Validating AAM Concepts and Algorithms in Simulation and Test

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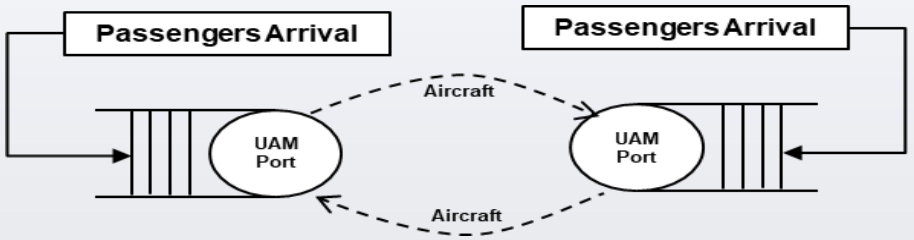
Lincoln AAM Testbed Framework

Modules

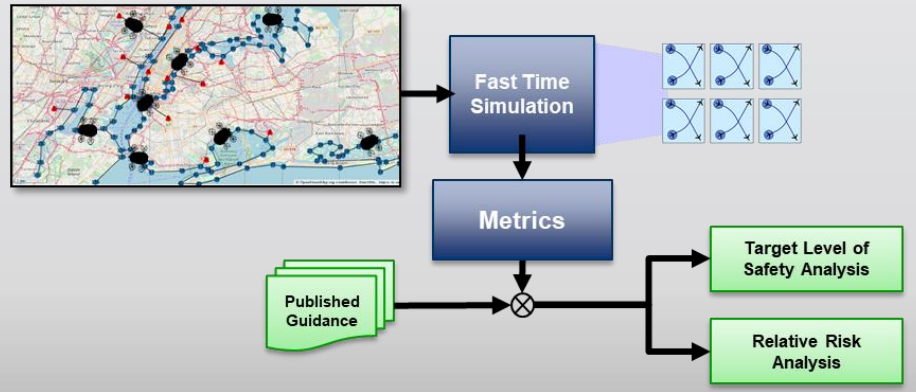
- UAM Demand
  - Based on census, ground traffic, or desired scenario throughput
- Vertiport
  - Capacity – parking/charging
  - Locations
  - Network connections
- Aircraft Fleet
  - Flight phase dynamics
  - Cargo/Passenger capacity
  - Turn around time
  - Reserve flight time
  - Weather resilience
- Flight Network
  - Altitude layers
  - Expert design or Rule set generation
  - Required vehicle separation
- Weather
  - Corridor shutdown criteria
  - Resolution (100m^2 - 1 km^2)
  - Simulated single day impact or historical playback

Simulators

Event Driven Simulator



Discrete Time Simulator



Example Supported Outputs

Infrastructure:
- Vertiport design tradeoffs
- Contingency planning analysis

Operations:
- Network tradeoffs, fleet size, routing strategies, rebalancing tradeoffs, passenger adoption rate

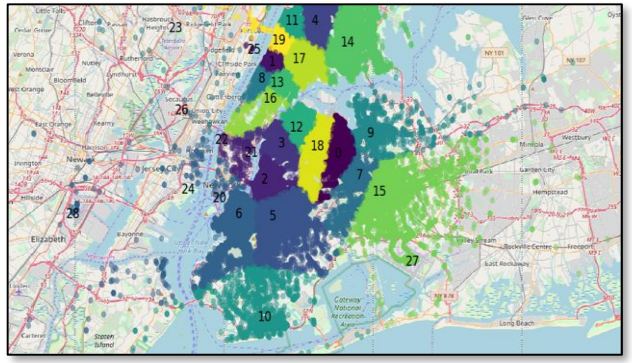
Conflict resolutions:
- Detect and Avoid, separation standards

Weather:
- Data requirements, operational restrictions, sensor standards

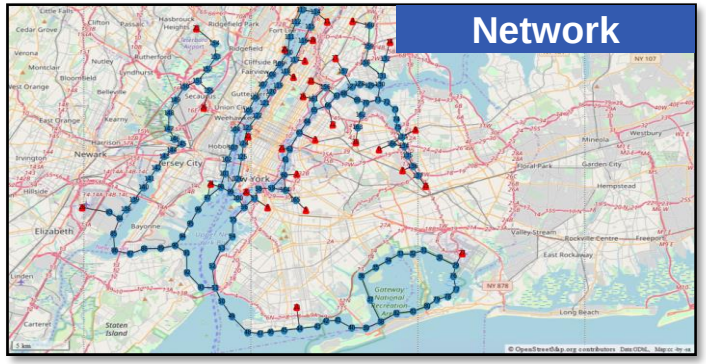
Societal:
- Noise analysis, energy distribution requirements

