Traffic Management Challenges in Advanced Air Mobility by Hamsa Balakrishnan, 5/18/23

Jason Luo

Part I. Literature (for further reading about Advanced Air Mobility)

Al Haddad, Christelle, et al. "Factors Affecting the Adoption and Use of Urban Air Mobility." *Transportation Research Part A: Policy and Practice*, vol. 132, 2020, pp. 696–712, https://doi.org/10.1016/j.tra.2019.12.020.

Cohen, A. F., Shaheen, S., & Farrar, E. J. (2021). Urban Air Mobility: History, Ecosystem, Market Potential, and Challenges. *IEEE Transactions on Intelligent Transportation Systems*, *22*(9), 6074–6087. https://doi.org/10.1109/tits.2021.3082767

Goyal R, Reiche C, Fernando C, Cohen A. Advanced Air Mobility: Demand Analysis and Market Potential of the Airport Shuttle and Air Taxi Markets. *Sustainability*. 2021; 13(13):7421. https://doi.org/10.3390/su13137421

Thipphavong, D. P., Apaza, R. D., Barmore, B. E., Battiste, V., Belcastro, C. M., Burian, B. K., Dao, Q., Feary, M., Go, S., Goodrich, K. H., Homola, J., Idris, H., Kopardekar, P., Lachter, J., Neogi, N. A., Ng, H., Oseguera-Lohr, R. M., Patterson, M. S., & Verma, S. (2018). Urban Air Mobility Airspace Integration Concepts and Considerations. In *2018 Aviation Technology, Integration, and Operations Conference*. https://doi.org/10.2514/6.2018-3676

Part II. Recent News

AsiaOne. (2023, May 16). AsiaOne. https://www.asiaone.com/business/geely-aerofugia-unveils-ae200-urban-air-mobility-solution-beyond-expo-2023

Menafn. (2023, May 18). Urban Air Mobility (UAM) Market Is Poised To Reach USD 30.7 Billion, Growing At A 30.2% CAGR By 2031. *Middle East North Africa Financial Network*. https://menafn.com/1106268287/Urban-Air-Mobility-UAM-Market-Is-Poised-To-Reach-USD-307-Billion-Growing-At-A-302-CAGR-By-2031

MSN. (n.d.-b). https://www.msn.com/en-us/travel/news/us-forms-team-to-set-strategy-on-flying-air-taxis/ar-AA1bgz5G

Part III: Q&A

Jinhua Zhao notes that there are around 100 flights in Paris daily, so even if it is increased 200-fold, it is a far cry from the millions of vehicles. He asks about the two contrasting control philosophies and asks which side this field will go towards, as well as if there is a third option.

Hamsa responds by saying that one approach that she has used so far is that in extreme cases a comparison can be made to say that things may work in the air if they work on the road. However, for planes, the costs are much higher. Affordable inefficiencies on the ground may not be affordable in the air, meaning the kind of inefficiencies that you have in a congested city may not translate to a viable business model for the air. Also the industry is moving towards having someone else in charge of responsibility which incites competition. Service providers are incentivized to say "Use my airspace because it is more efficient". The right answer might be somewhere in between.

Jinhua mentions that the safety standards and norms for air traffic and road traffic are very different. He asks if the idea for this technology is to enforce zero tolerance for accidents or will there be some allowable threshold.

Hamsa says the community is a bit divided on this issue. Some people want similar standards of safety as commercial aviation. In theory aircraft are supposed to tactically avoid each other but when the amount of aircraft gets higher we have less of an idea of what might happen. We do have large collections of drones that avoid each other but that is different from what it would be like in a competitive environment with multiple different operators..

Later questions were more or less answered in aggregate.

Alex Jacquillat asks about the potential impact of weather on the reliability and safety of the system.

Hamsa responds by saying that weather conditions can pose challenges, mostly for smaller and cheaper aircraft. Urban environments in particular may have wind tunnels that may impact the stability of these aircraft. Having a good understanding of weather impacts is an important topic, and businesses are incentivized to have drones that are resistant to bad weather conditions.

Alex asks about the unintended consequences of these systems such as public acceptance and noise impacts.

Hamsa says that public acceptance and noise impacts are indeed important considerations. This answer also ties into the next question about early deployments being in rural areas. Additionally public acceptance will depend on public perception on reliability, safety, and affordability.

Thomas Magnanti asks whether early deployments of this will be in rural areas or specific neighborhoods.

Hamsa says that the first deployments are indeed likely to be in rural areas for disaster response scenarios because these areas have fewer alternatives, implying a greater need. Also, use of this technology in cities will be a long road because there are issues such as public acceptance, safety, infrastructure, etc. The answer will also depend on equity concerns.

Part IV. Summary of Memos.

Themes from memos:

Safety is a key factor. People need to be able to believe that the technology is safe before it can be widely adopted. This can be done through ads and public events.

Collaboration between different companies is important to make a sufficient infrastructure network to support this kind of technology. Attention needs to be paid to make it not only profitable but also sustainable.

Many of the typical considerations of factors for regulation of transportations systems apply here: public acceptance, fairness, privacy, competition, efficiency, safety, etc. Many memos mentioned similarities between more common areas of research such as EVs and autonomous vehicles with urban air mobility.

The idea of having a big company such as Amazon own the logistics and delivery systems of this technology was mentioned. There was also discussion about nationalizing a company like Uber to get such a technology up and running.

My Reflection

This week we had the pleasure of listening to Hamsa Balakrishnan give a talk on some of the largest challenges and open questions ahead for advanced air mobility, or the use of autonomous aircraft as a form of transportation. More than a century ago, there were already test flights for this technology. However, a century later, this technology is still yet to be efficiently and safely usable on a regular basis. One barrier to this is the lack of investment in traffic management systems for this type of new technology, where difficulties arise from having multiple operators with potentially limited communication. Balakrishnan discussed the shift to venture capital to raise funds for this technology, where there is a large potential upside for companies even in the face of these issues. These issues are compounded when the aircraft are autonomous and numerous, leading to the desire for some sort of centralized traffic control system. Thus, there is a need to perform further research to address these issues. In addition, dealing with efficiency when scalability gets in the way may be another issue. Also, the technology would have to be able to balance different objectives for competing interests, such as fairness, equity, safety, privacy, etc. Balakrishnan also talked on ideas involving public policy and regulation for the new technology. Overall I thought professor Balakrishnan's talk was very informative and served as a great introduction to problems in the sphere of autonomous aircraft. This information can be used by researchers in closely related areas to potentially apply their research in a previously unanticipated area. In that way, it seems that this is a very effective presentation for a seminar where there are transportation researchers of all kinds and many with no background in an area related to autonomous aircraft.

