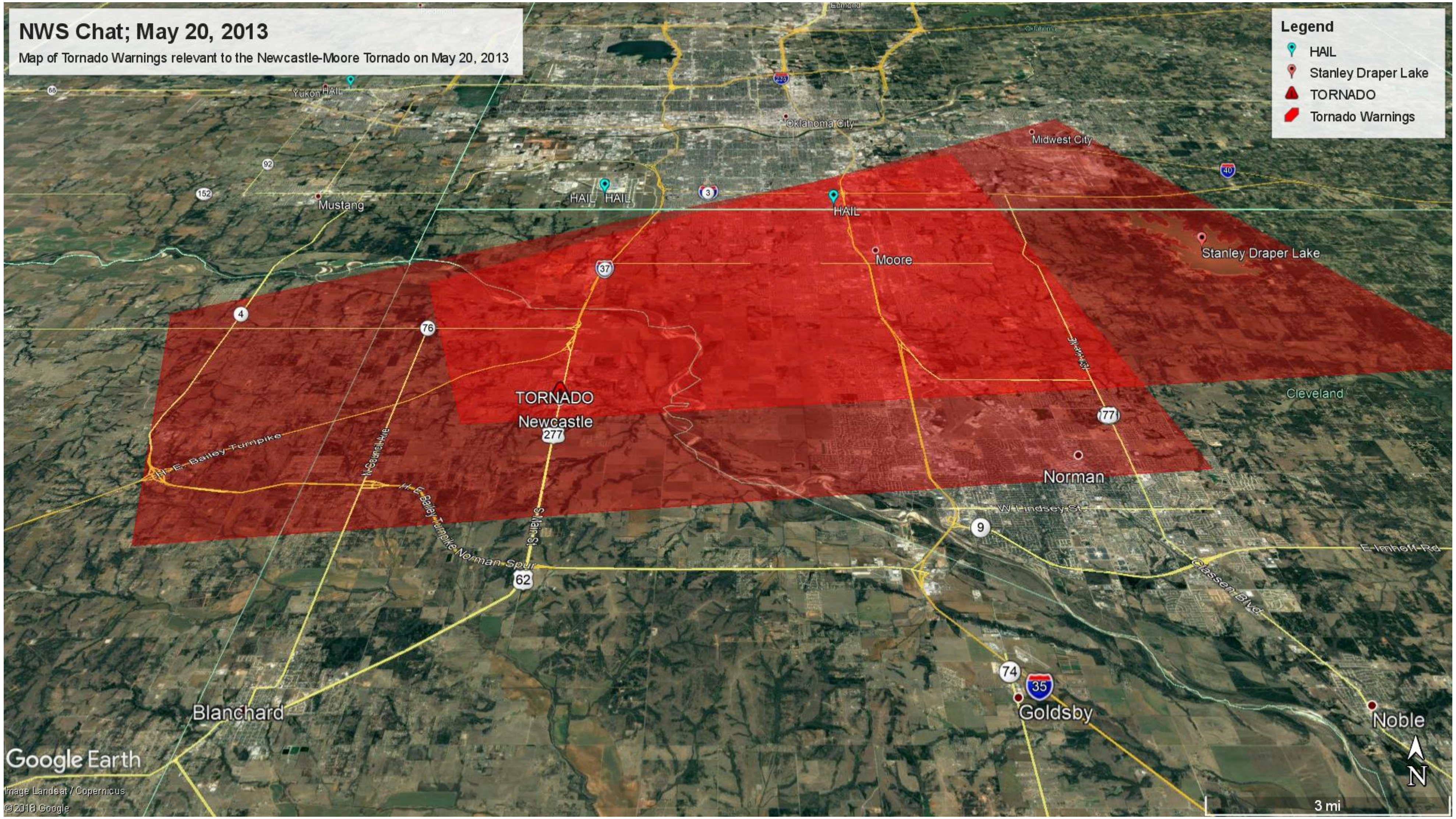
A sample of a storm based warning and a local storm report