Each input module can be replaced with user specified custom modules/algorithms

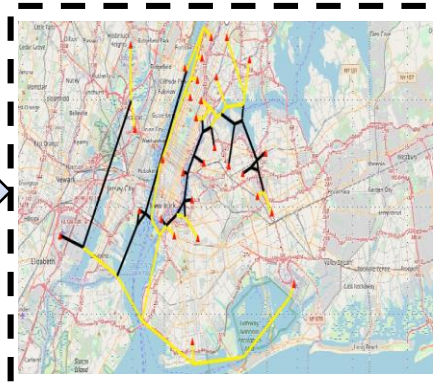
Overview

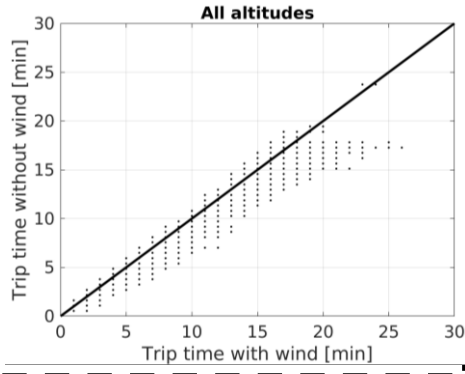


Catchment area of each vertiport and demand



Network module provides all paths to vertiport ranked by path length





Sector Status based on weather go/no-go

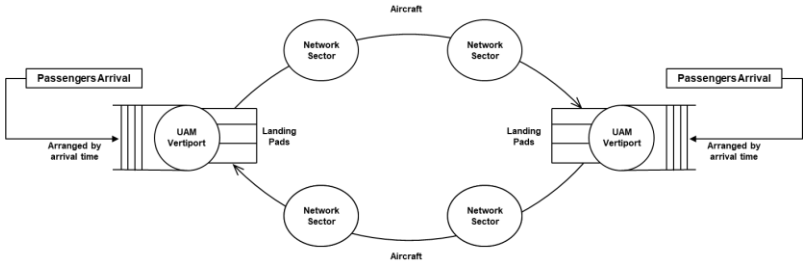
Trip Time with Wind

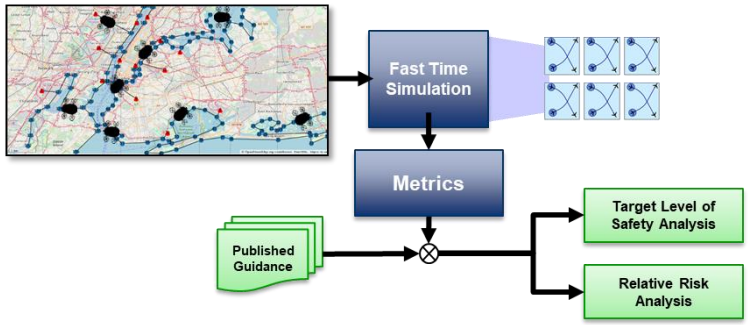
Final simulator used depends on research

- **Queueing simulator**
  - **System level efficiency/throughput**
  - **Scenario exploration (~2-5 min simulations)**
  - **Currently no en-route actions possible**
  - **No limit on vehicle/vertiports (tested up to 7,000 simultaneous operations)**

- **Discrete time simulator**
  - **Limited simulation environment (~100 simultaneous operations)**
  - **En-route actions detect and avoid, or other algorithms possible**

- **All state information available in both simulators**



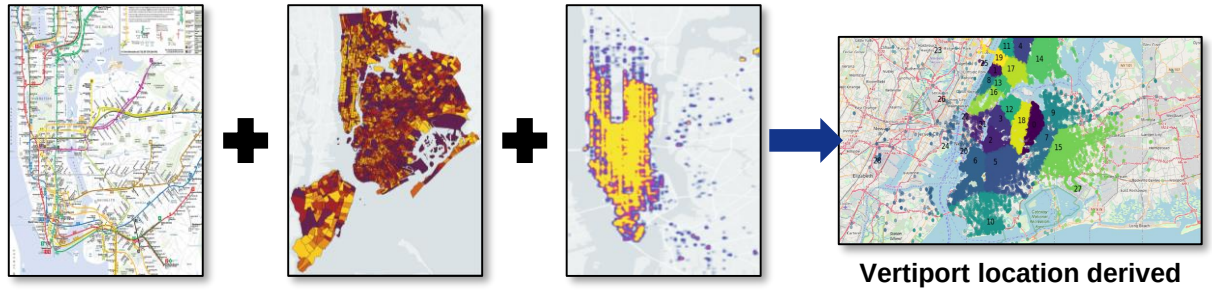


Helicopter	Origin	Destination	Depart Time	Arrival Time	Passengers
229	21	22	0	10	4
1	20	6	1	3	1
8	27	21	1	33	1
10	22	2	1	10	1
12	16	8	1	19	1
14	2	5	1	4	2
17	24	22	1	5	0
18	22	5	1	11	1
23	22	6	1	7	2
31	22	8	1	7	2
33	16	21	1	5	2
42	20	21	1	5	3

Output from scheduling algorithm or playback of operations fed through weather module