Part V. Other Information

Goodrich, K. H., & Barmore, B. E. (2018). Exploratory Analysis of the Airspace Throughput and Sensitivities of an Urban Air Mobility System. In *2018 Aviation Technology, Integration, and Operations Conference*. https://doi.org/10.2514/6.2018-3364

Pisoni, E., Christidis, P., Thunis, P., & Trombetti, M. (2019). Evaluating the impact of “Sustainable Urban Mobility Plans” on urban background air quality. *Journal of*

Environmental Management, *231*, 249–255. https://doi.org/10.1016/j.jenvman.2018.10.039

Verma, S., Keeler, J., Edwards, T., & Dulchinos, V. (2019). Exploration of Near term Potential Routes and Procedures for Urban Air Mobility. In *AIAA Aviation 2019 Forum*. https://doi.org/10.2514/6.2019-3624

Traffic Management Challenges in Advanced Air Mobility

Hamsa Balakrishnan

Massachusetts Institute of Technology

Dynamics, Infrastructure Networks, and Mobility (DINaMo) Group

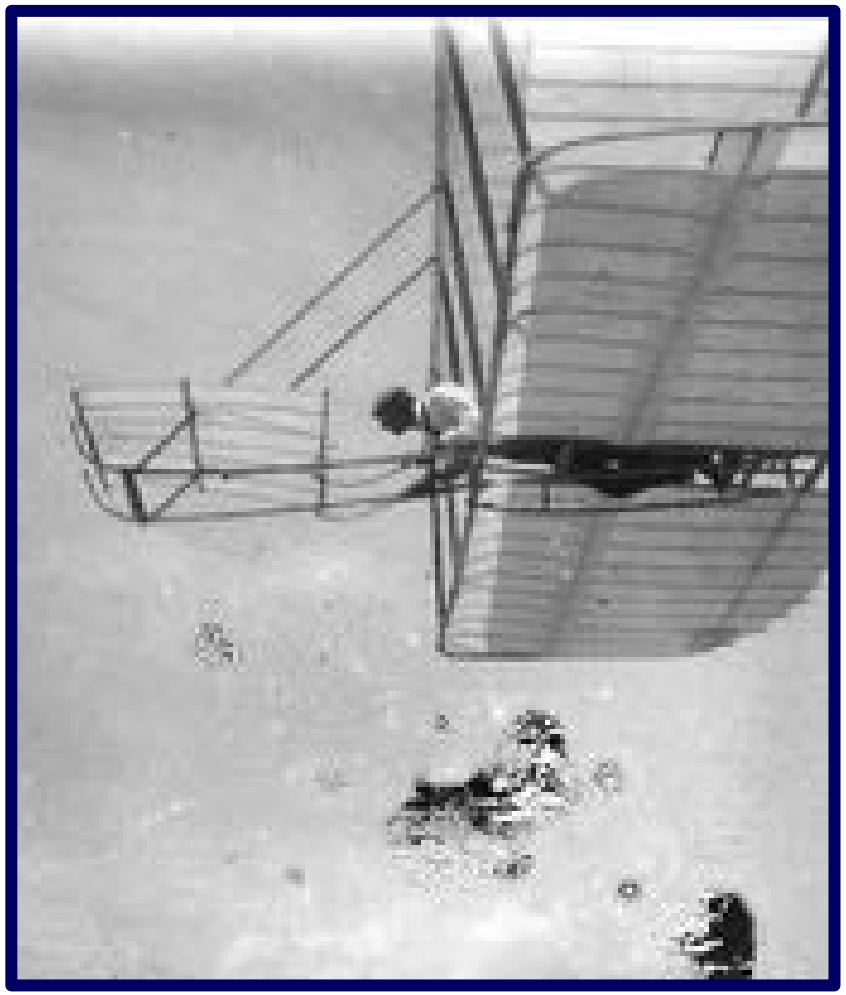
dinamo.mit.edu

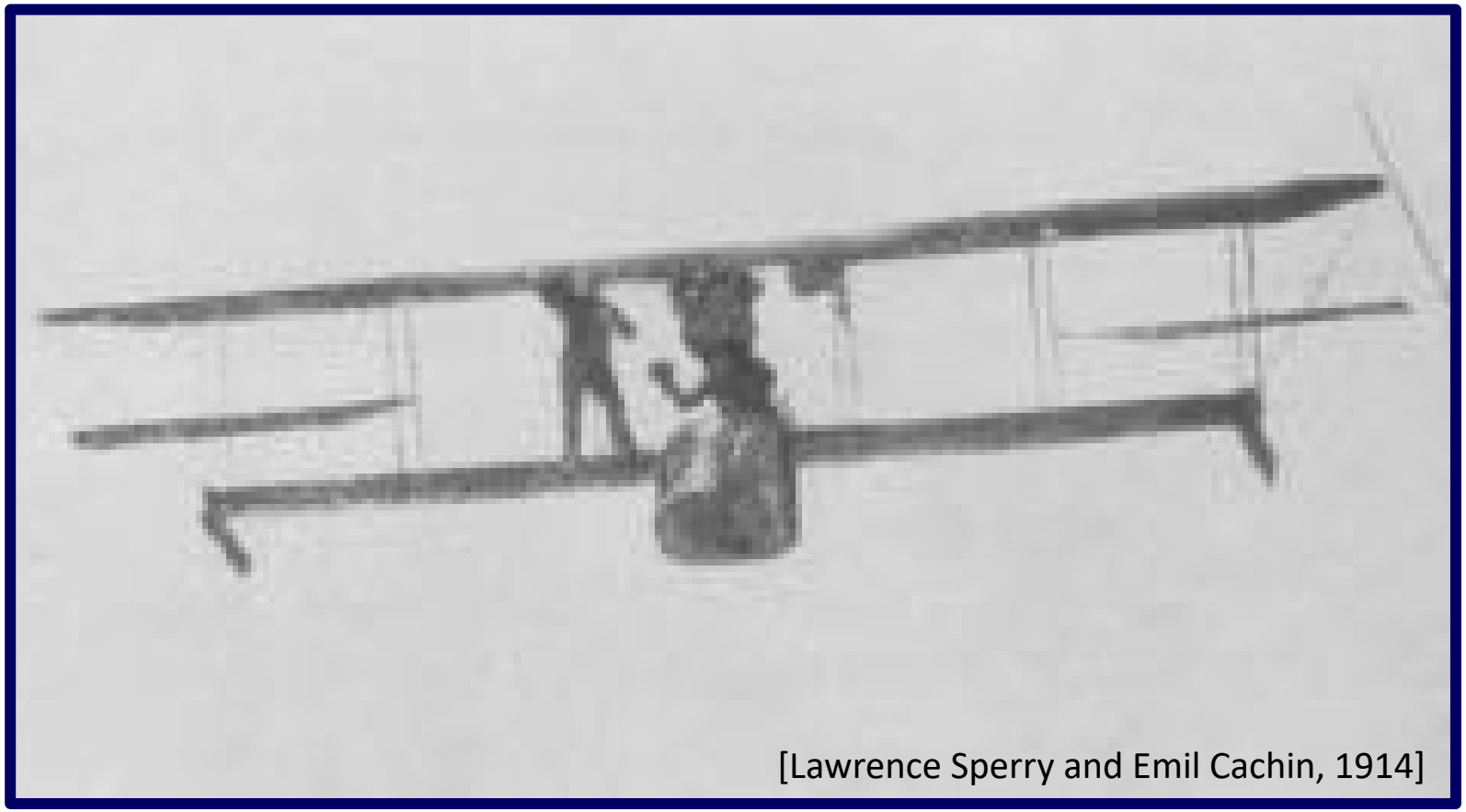
MIT Mobility Forum, April 2023

The Vision of Advanced Air Mobility

Image: NASA: https://www.nasa.gov/aero/taking-air-travel-to-the-streets-or-just-above-them

More Than a Century of Transformation in the Air





[Lawrence Sperry and Emil Cachin, 1914]

http://www.wright-brothers.org/History_Wing/Wright_Story/Inventing_the_Airplane/Kitty_Hawk_in_a_Box/Some-Aeronuatical-Experiments-by-Wilbur-Wright.htm
http://fly.historicwings.com/2012/08/george-the-autopilot/

More Than a Century of Transformation in the Air

Robot-Piloted Plane Makes Safe Crossing of Atlantic

No Hand on Controls From Newfoundland to Oxfordshire—Take-Off, Flight and Landing Are Fully Automatic

By ANTHONY LEVIERO

Special to THE NEW YORK TIMES.

