

# Fairness in 3D Urban Transportation

**NSF-PIRE Workshop, June 2021**

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Joint work with Hamsa Balakrishnan, Arjun Balasingam, Christopher Chin, Maxim Egorov, Antony Evans, Hari Balakrishnan and Mohammad Alizadeh

# Motivation: Equitable access to the airspace

- ICAO UTM Framework: “The policies, rules and priorities required to support equitable access to airspace must be developed”

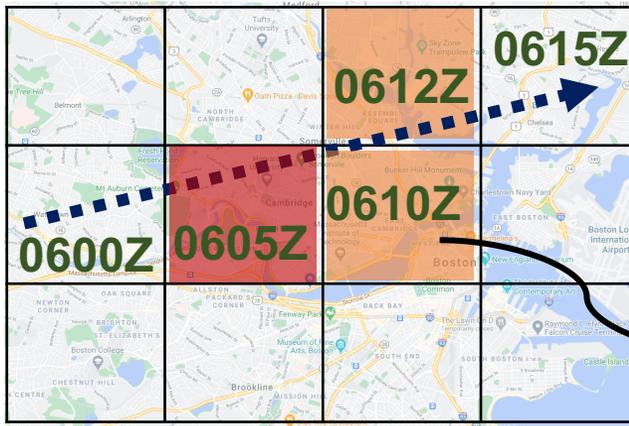
**Google drones could have a monopoly over Canberra's airspace as Wing takes flight**

By [Jake Evans](#)

Posted Thu 6 Jun 2019 at 7:02pm, updated Mon 10 Jun 2019 at 8:37pm

**We lack a principled approach to deal with fairness:**  
“it will be problematic... when two operators want to use the same space” – CASA officials

- Several challenges:



Congestion from other traffic

**Desired sector entry time**

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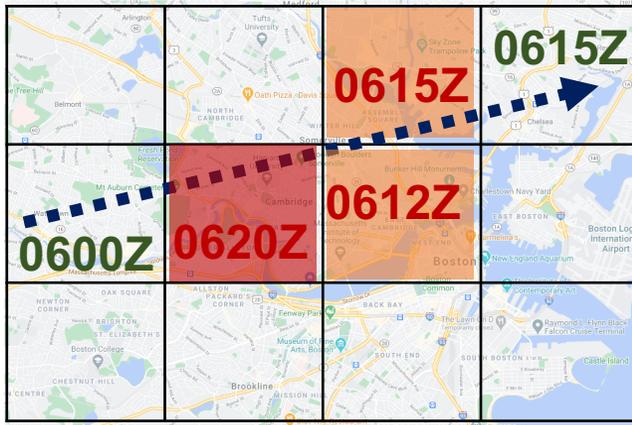
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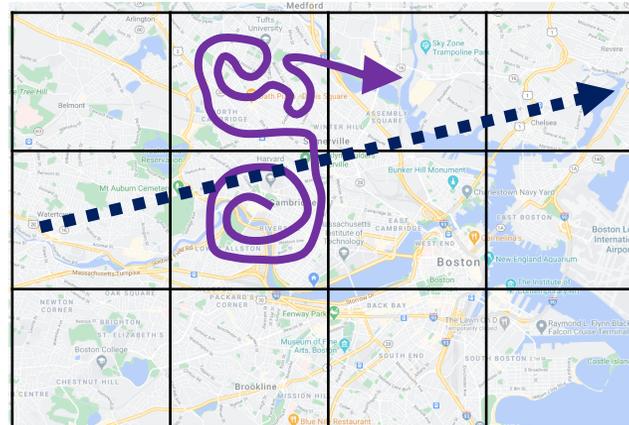
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**Locally First-come-first-serve allocation may be infeasible**



**Diverse resource requirements**

**Monitoring in fixed sectors  
VS  
Quick transit across sectors**

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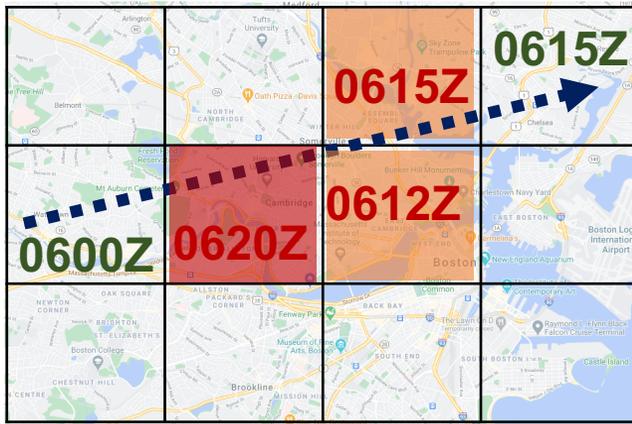
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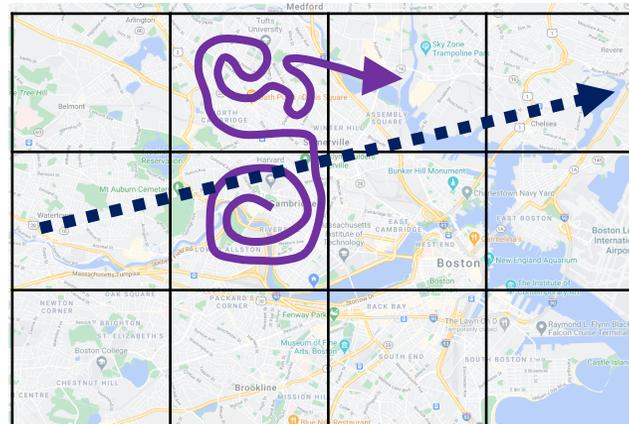
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**Diverse resource requirements**

amazon Prime Air

“30 min delivery”