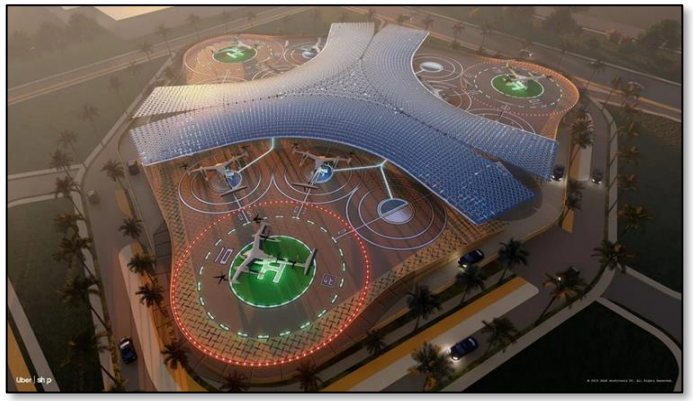
Vertiport Modeling

- **Vertiport candidates can be selected by assessing:**
  - **Connectivity to public transport**
  - **Demand for for-hire vehicles (value of time)**
  - **Population density**
  - **Concept of operations**



Subway network | Subway connectivity[1] | FHV Data[2] | Vertiport location derived from FHV data

- **Vertiport characteristics affecting operations:**
  - **Uniform or pre-selected parking availability at each vertiport**
  - **Connections to network**
  - **Landing slot availability**
  - **Turn around time (constant or random)**
  - **Universal use or proprietary**



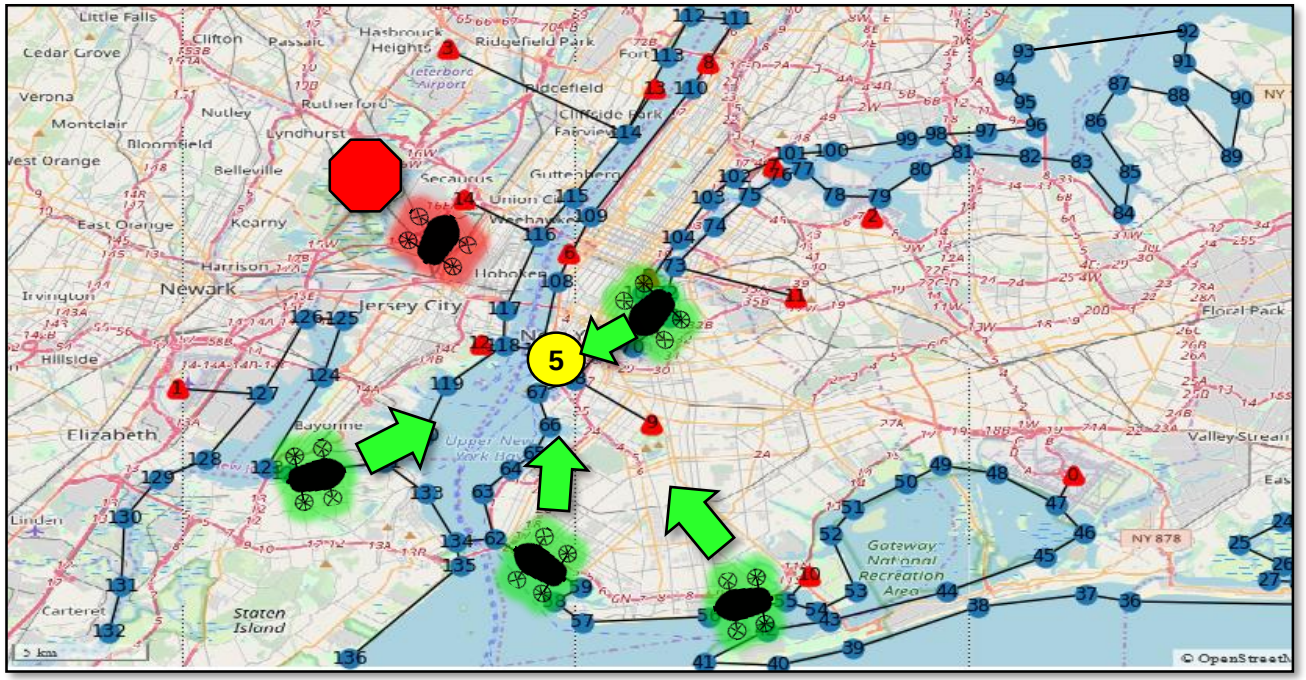
Framework can assess impact of vertiport properties on day to day operations