WASHINGTON, Sept. 22 — A Douglas C-54 Skymaster with a mechanical brain landed without human aid near London today after a robot directed hop from Newfoundland.

The revolutionary flight across the Atlantic, effected by the push of the button, was hailed by Air Force spokesmen said. Two ships somewhere in the Atlantic furnished bearings to the Skymaster's brain. She had 3,700 gallons of fuel aboard.

Great Britain several weeks ago had asked as a favor that the Air Force send the Skymaster there to make demonstration flights for

THE NEW YORK TIMES, TUESDAY, SEPTEMBER 23, 1947.

MAKES TRANSATLANTIC FLIGHT UNDER CONTROL OF 'MECHANICAL BRAIN'

The Army Air Forces Douglas C-54 Skymaster, which completed the 3,400-mile trip from Stephensville, Nfld., to Brize Norton, forty miles west of London.

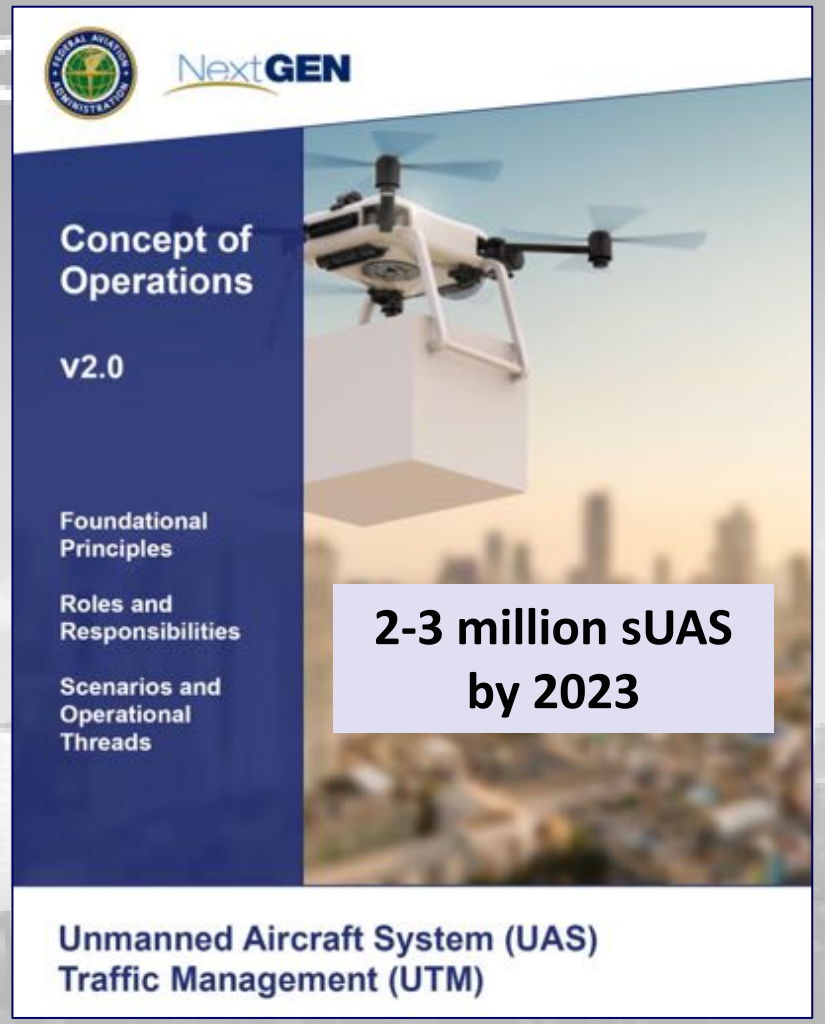
"Air Force officers speculated on the possibility of loading robot planes… For peaceful purposes, it was suggested that they might be used as cargo carriers."

The Changing Skies

Artist's rendition: Airbus. Vehicle images: Amazon Prime Air, Joby Aviation, CNN/Alphabet Wing