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Problem description (1/2)

- Using fixed wing drones with wireless sensor and other sensors
- Stationed at fire stations throughout the state
- Data from:
  - Weather information from the NWS
  - Geospatial data from the state of Oklahoma

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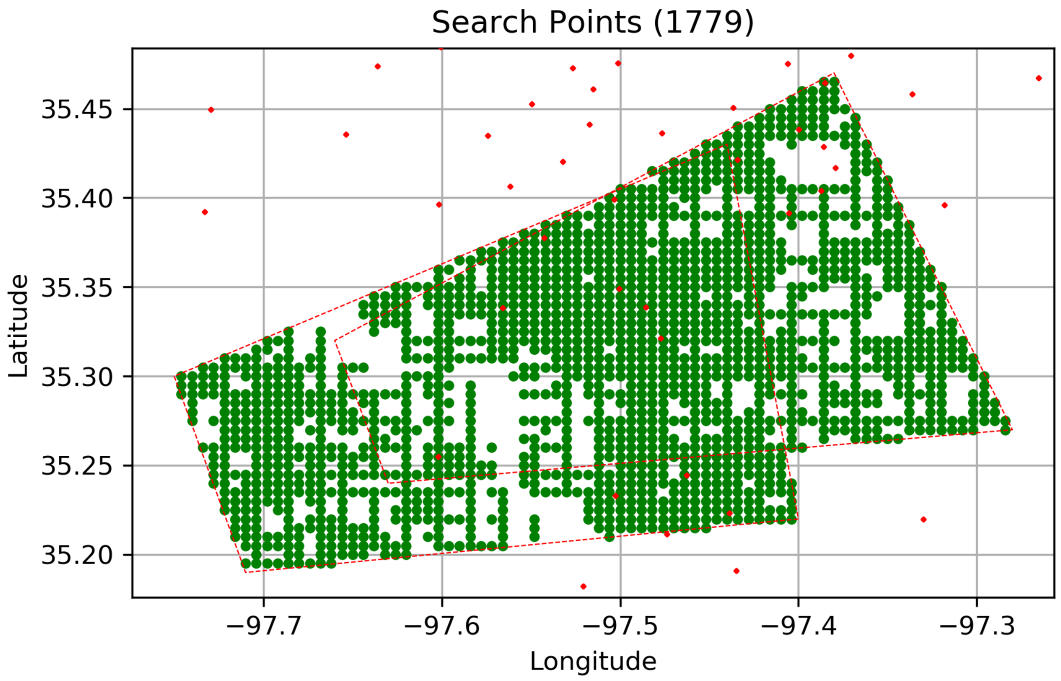
Problem description (2/2)

- Formulation envisioned as a distance-constrained vehicle routing problem (DCVRP) with multiple depots
- Began with formulation from Kek, et al (2008) and modified to suit the problem here
- Overall service time is paramount
- Tertiary goals include minimizing the number of drones used and the distance each drone takes in it's tour



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Problem Formulation and Constraints (1/2)

Sets:

$i \in W$	Set of waypoints (customers)
$s \in S$	Set of stations (depots where drones depart)
$i \in V = \mathrm{W} \cup \mathrm{S}$	Set of hubs and customers

Parameters:

t_{ij}	Cost (time) of going from i to j
E	The upper limit of time a drone can fly (endurance)
K	The upper limit on the number of drones available
M	Big-ass number, specifically $Q + \max_j [t_{ij}]$

Variables:

$x_{ijk} \in \{0,1\}$	Arc i to j is traveled by drone from depot k
$y_k \in \{0,1\}$	Indicator variable that drone route k is used
$z_{ik} \in \mathbb{R}^+$	Load variables specifying the total load serviced by vehicle since its last visit to a depot by the time it reaches customer node. Read as maximum load on route k.
$\bar{t} \in \mathbb{R}^+$	Time it takes for the longest drone to complete it’s tour

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Problem Formulation and Constraints (2/2)