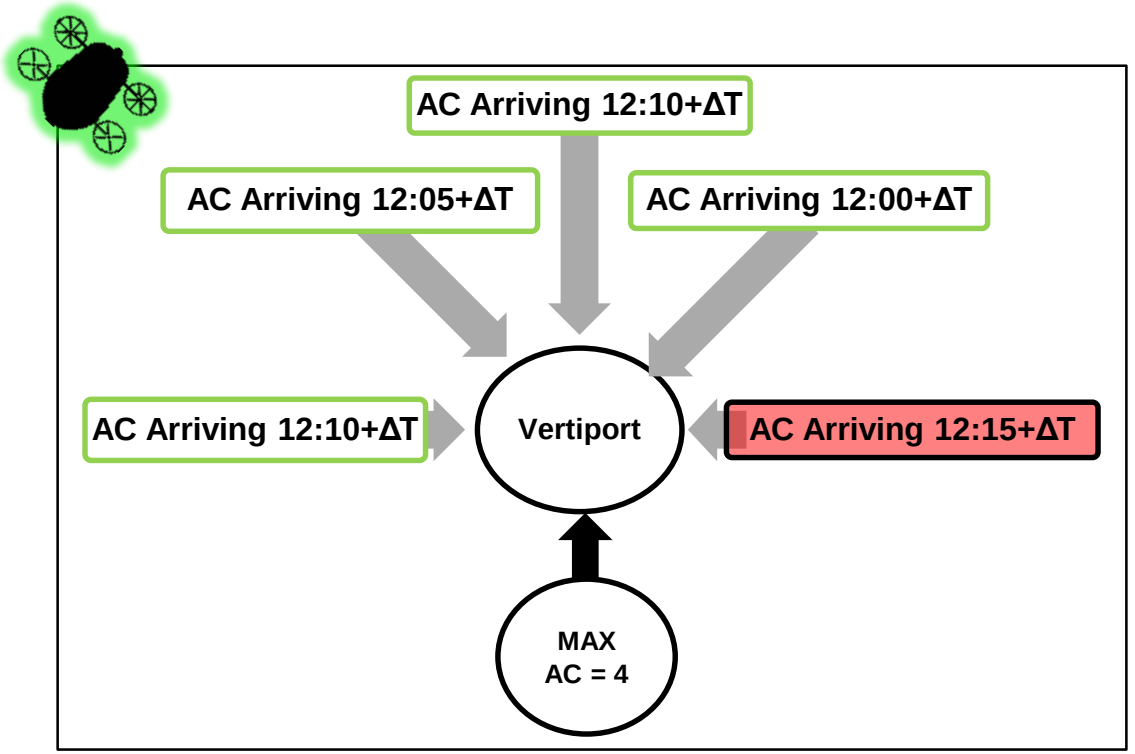
1. NYC 2010 Census Data
2. NYC Taxi & Limousine Commission

FHV = For-Hire Vehicle

Aircraft Management

- **Discrete event model sequences landing sites based on a priority queue**
  - **Impacted by assumptions on (un)loading , maintenance logs, refueling or battery swap and traffic flow**





Network Topology Design

- **Flexibility in network design to assess the impact of various policy decisions**

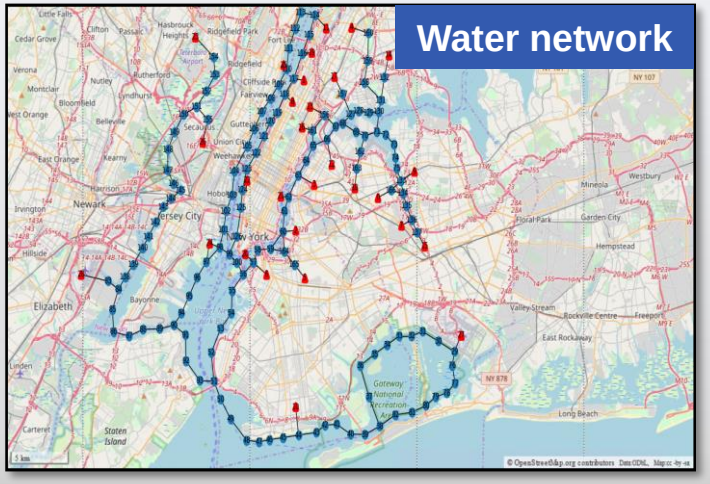
Network Generation Rule Sets +

Expert Assisted Design

- **Network structure created from user defined rule sets:**

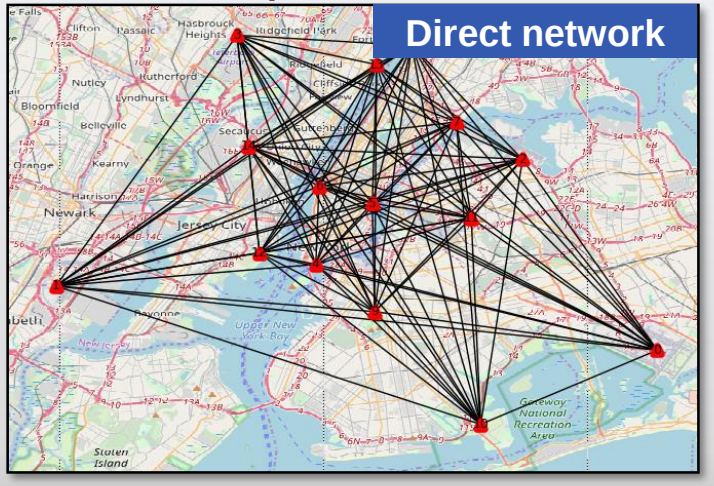
Strict noise restriction
Strict restriction on flight over land
Preference for helicopter corridors