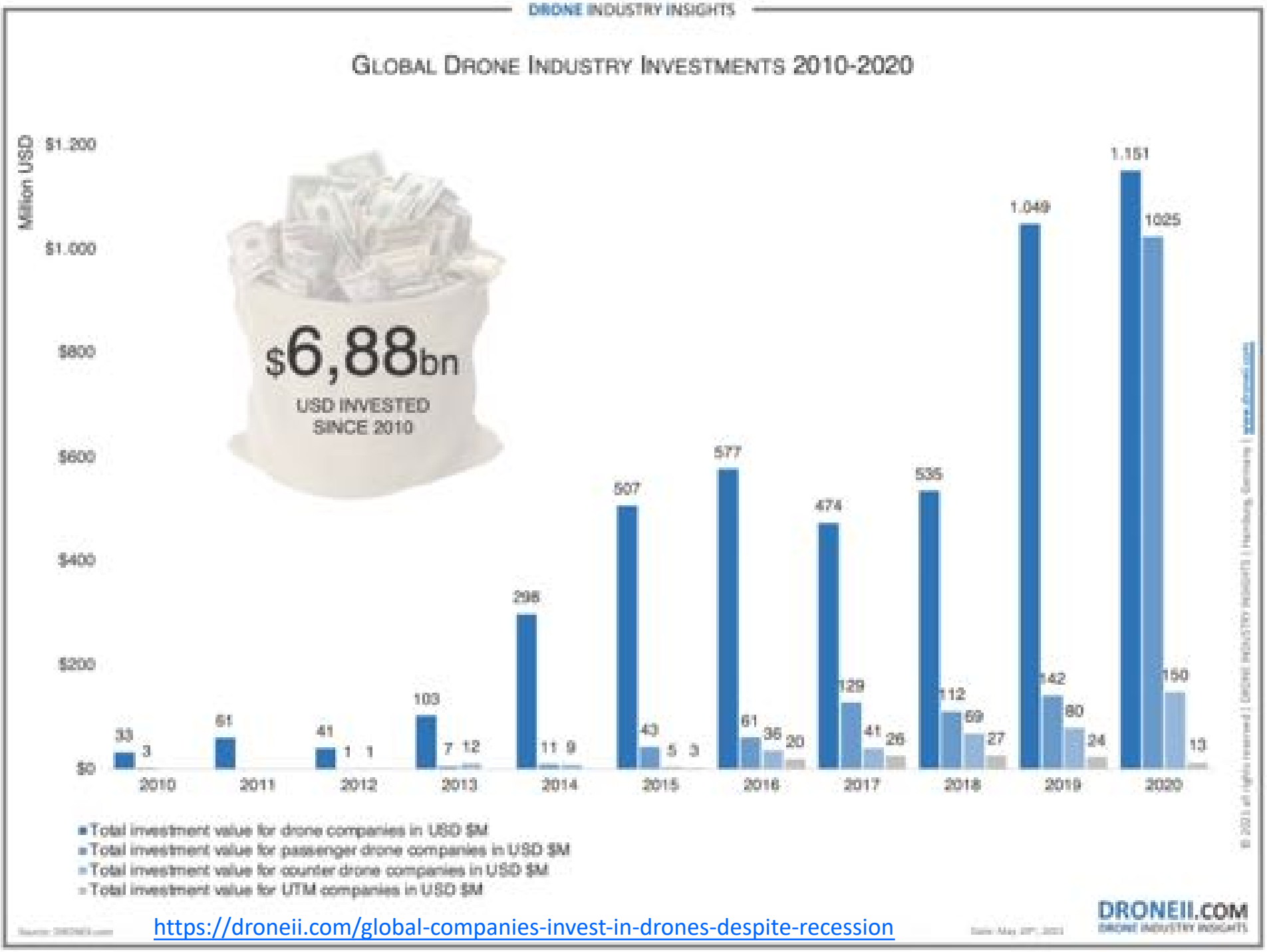
The Changing Skies

[Airbus UTM Blueprint for the Skies, 2018]



[FAA UTM Concept of Operations, 2020]

Airbus



https://droneii.com/global-companies-invest-in-drones-despite-recession

$5bn USD investment in eVTOL sector in 2021

Aerospace America, Apr '22

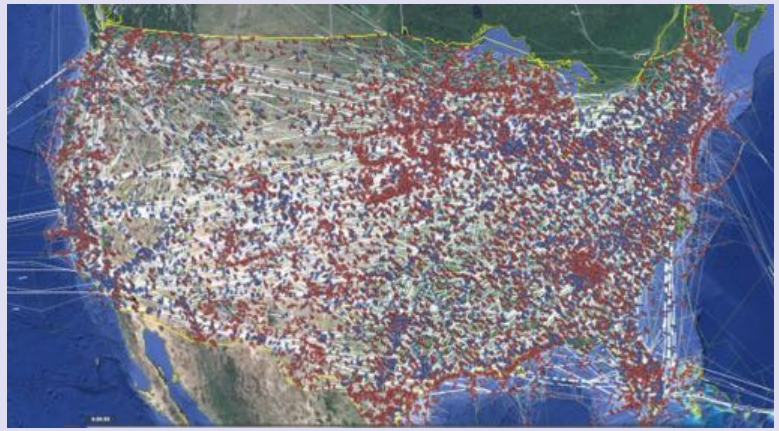
$7.9bn USD investment in the global drone industry in 2021

$4.8bn USD investment in the global drone industry in 2022

https://droneii.com/drone-industry-investments-in-2022

Emerging System Challenges

Unprecedented numbers



20K flights/hr over Paris
2-3M small drones

How do we achieve efficiency at these scales?

New competitive landscape

UNITED A STAR ALLIANCE MEMBER
DELTA
AIRFRANCE
KLM

+

amazon Prime Air
Joby
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Emerging System Challenges

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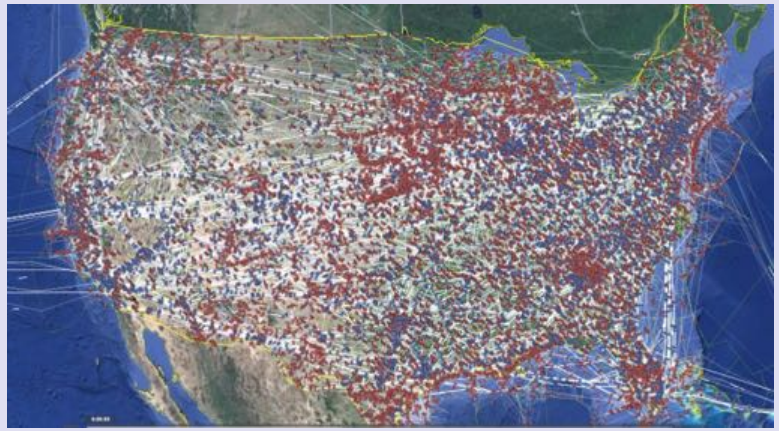

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+

amazon Prime Air · Joby · Wing

New privacy concerns

AEROSPACE AND DEFENSE DECEMBER 31, 2020 / 4:38 PM / UPDATED 24 DAYS AGO

Alphabet unit Wing blasts new U.S. drone ID rule, citing privacy

By David Shepardson 3 MIN READ

How do we improve privacy and incentivize information sharing?

Fairness to users

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

How do we equitably serve airspace users with differing priorities?

Who Manages Advanced Air Mobility Traffic?

“*[T]*he FAA will not play an active operational role in managing the UAM aircraft *[similar provisions for UAS]* under nominal conditions (i.e., ATM services will nominally not be actively provided by the FAA to UAM aircraft).”

[Images: faa.gov; natca.org, panynj.gov, bls.gov]

Three Challenges Highlighted Today

- How can a service provider manage traffic (of different fleet operators) in an efficient and fair manner?
- How can a fleet operator serve its customers in an efficient and fair manner?
- How can we incentivize cooperation among different service providers?

Three Challenges Highlighted Today

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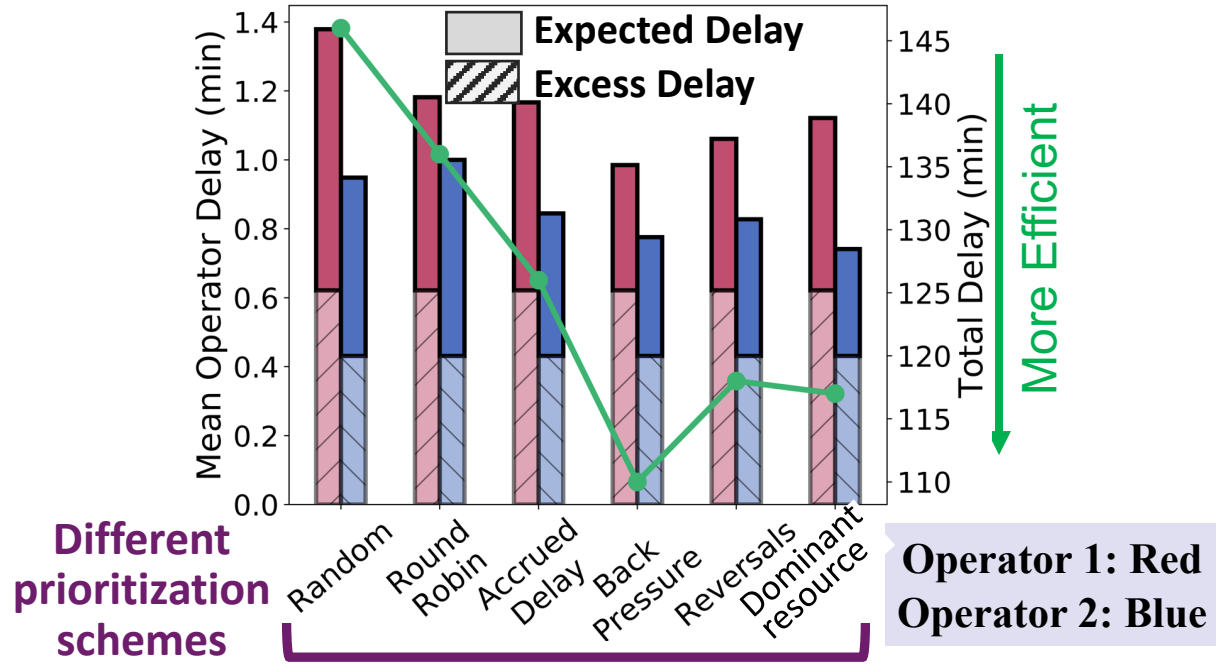
A Service Provider's Challenge: Very Large-Scale Traffic Flow Management

- Distributed optimization algorithms for large-scale air traffic flow management

- Protocol-based ("rules-of-the-road") AAM congestion management algorithms that prioritize different fairness metrics
  - e.g., balance delays or excess delays across aircraft operators
  - Cost-aware congestion management protocols



Balakrishnan & Chandran ATM Seminar 2017.