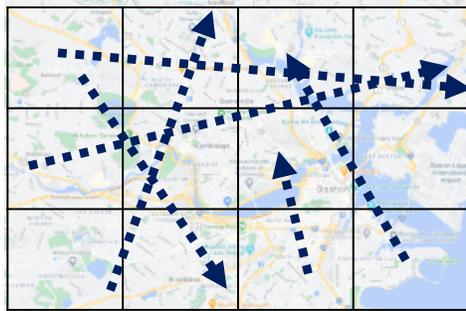
UBER Elevate

On-demand mobility

**Large-scale, dynamic environment**

How do we allocate the airspace fairly to different flights/operators?

# Algorithms for fair airspace allocation



Solve a centralized optimization problem

## Minimize

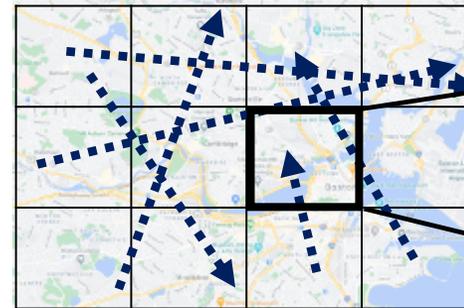
Total delay costs +  $\lambda$  Unfairness-penalty

## Subject to

Departure/Arrival/Sector Capacity  
Vehicle performance  
Flight-continuity

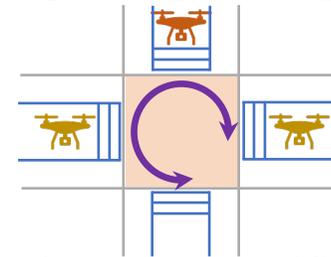
## Decision variable

Sector entry time

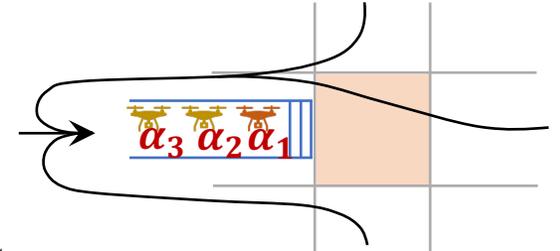


Rules-of-the road style protocols for entering each sector

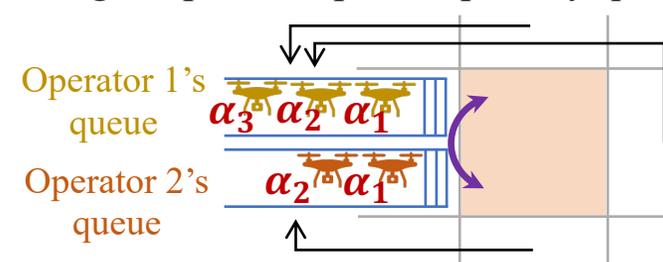
(a) Sector-specific priority queues



(b) Merged priority queue



(c) Merged operator-specific priority queues



 Operator 1  
 Operator 2  
 Queue selector  
 $\alpha_i$  Priority score for  $i$

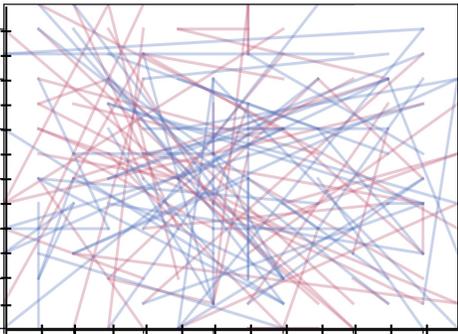
- What are measures of unfairness?

- Standard deviation of delays, flight schedule reversals, flight overtaking, time-ordered-deviation, accrued delay, dominant-resource-fairness, ...

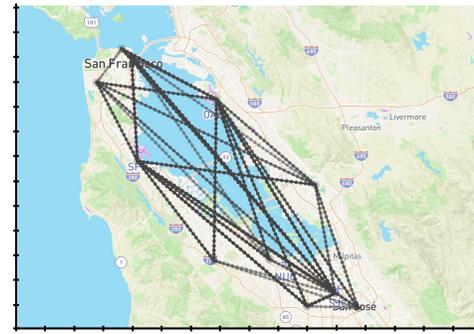
# What did we learn..