Water network



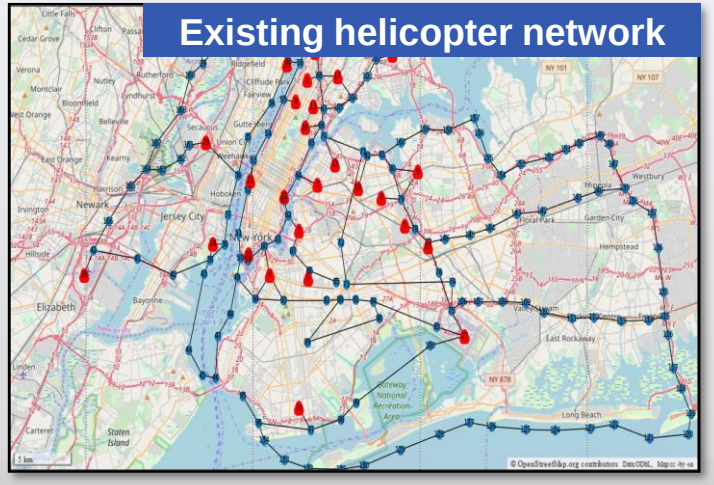
No noise restrictions
Prioritize decrease in flight times
No airspace restrictions

Direct network



Medium noise restrictions
Prioritize helicopter corridors
Some airspace restrictions

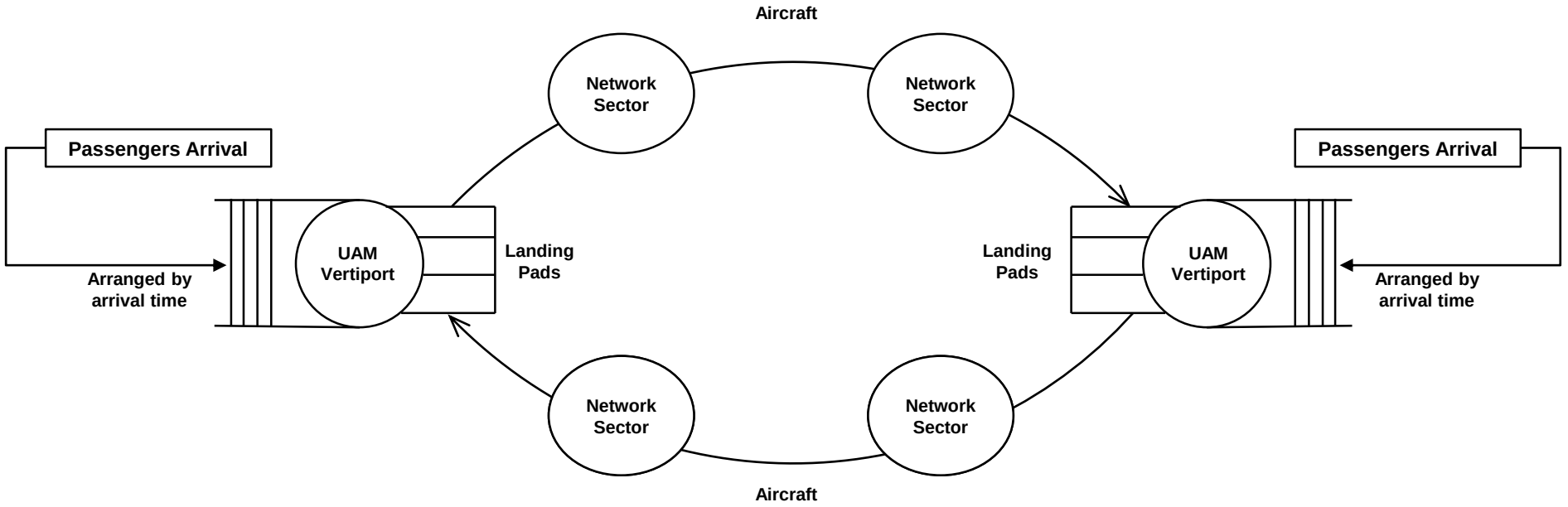
Existing helicopter network



Analysis of network topology is required for policy makers to understand efficiency and safety tradeoffs