Chin et al. ATM Seminar 2021; Qin & Balakrishnan ICRAT 2022.

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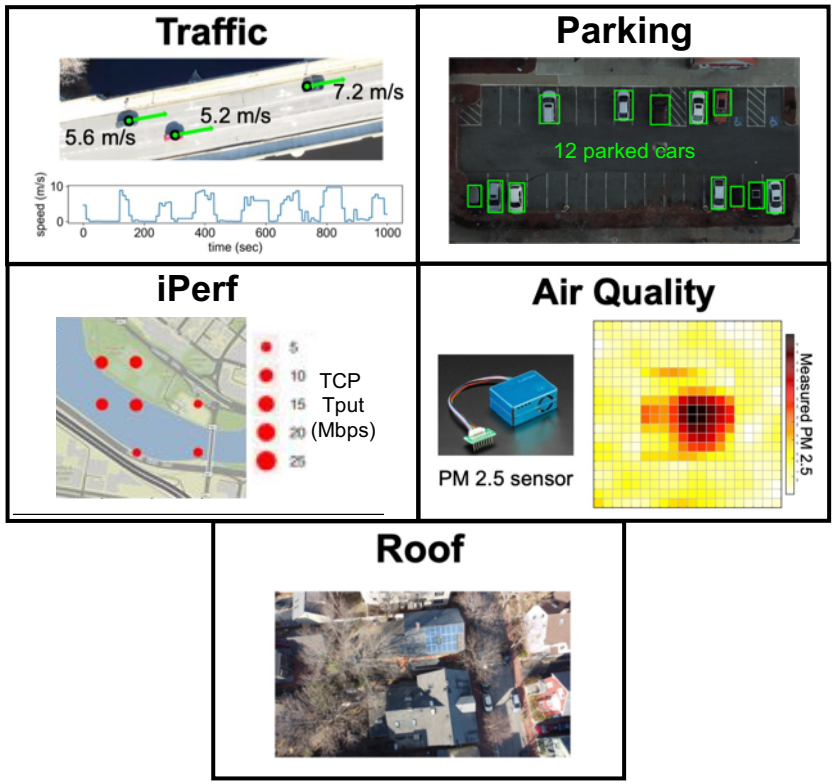
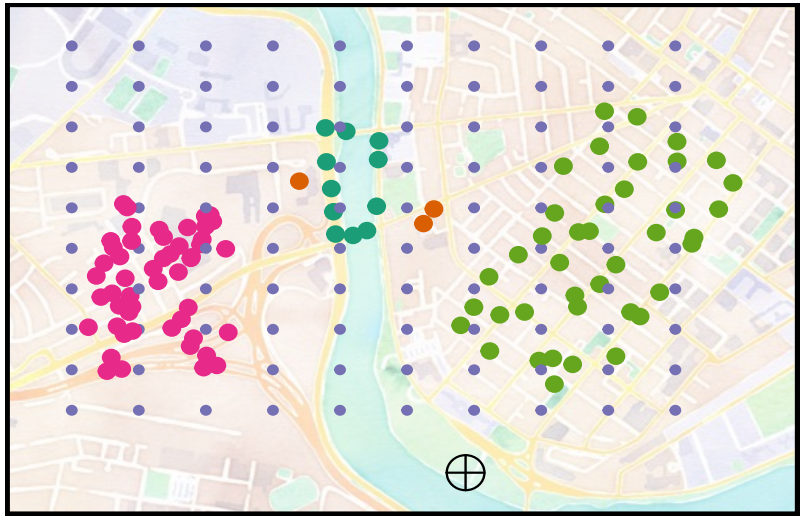
A Fleet Operator's Challenge: Navigating Efficiency-Fairness Tradeoffs in Shared Mobility

Fleet of 5 drones (battery life of 15 min)

Five apps (customers) that submit sensing tasks



Sensing tasks are spread over a city



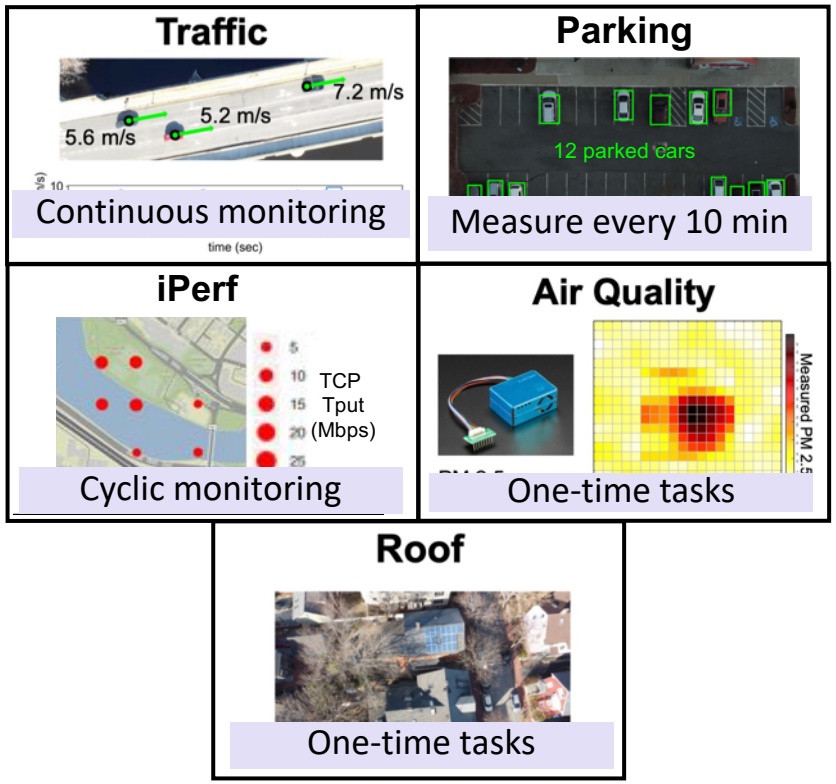
Cambridge, MA

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

Navigating Efficiency-Fairness Tradeoffs in Shared Mobility Platforms: Mobius

Fleet of 5 drones (battery life of 15 min)