Objective Function:

$$\min \bar{t} + \lambda \sum_{s \in S} y_s \qquad (1)$$

Maximum tour time:

$$\sum_{i \in V} \sum_{\substack{j \in W \\ j \neq i}} t_{ij} x_{ijs} \leq \bar{t} \qquad \forall s \in S \qquad (2)$$

Endurance limit:

$$\sum_{i \in V} \sum_{\substack{j \in V \\ j \neq i}} t_{ij} x_{ijs} \leq E \qquad \forall s \in S \qquad (3)$$

Drone used indicator:

$$\sum_{j \in W} x_{sjs} = y_s \qquad \mathrm{s} \in S \qquad (5)$$

Flow constraints:

$$\sum_{\substack{j \in V \\ j \neq i}} \sum_{\mathrm{s} \in S} x_{ijs} = 1 \qquad i \in W \qquad (5)$$

$$\sum_{\substack{i \in V \\ i \neq j}} x_{ijs} - \sum_{\substack{\mathrm{k} \in V \\ j \neq \mathrm{k}}} x_{j\mathrm{k}s} = 0 \qquad s \in S,\ j \in V \qquad (6)$$

Load and subtour elimination constraints:

$$z_{ss} = 0 \qquad s \in S \qquad (7)$$

$$\left(z_{is} + t_{ij} - z_{js}\right) \leq M\left(1 - x_{ijs}\right) \qquad i \in V,\ j \in W,\ s \in S,\ i \neq j \qquad (8)$$

$$\left(z_{is} + t_{ij} - z_{js}\right) \geq -M\left(1 - x_{ijs}\right) \qquad i \in V,\ j \in \mathrm{W},\ \mathrm{s} \in \mathrm{S},\ i \neq j \qquad (9)$$

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Proposed heuristic

- A version of the nearest insertion heuristic
- $\bar{t}$ is defined in (2) which is the longest tour in the problem
- n_d is defined as number of depots used, i.e. $\sum_{s \in S} y_s = n_d$
- t_{wp} is the time it takes to traverse the waypoints
- t_s is the length of a given tour starting from depot s

```
Begin with shortest arc between a station
and a waypoint
```

$\bar{t}, n_d \leftarrow$ `0,0`

```
While there are no waypoints unvisited
    Cycle through the remaining waypoint and depot
     combinations and add the waypoint that
     increases t̄ the least
    In case of a tie, add the waypoint that
     minimizes n_d
    In case of a tie, add the waypoint that
     minimizes t_wp
    In case of a tie, add the waypoint that
     minimizes t_s
    Else add the waypoint randomly
```

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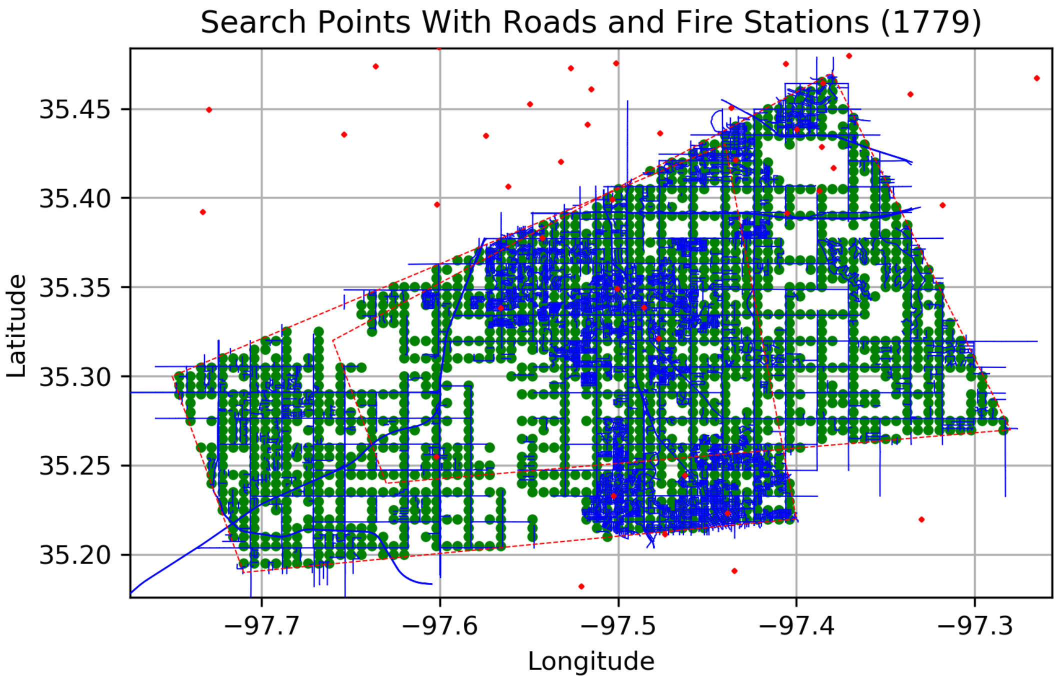
Test case