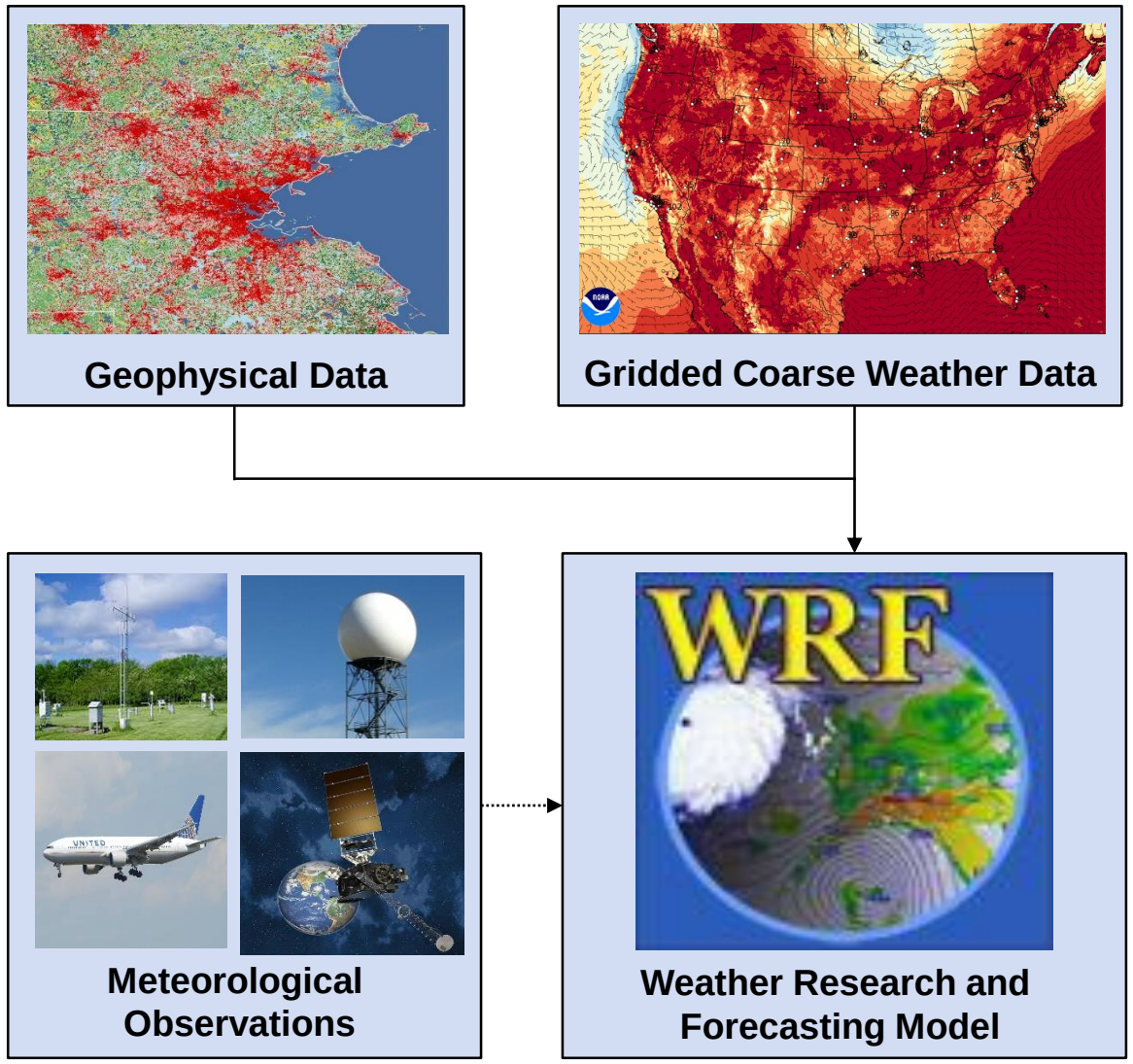
Queuing Model

- **Queuing model defines limited resources for sectors, vertiport parking, passenger queue, and controls passenger gave up criteria**
  - **Sector capacity constrain traffic through network and acts as a surrogate to separation requirements**
- **Vehicles are distributed among vertiports and dynamically assigned to ride request**
  - **Vehicle-Request pair defined by distance of vehicle to passenger, capacity**



The Weather Research and Forecasting (WRF) Model

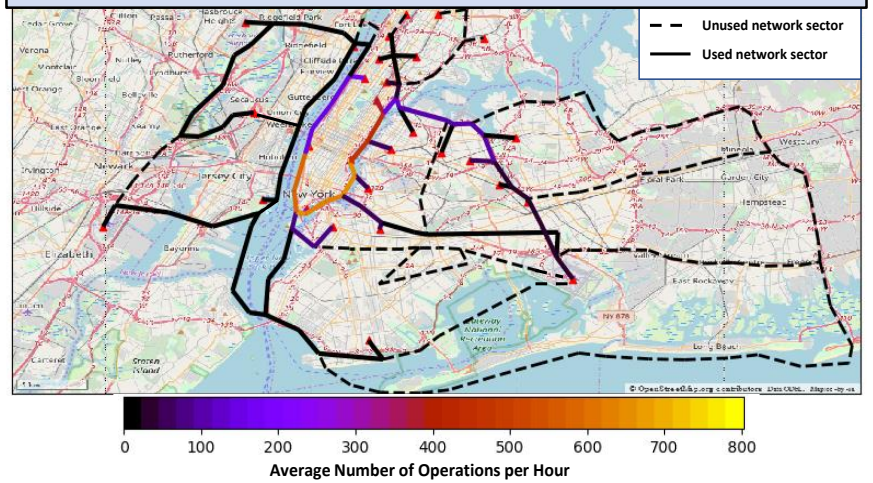
- **WRF codebase is open source**
  - **Primarily maintained and supported by NCAR**
  - **Framework for the HRRR operationally run by NOAA**
- **Highly customizable**
  - **Resolution**
  - **Domain**
  - **Physical parameterizations**
- **Produces 3-D gridded volumetric weather data**
- **Optionally can assimilate meteorological observations through WRFDA**
- **Limitations**
  - **Unable to simulate flow around buildings**
  - **Cannot resolve small-scale turbulence**



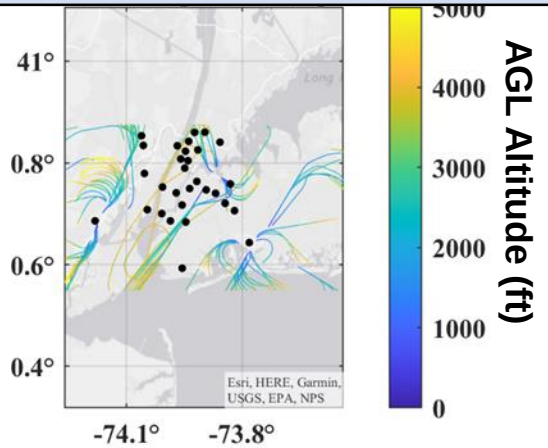
NCAR – National Center for Atmospheric Research
HRRR – High Resolution Rapid Refresh **WRFDA – WRF Data Assimilation**