**No fairness metric is ideal across a wide range of traffic patterns...  
... although time-ordered-deviation is more robust than others**

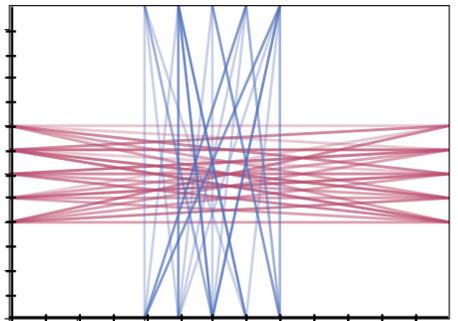
(a) Random OD pairs



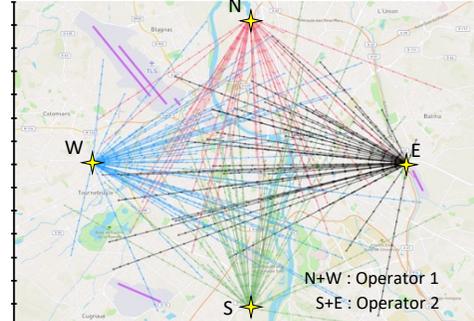
(b) Structured flows



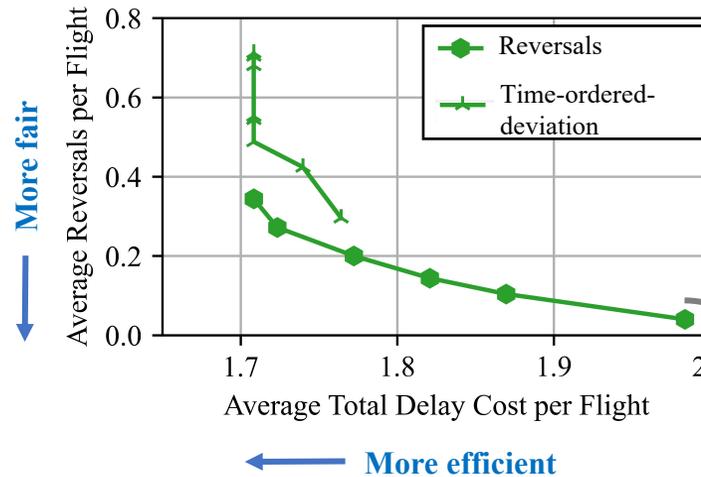
(c) Cross-flows



(d) Hub-operations



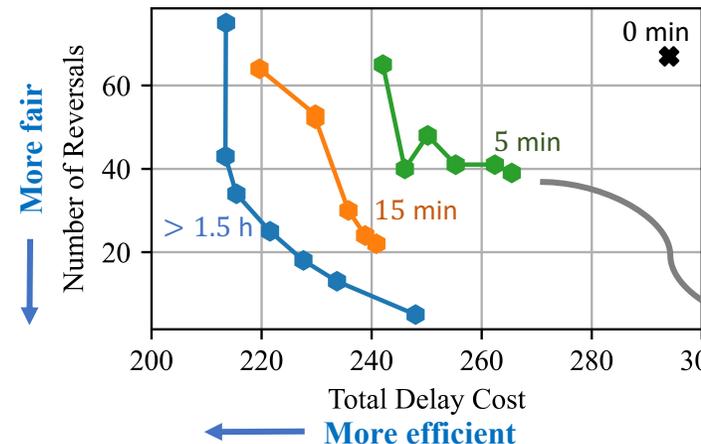
## The price of fairness is not very high



80% decrease in unfairness for only 10% increase in delay cost

Pareto-frontier for each fairness metric

## Sharing trajectory in advance can have significant benefits



Filing  $\geq 15$  min in advance can improve performance by 60%

Pareto-frontier for each file-ahead time

# Fair airspace allocation alone will not suffice...

Operators of emerging aerial services also need to serve society equitably

E.g. On-demand air-taxi service to JFK airport

BUSINESS

## Forum: How the airline industry made inequality worse

Increasing flight connections to second-tier cities would help reduce geographic inequality by creating better links with the thriving superstar cities.

By **Conor Sen** Bloomberg Opinion | JANUARY 19, 2020 — 2:58PM

## The Essential Air Service Keeps Small Towns in the Thick of Things

This little-known government program provides subsidies to airlines to keep servicing small towns across America.