- Data from Moore-Newcastle Tornado in 2013
- 1779 waypoints + 200 fire stations (depots) generated from the data
  - MBILP of $\cong 778 \times 10^6$ binaries and $\cong 354 \times 10^3$ continuous and $\cong 1 \times 10^9$ equations



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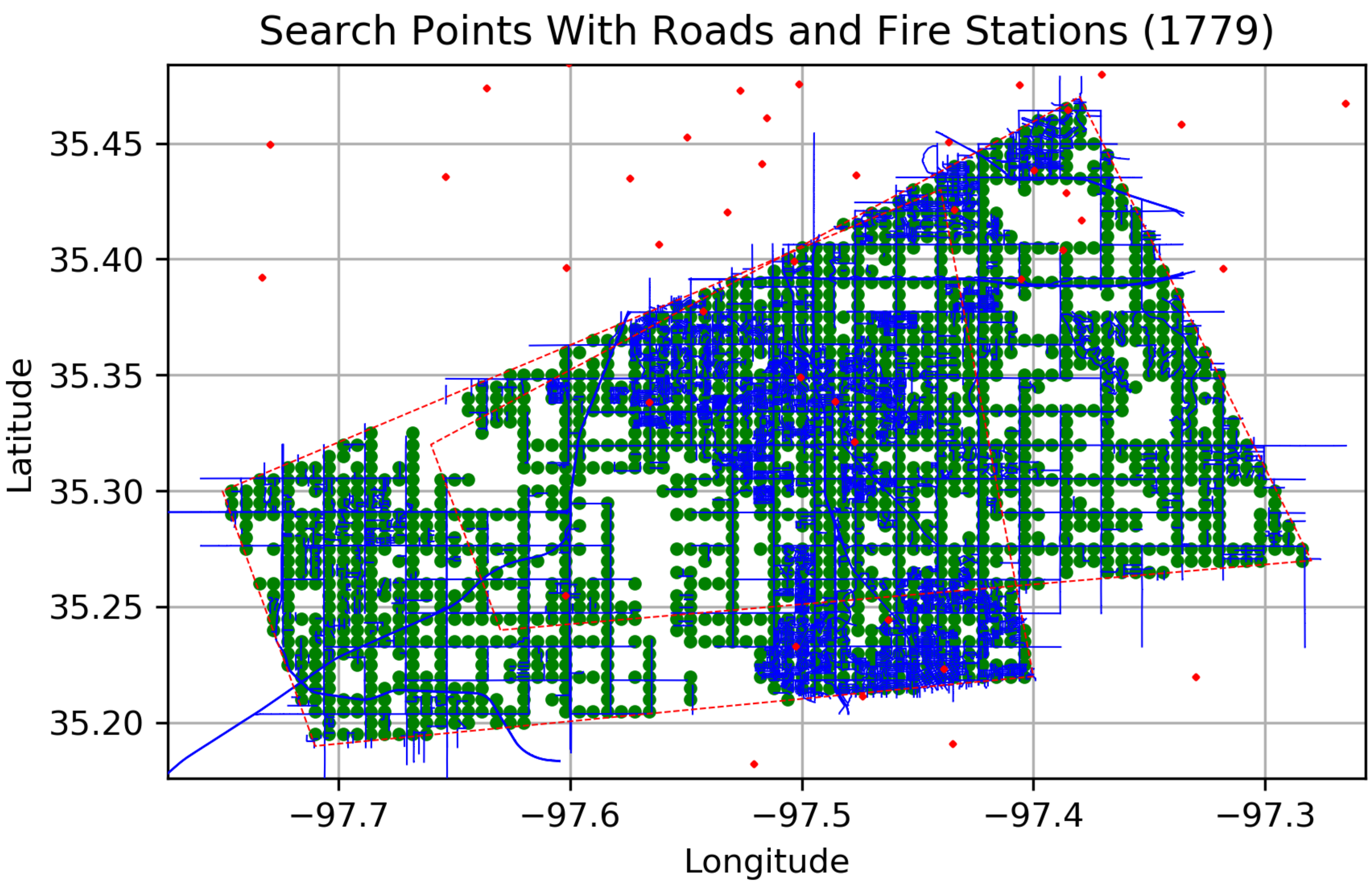
Test case