Five apps (customers) that submit sensing tasks



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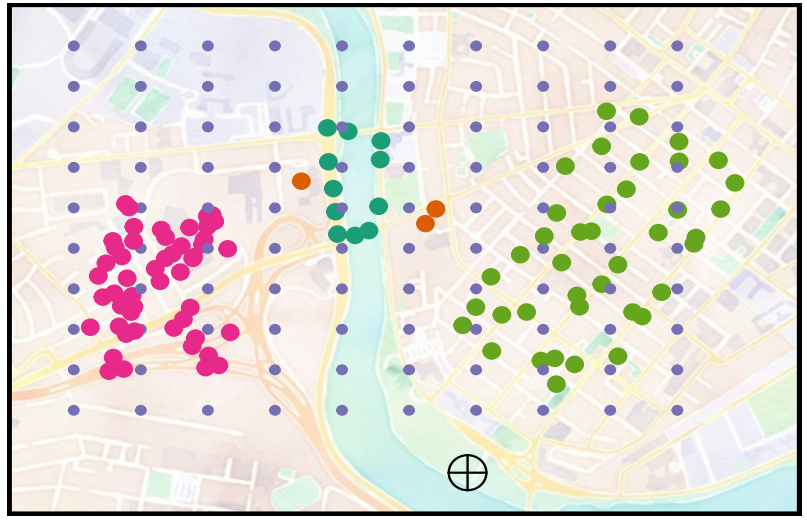

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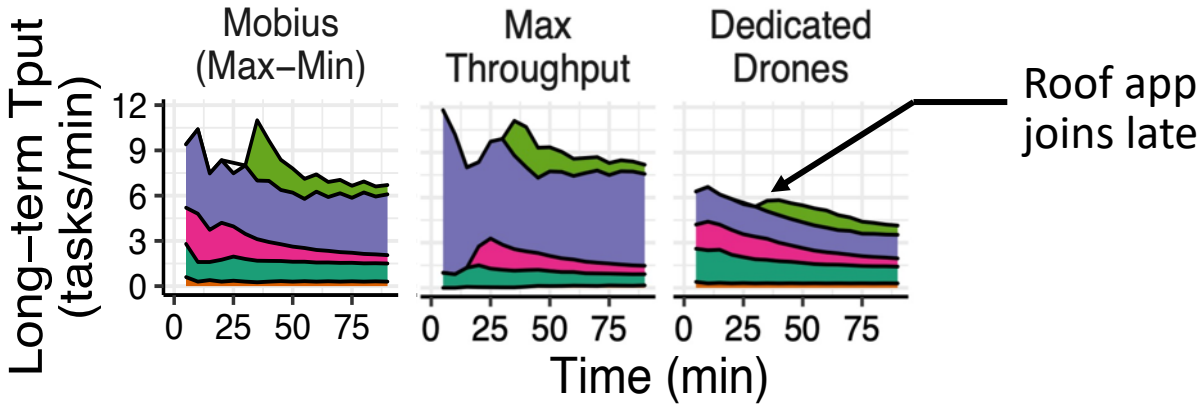

Three Challenges Highlighted Today

- How can a service provider manage traffic (of different fleet operators) in an efficient and fair manner?
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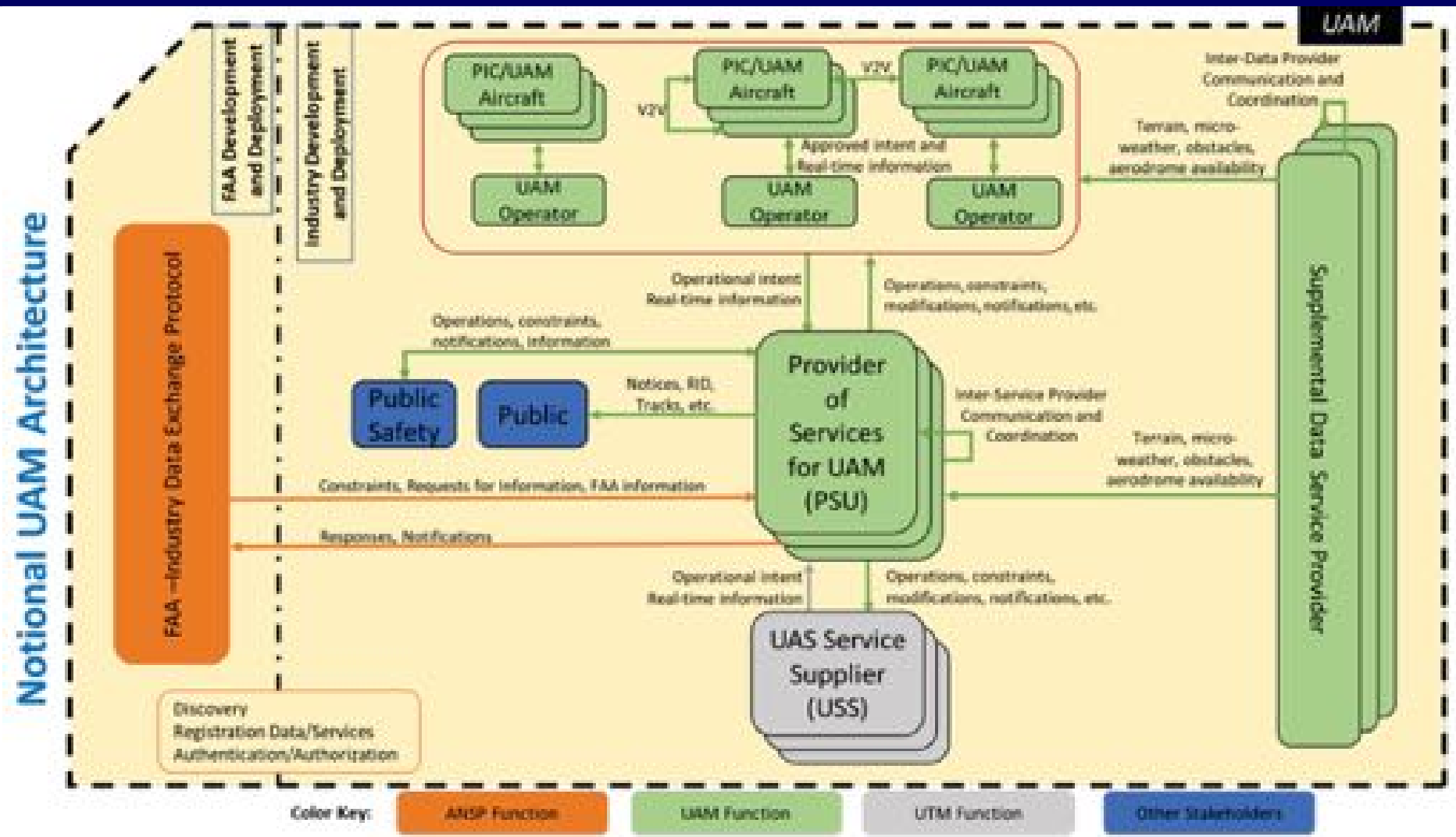
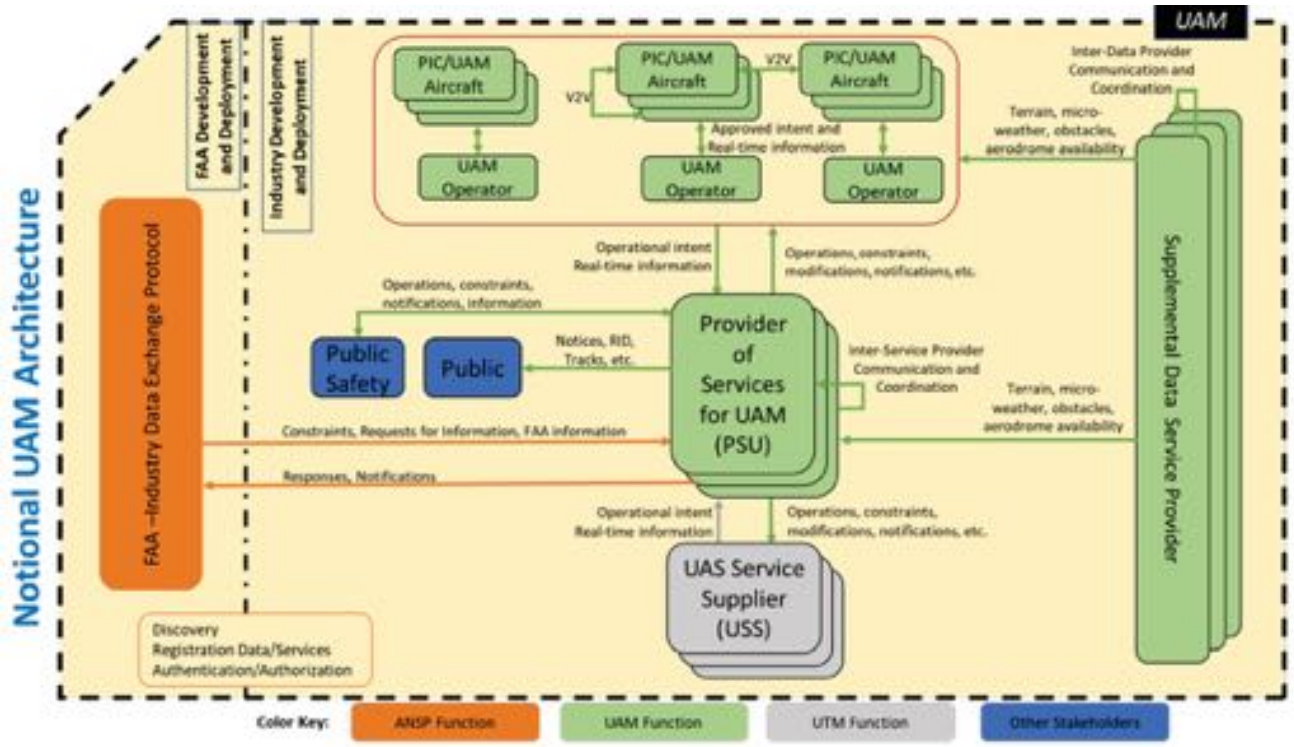
A System Designer's Challenge: Incentivizing Cooperation Among Service Providers