By **Marcia Wendorf**  
Apr 17, 2021

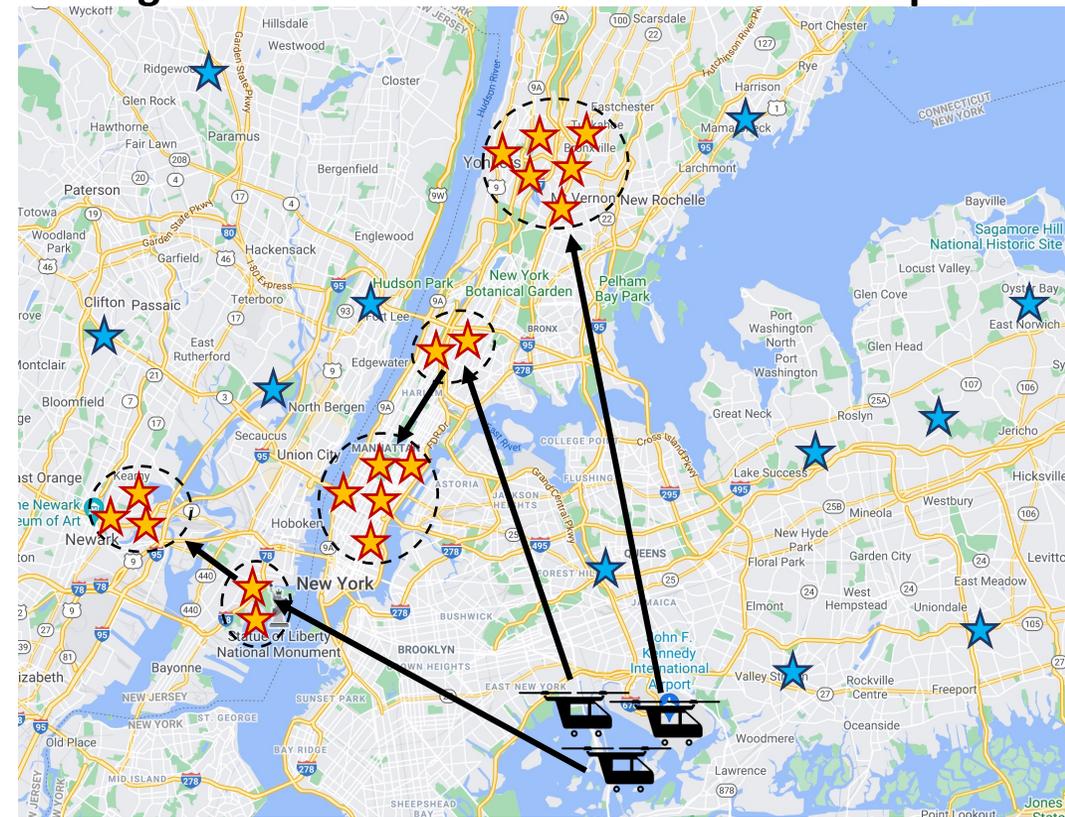
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**CITYLAB**

## Did Uber Just Enable Discrimination by Destination?

In California, the ride-hailing company is changing a policy used as a safeguard against driver discrimination against low-income and minority riders.



★ Satisfied customers

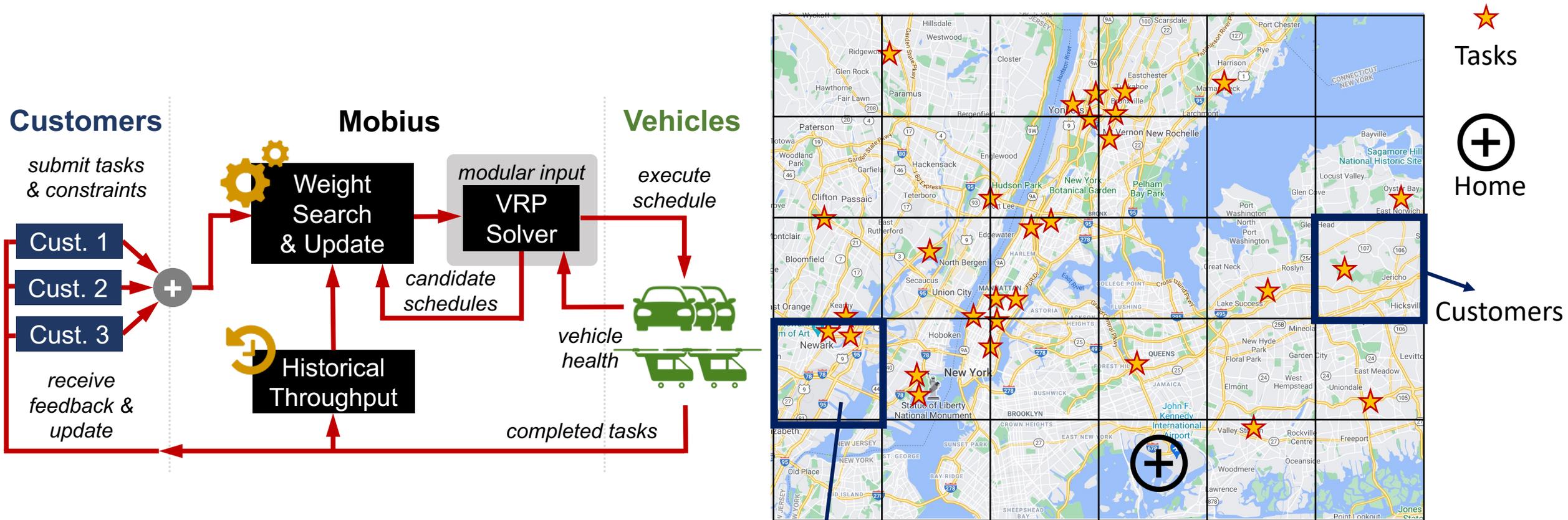
★ Unsatisfied customers

Efficient routing would not serve many communities well

How do we schedule fleets of vehicles to maximize both system-efficiency and customer-fairness?