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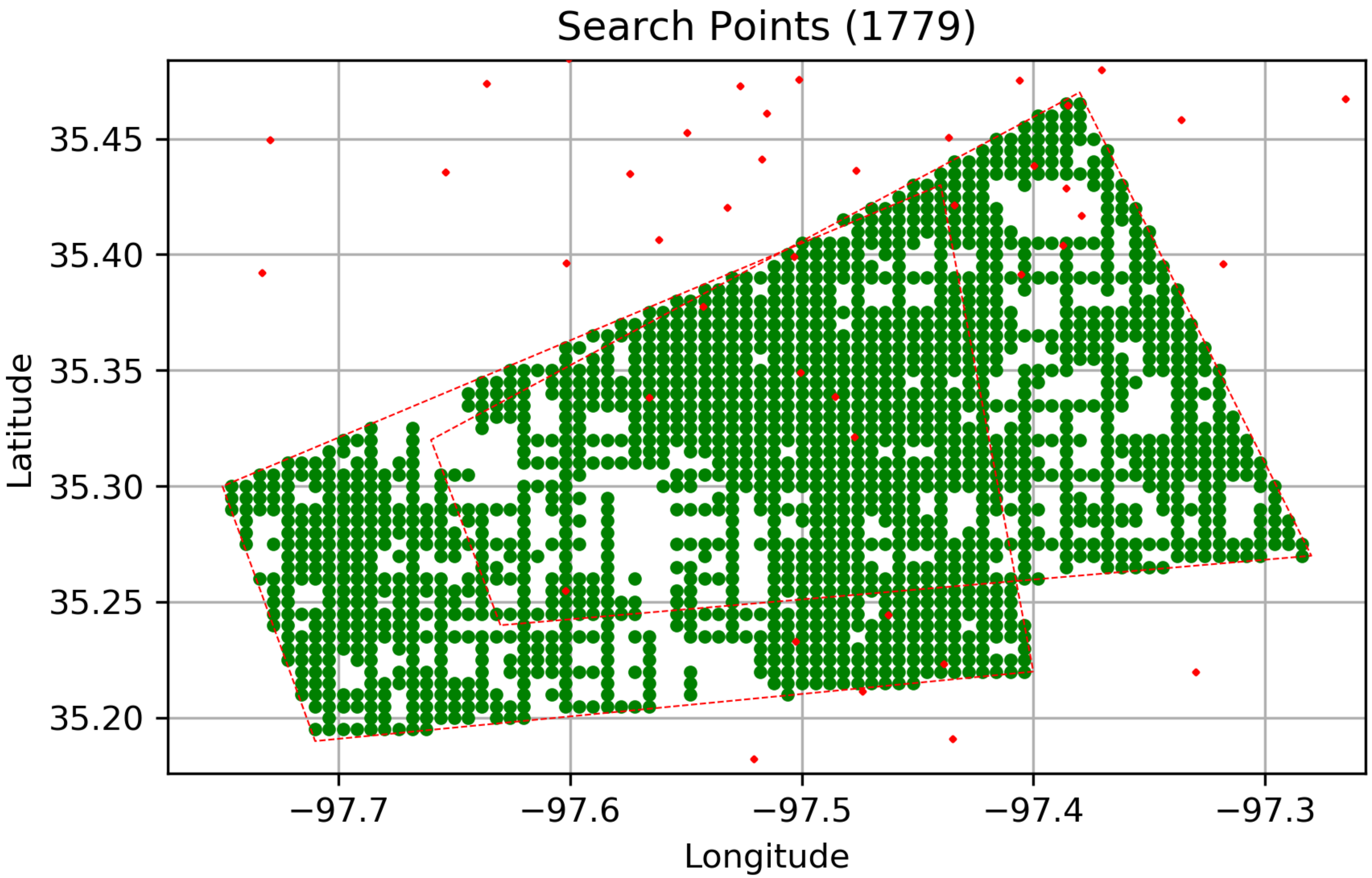
Test case