Example Use of Outputs

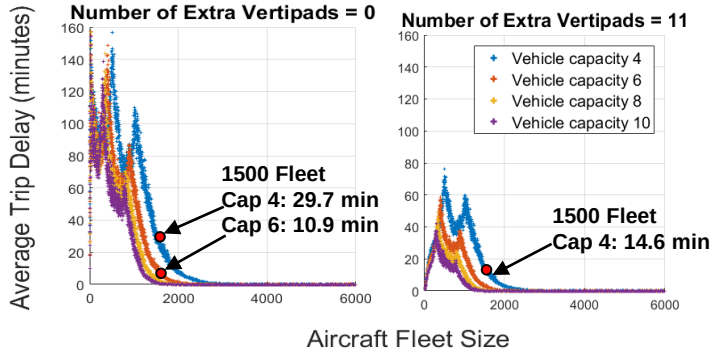
Network utilization rates



Surrounding Traffic Assessment



Infrastructure Exploration



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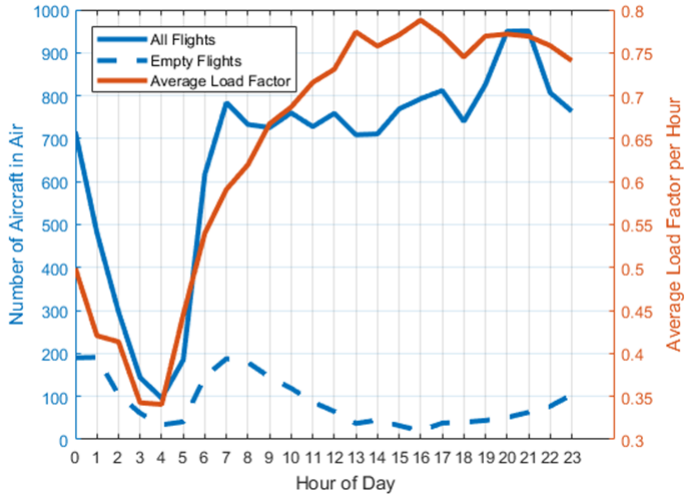
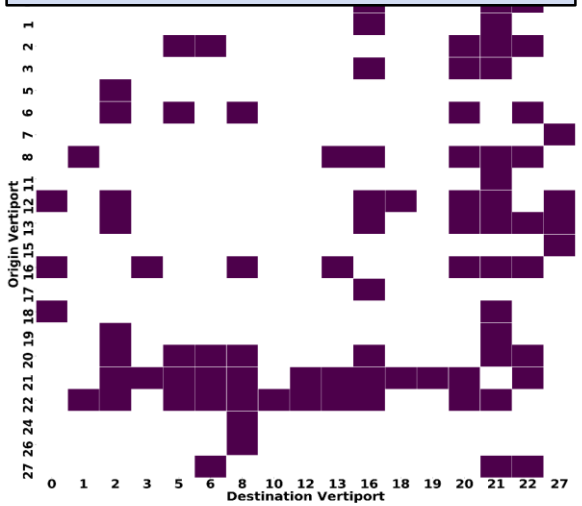
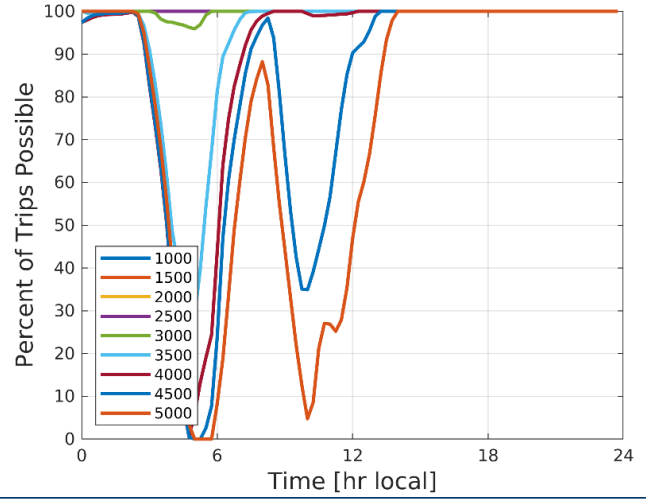