# Our solution: Mobius

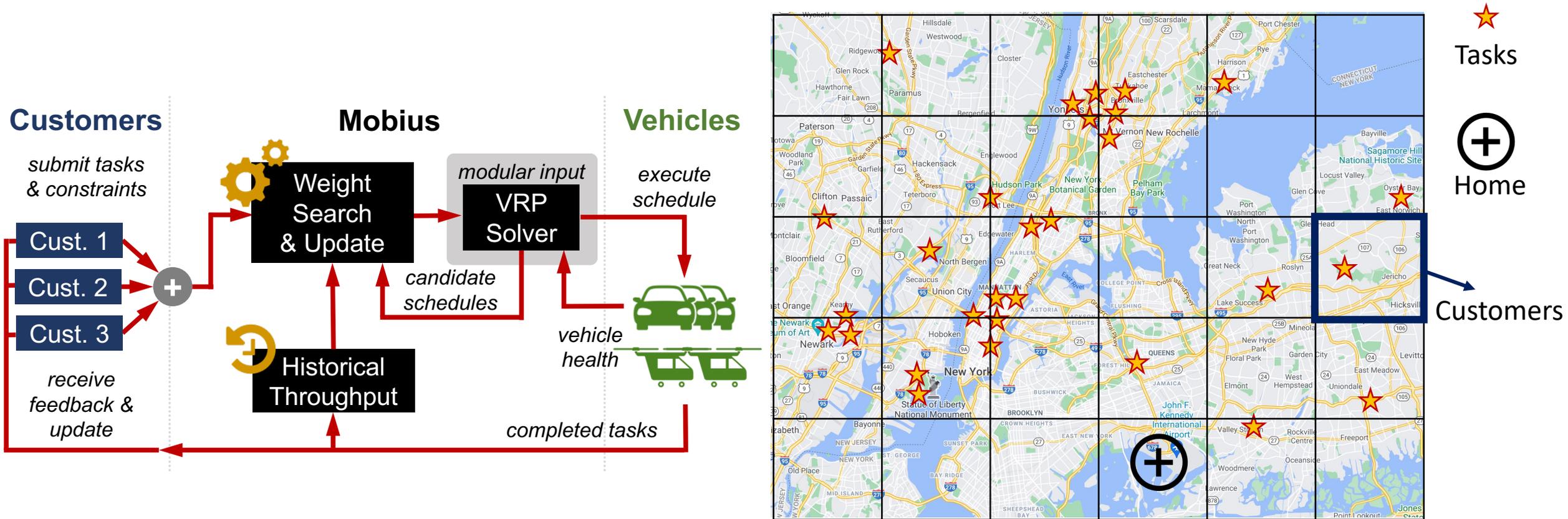
Mobius uses adaptive optimization to achieve max-min task-completion rates for customers



For each customer,  
track historical throughput and  
adjust weights in each round

# Our solution: Mobius

Mobius uses adaptive optimization to achieve max-min task-completion rates for customers



Mobius is theoretically sound

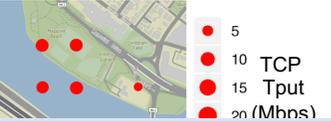
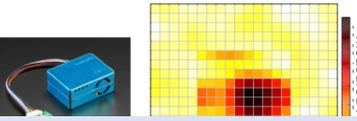
- Efficiency weight search and update
- Converges to optimal efficiency and fairness

# Application: Drone-as-a-service platform

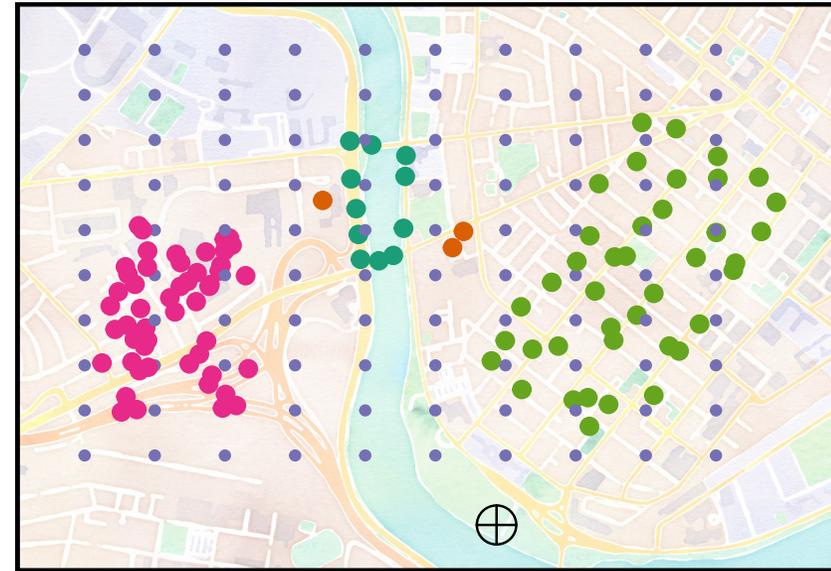
Fleet of 5 drones (recharge every 15 min)