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Executing the test case

- Executed on an AMD A7-7600 APU processor with 16GB of ram
- Loading and processing data takes approximately 120 seconds
- Two heuristics tested: cluster-first route second and nearest neighbor
  - Clustering was parallelized

	t_bar (hr)	Time (s)	Launches
Clustering	7.9	10	25
Nearest	3.1	363	21

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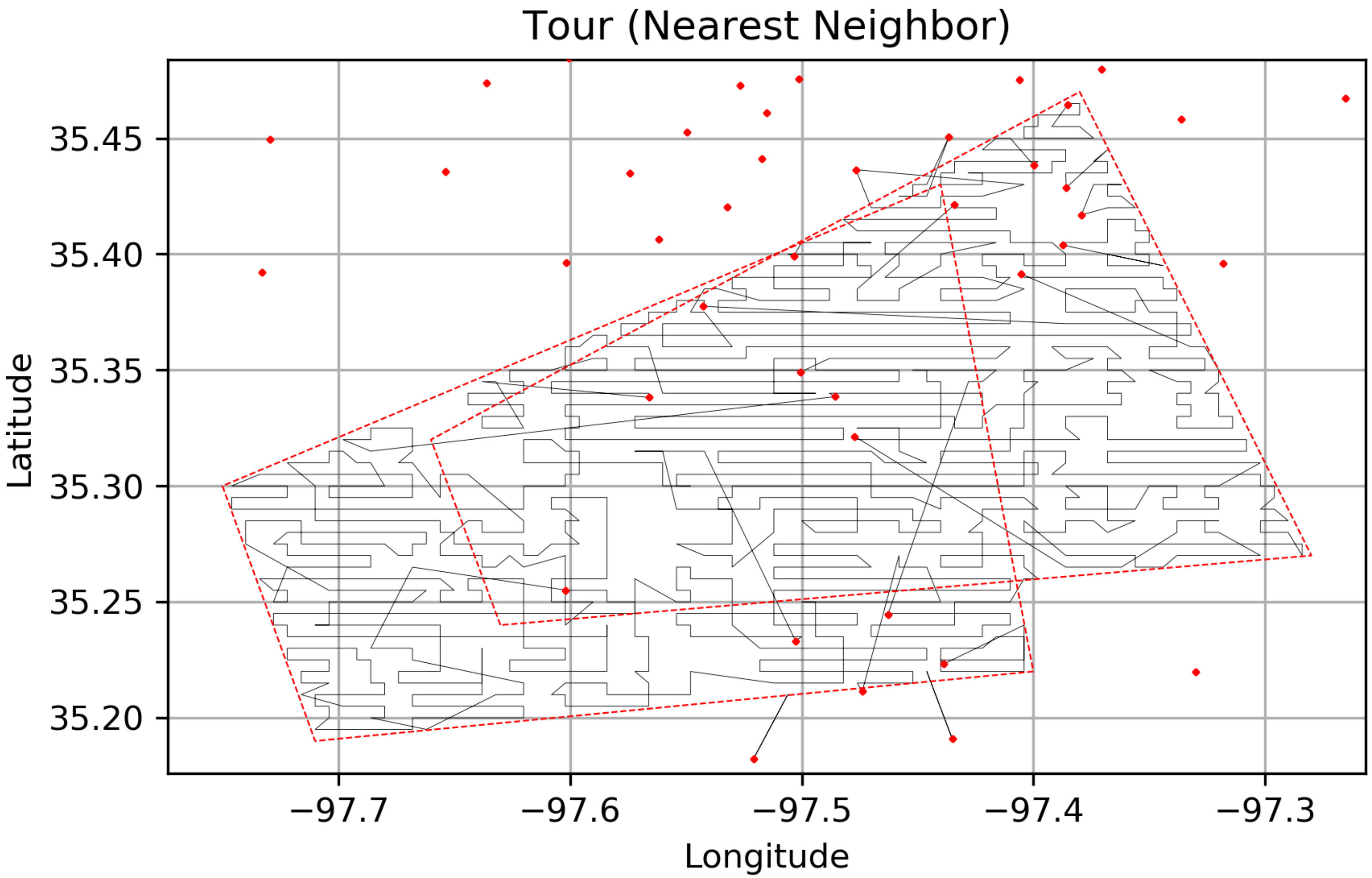