OD – delay matrix

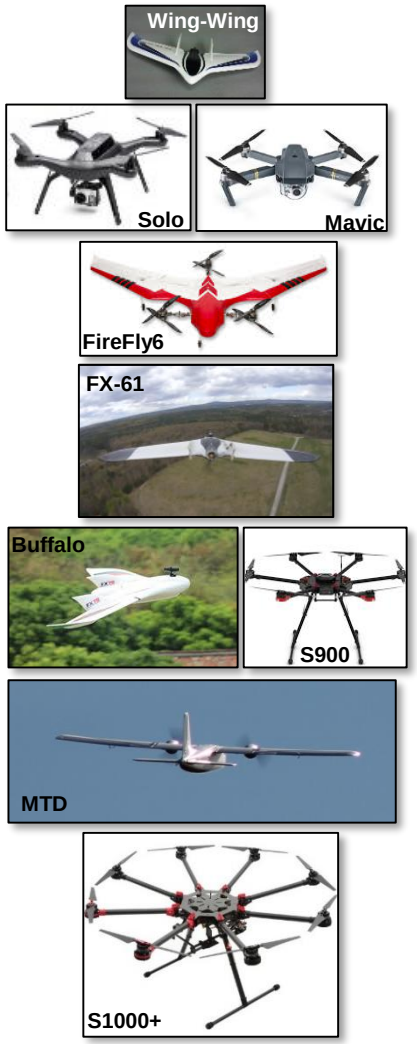


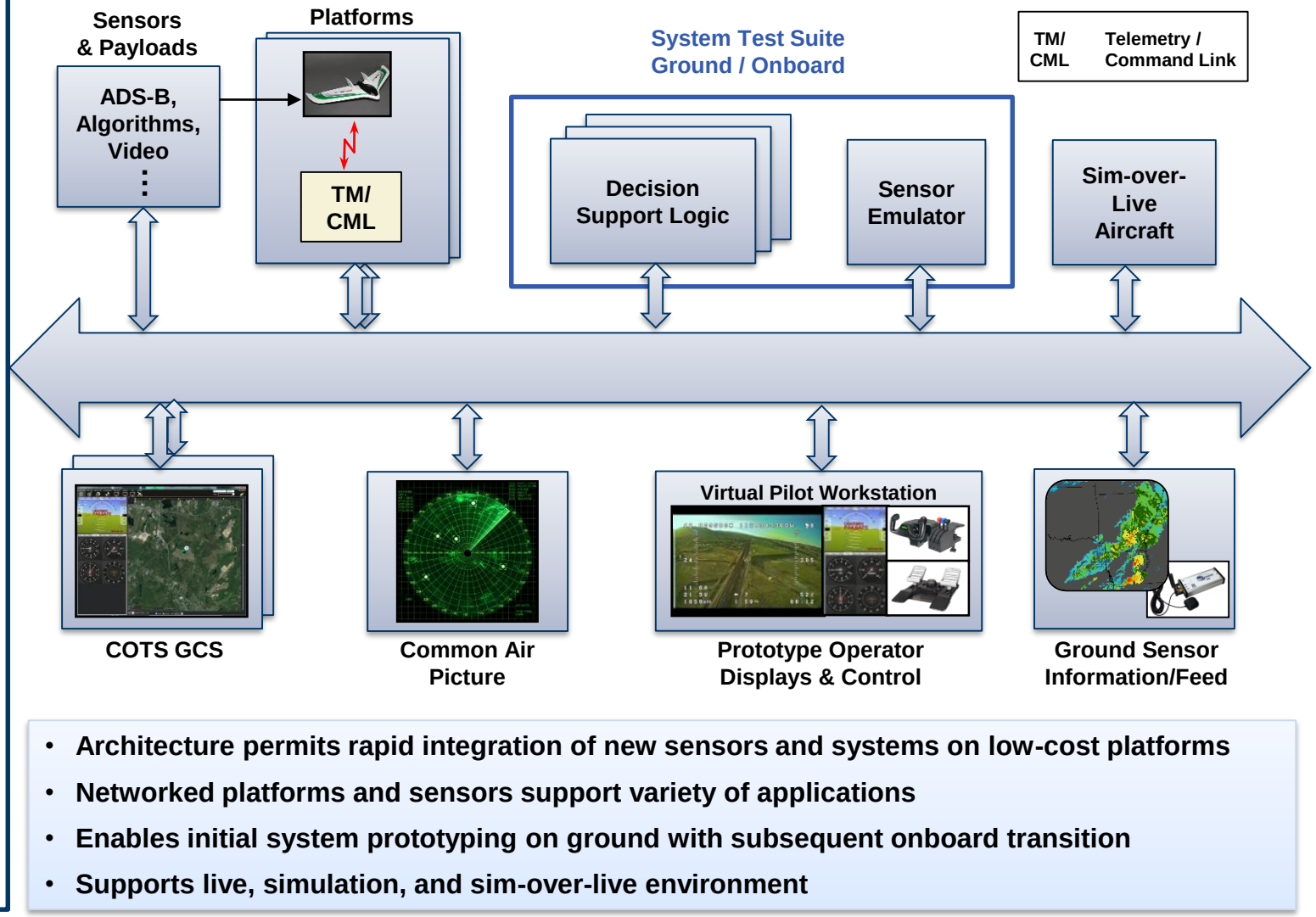
Weather impacts



Testbed Architecture, Platforms and Sensors

Platforms





- Architecture permits rapid integration of new sensors and systems on low-cost platforms
- Networked platforms and sensors support variety of applications
- Enables initial system prototyping on ground with subsequent onboard transition
- Supports live, simulation, and sim-over-live environment

Sensors