5 Apps (customers) which submit sensing tasks

<b>Traffic</b>  Continuous monitoring	<b>Parking</b>  Measure every 10 min
<b>iPerf</b>  Cyclic monitoring	<b>Air Quality</b>  One-time tasks
<b>Roof</b>  One-time tasks	

Sensing tasks are spread over a city



Cambridge, MA

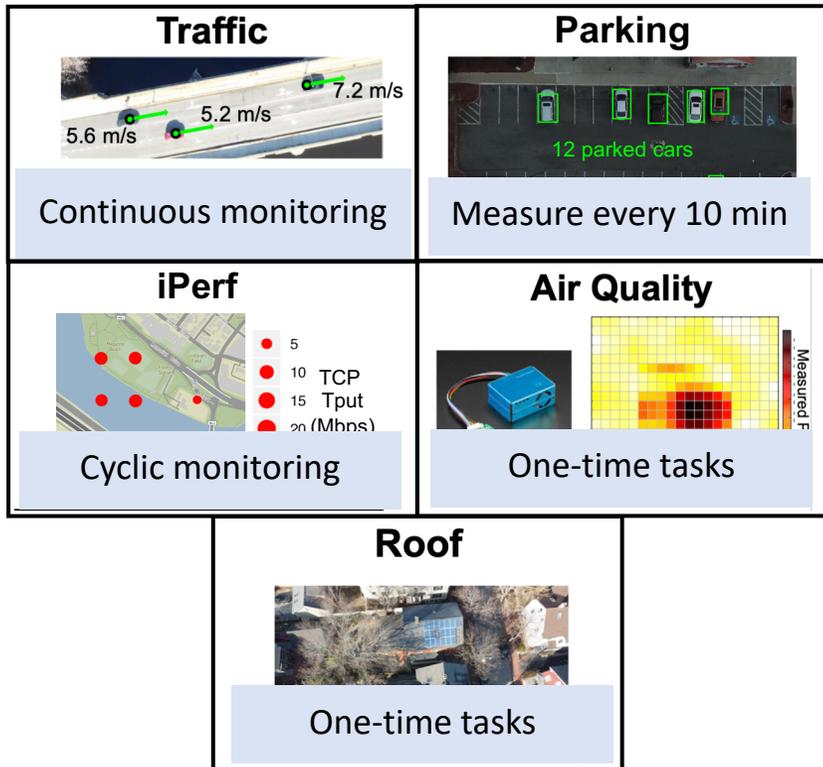
How do we efficiently multiplex tasks from different applications in each flight but also share the throughput equitably across customers?