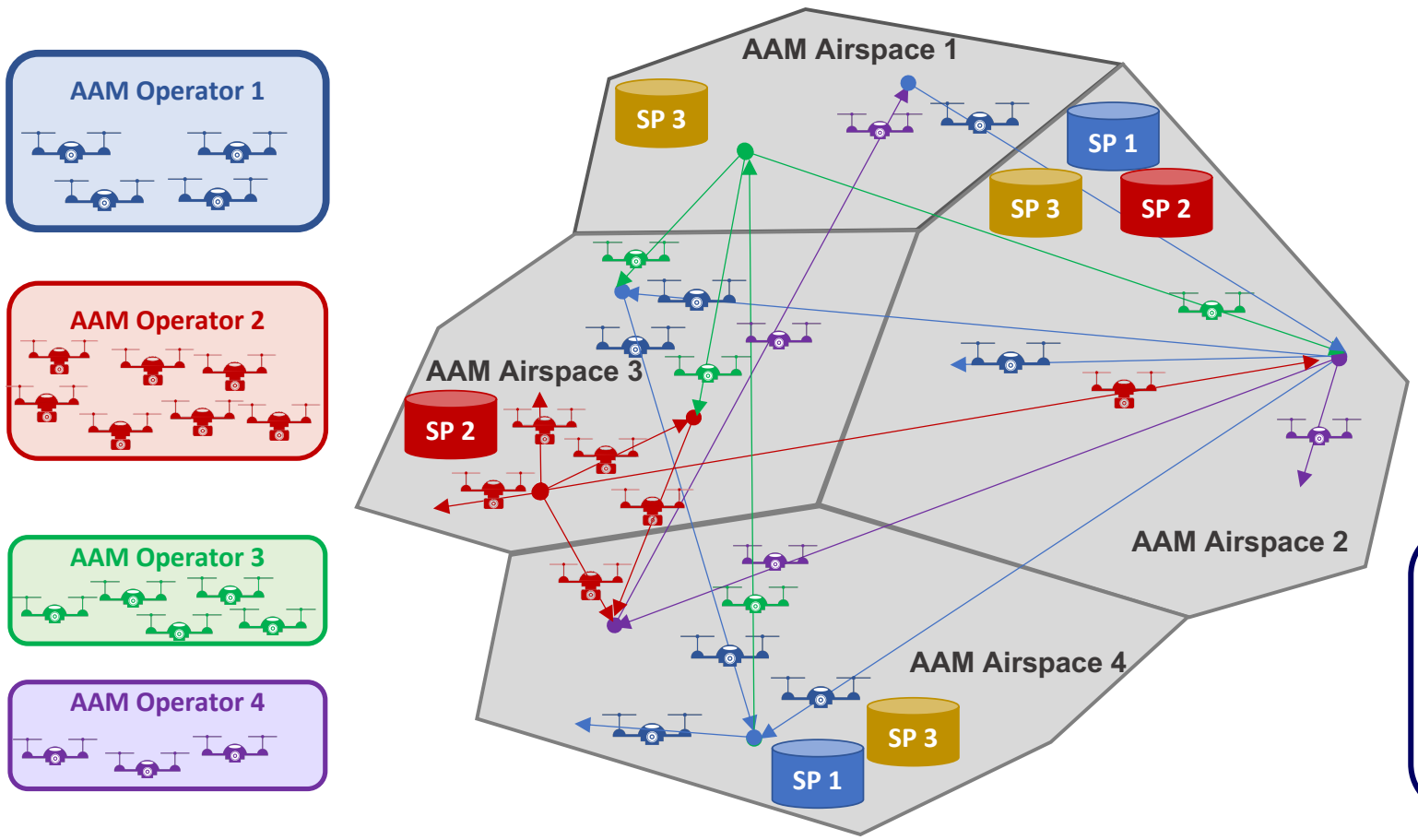
We focus on the Service Providers (SP) i.e., the PSU or USS, providing traffic management services

What is Expected of Service Providers?