	t_bar (hr)	Time (s)	Launches
Nearest	3.1	363	21

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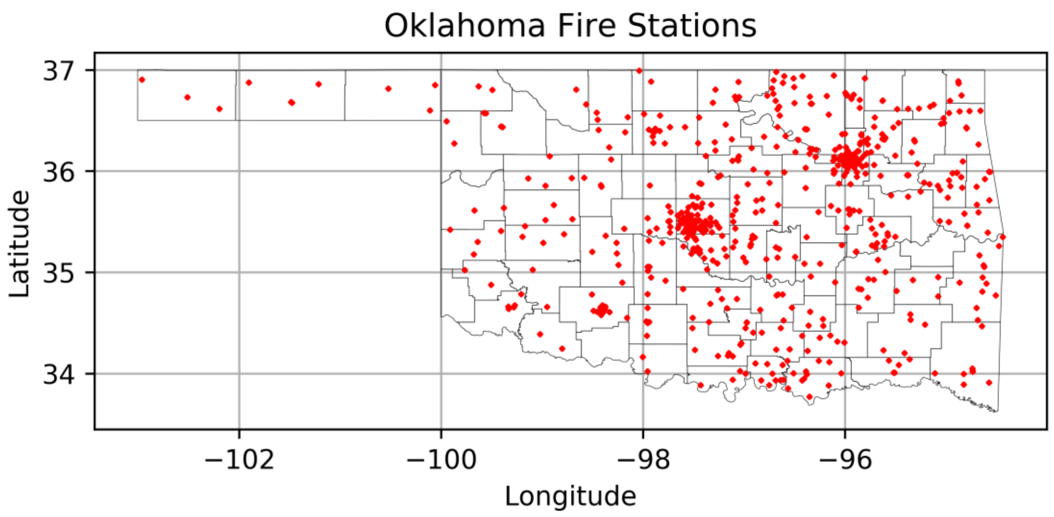
Conclusions and future steps

- Finish the (meta)heuristic.
- While we task the UAVs to search the entire area; often times, the damage associated with the tornado is a small part of this initial search area.
- While the objective of this paper was to scan the entire search area in as short amount of time - in practice the objective should be to find the damaged area as quickly as possible.
- In an operational sense, once some damage is uncovered, the drone can re-allocate itself to prioritize adjacent areas as the best indicator of a damaged structure is another damaged structure.
- In practice, manned aircraft must return to base, but the UAVs could potentially land away from base and be picked up by a staff member.

Thank You



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Badge Code

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