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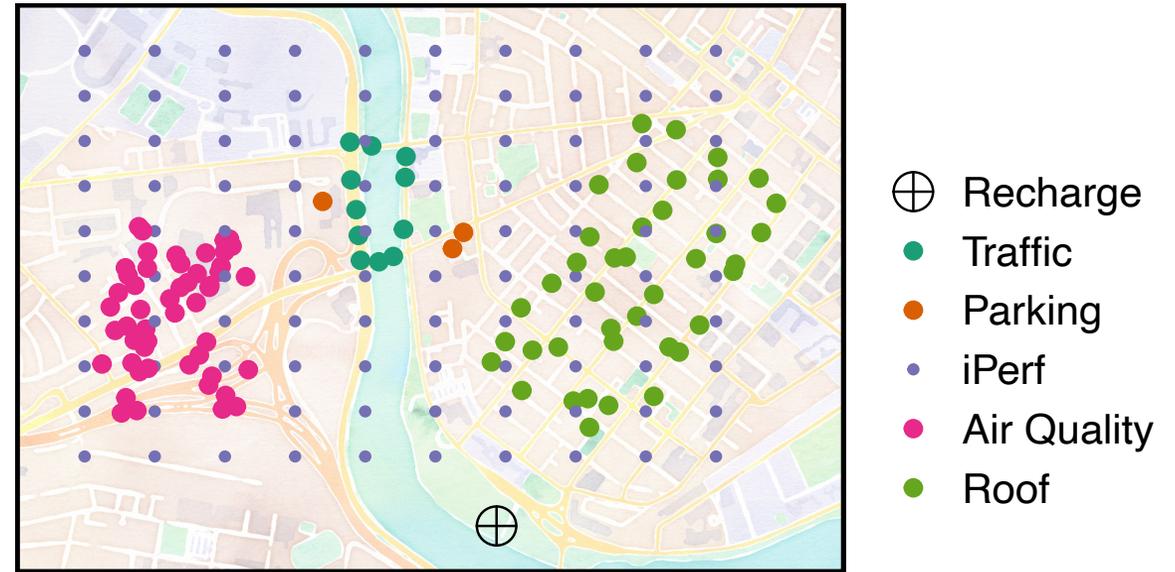
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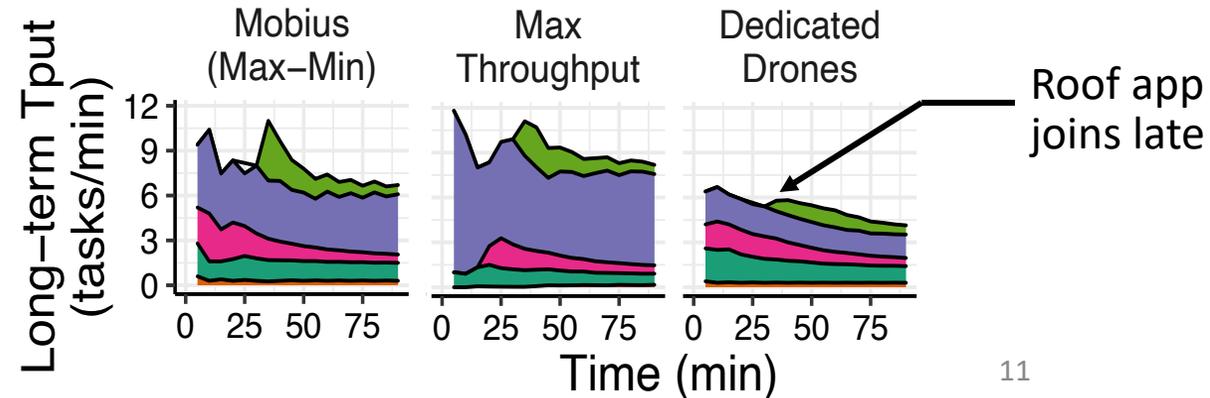
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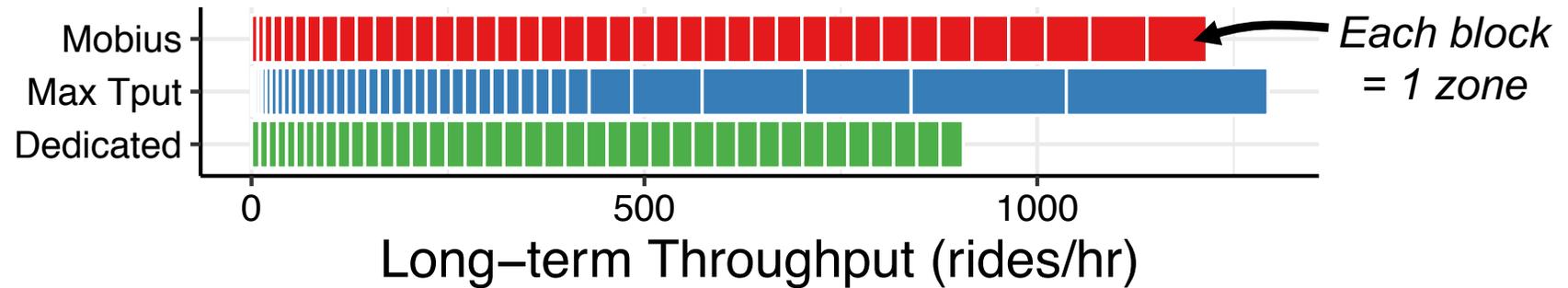
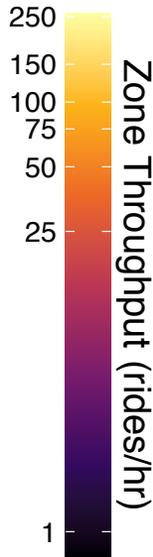
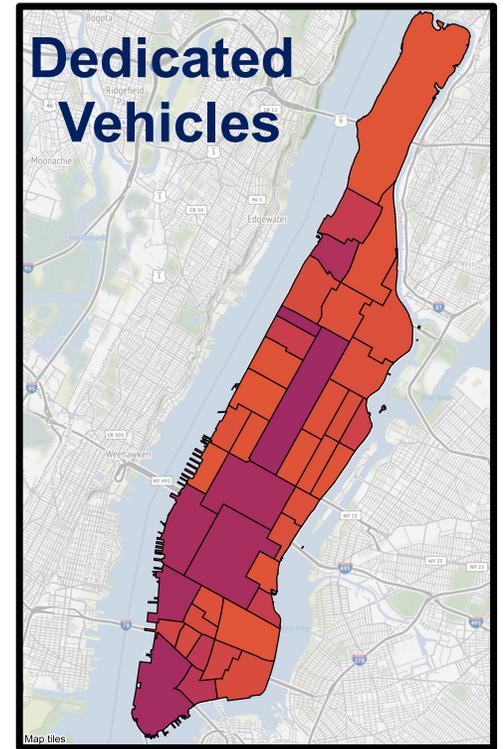
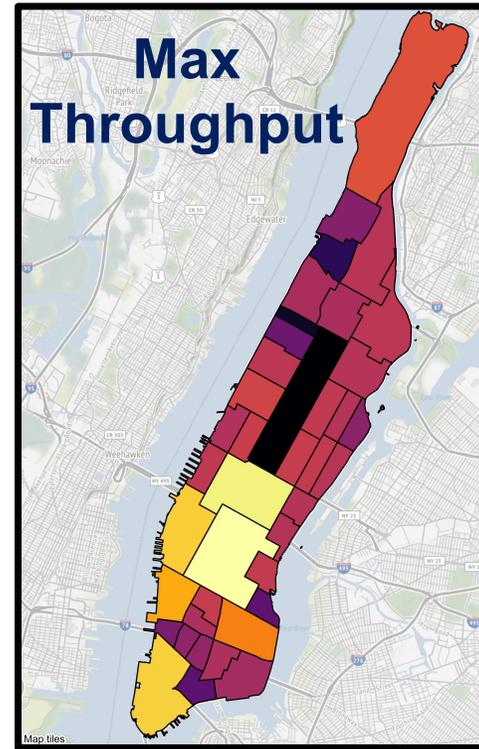
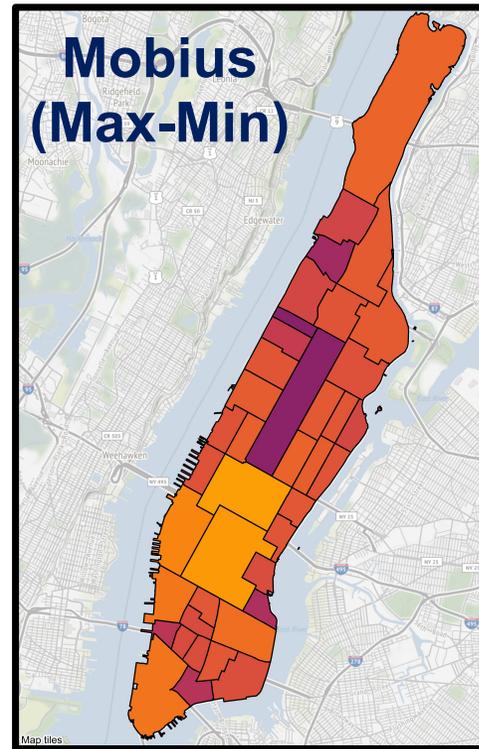
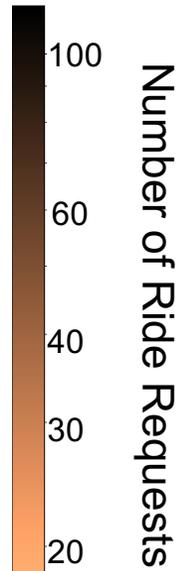
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Cambridge, MA