- Federated set of (possibly private) actors over a distributed PSU network
- Multiple PSUs can provide services in the same geographical area
- Same entities could play multiple roles (e.g., aircraft operators and service providers)
- Strategic deconfliction (i.e., demand-capacity balancing) is exercised by PSUs (e.g., through congestion management protocols)
- PSUs could support tactical deconfliction: primarily responsibility of aircraft operators



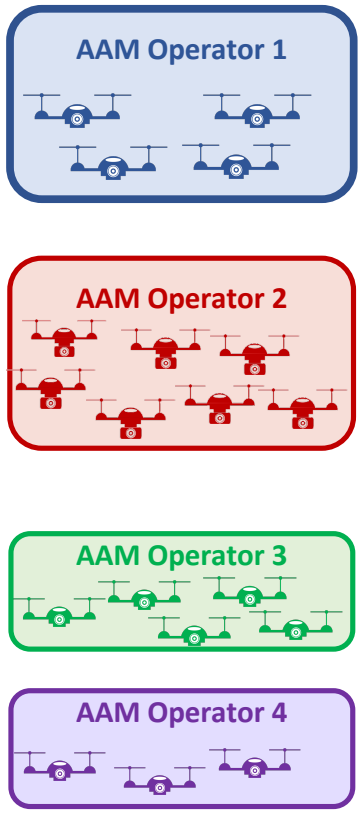
A Notional Illustration of AAM Airspace

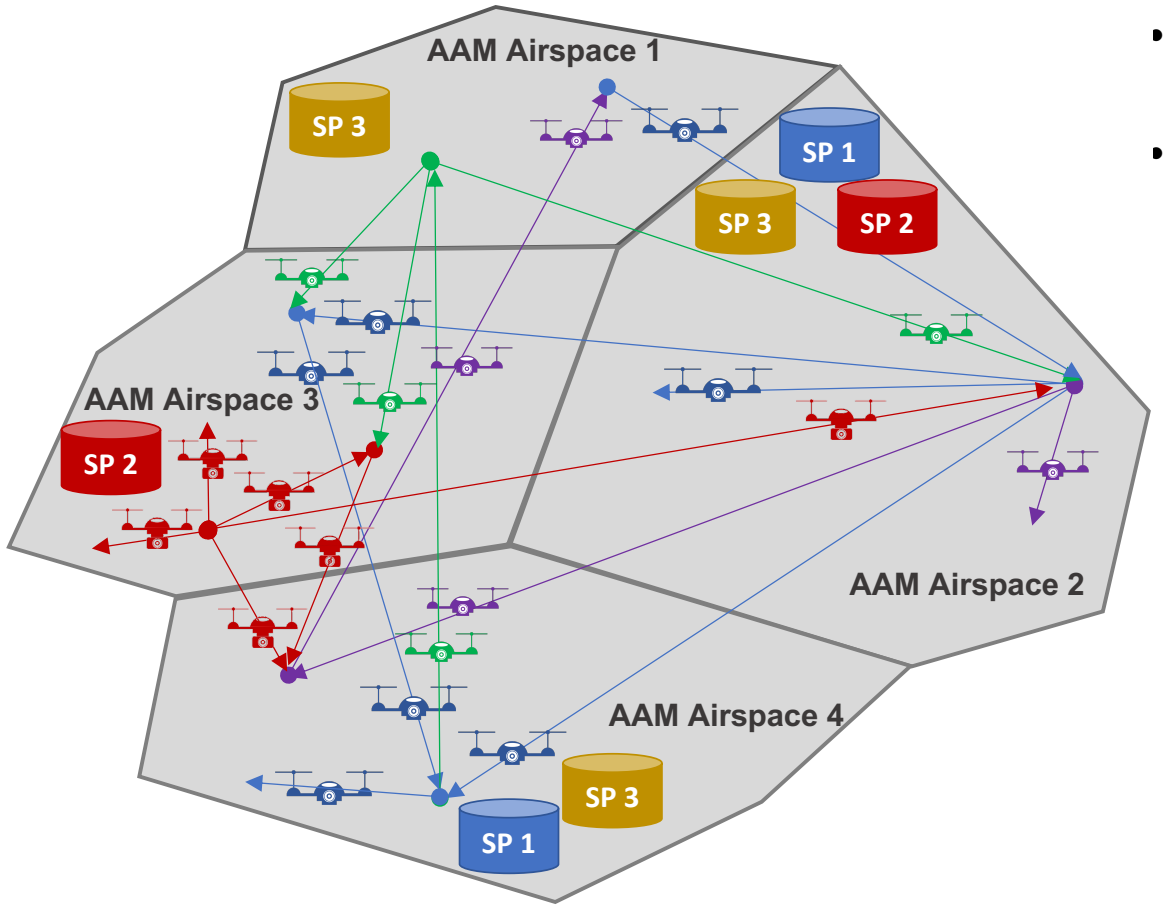


- **Federated, possibly private SPs**
- Multiple SPs can provide services in the same geographical area
- Same entities could be aircraft operators and service providers

Our solution approach:
Design a profit-sharing mechanism that incentivizes cooperation between traffic management service providers

Open Challenges





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Open Challenges:

Interaction with intra-SP traffic management

How do multiple SPs manage traffic in the same airspace?

Mitigating "net-neutrality" type effects

When do market mechanisms work and when is regulatory action necessary?

SP: (AAM) Service Provider

Coming Soon, to a Neighborhood Near Us…

May 24, 2022 - Economy & Business

Walmart to begin America's first large-scale drone operation in 6 states

Axios, May 24, 2022

Joann Muller, author of Axios What's Next

DroneUp is delivering packages for Walmart. Photo courtesy of DroneUp

"Walmart's DroneUp delivery network will expand to 34 sites by the end of the year, potentially reaching 4 million U.S. households"

"Walmart and DroneUp will offset the cost of delivery with revenue from other drone-related services, such as insurance inspections, emergency response and construction oversight"

Dec 3, 2018

NASA Collaborates with JAXA to use Drones for Disaster Recovery Drill

Tech > Computing

Zipline's New Drone Brings Aerial Delivery Closer for Millions More of Us

The new aircraft are in testing and should go into service by early 2024.

CNET, March 15, 2023

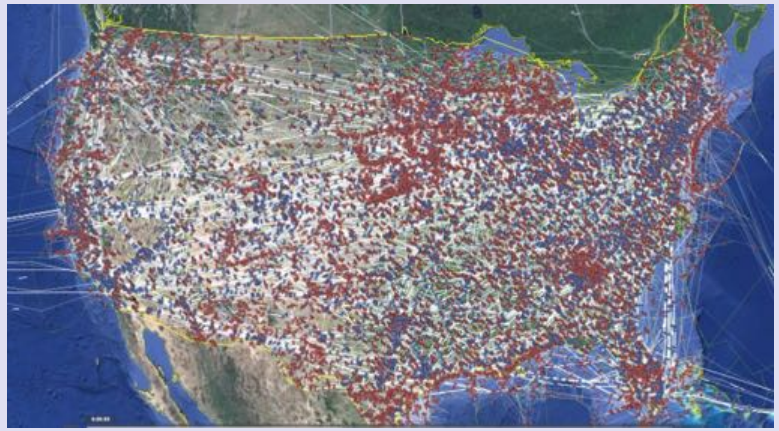
Stephen Shankland
March 15, 2023 10:37 a.m. PT

3 min read

Zipline's drone delivery aircraft use a cable to lower this delivery device, called a droid, to deliver packages onto a precise spot.
Zipline

Traffic Management Challenges for AAM

Unprecedented numbers



New competitive landscape

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New privacy concerns

AEROSPACE AND DEFENSE DECEMBER 31, 2020 / 4:38 PM / UPDATED 24 DAYS AGO

Alphabet unit Wing blasts new U.S. drone ID rule, citing privacy

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Fairness to users

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Provide *efficient*, *equitable*, and *sustainable* airspace access for a wide range of Advanced Aerial Mobility vehicles and services