# Another application: Fair rideshare in NYC



# Summary

Achieving Fairness =

Fair airspace/ vertiport resource allocation



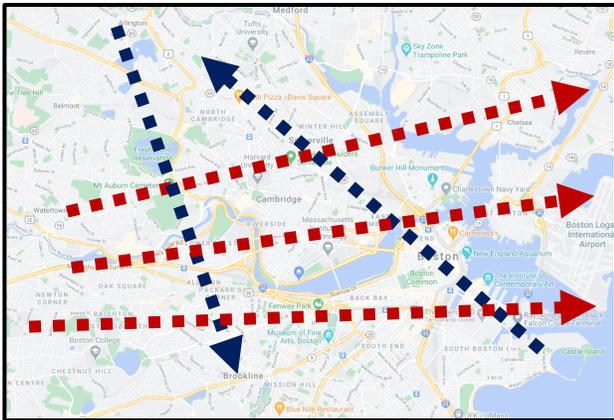
Fair quality of service to all customers

amazon Prime Air



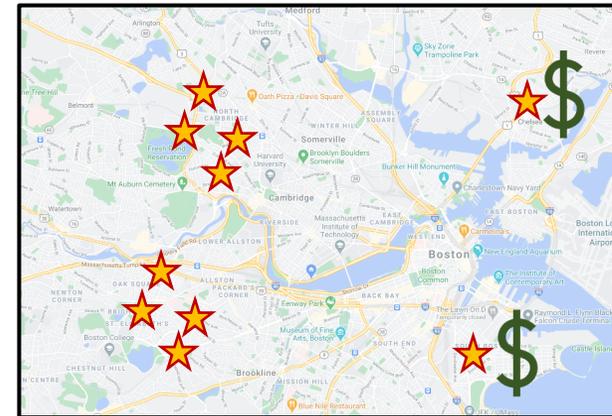
## • Future work: Incentives for fair behavior

UAS Service Supplier/ Provider of Services for UAM



Wing drones  
Amazon drones

What happens when the USS/ PSU and aircraft operator are the same entity?



★ Tasks  
\$ Tasks with subsidy

Can subsidies/payments induce aircraft operators to serve communities equitably?