Faculty of Power and Aeronautical Engineering
WARSAW UNIVERSITY OF TECHNOLOGY

Urban Air Mobility Traffic Analysis Tool

Antoni Kopyt – Warsaw University of Technology
Chad Stephens – NASA Langley Research Center

Contents

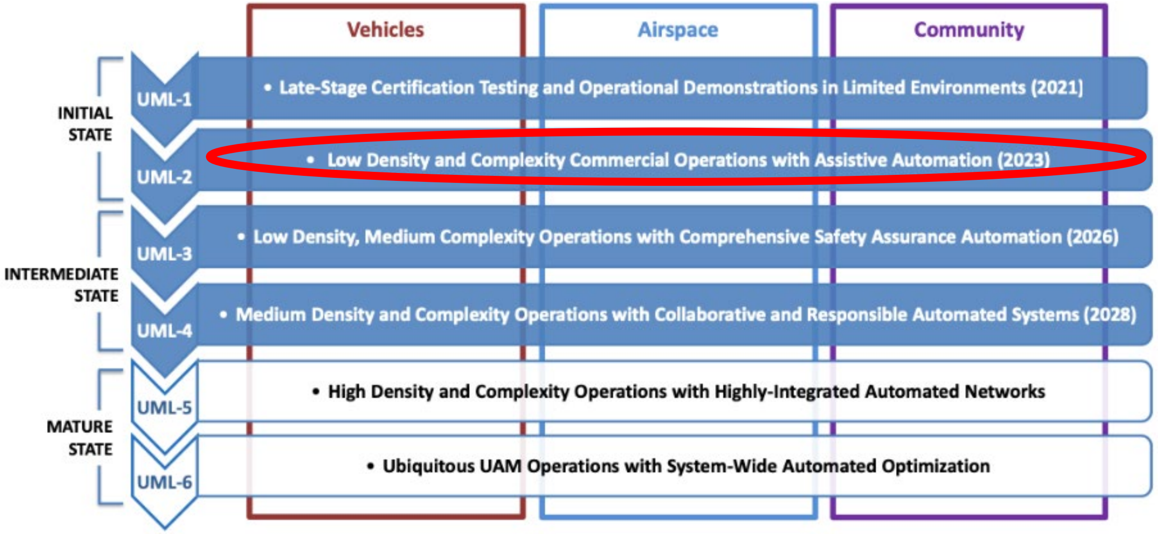
Emerging challenges in Urban Air Mobility in near future

Next Generation Air Transportation System (FAA)

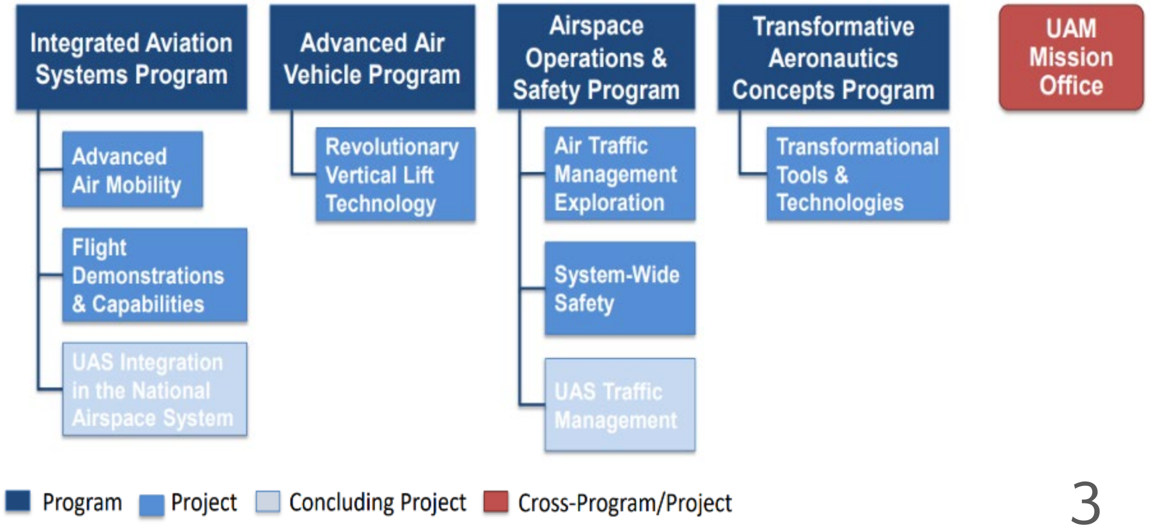
Advanced Air Mobility (AAM)

Documents

- Part 107 - Small Unmanned Aircraft Systems
- In-Time Aviation Safety Management: Challenges and Research for an Evolving Aviation System
- Urban Air Mobility (UAM) Concept of Operations v1.0
- Unmanned Aircraft Systems (UAS) Traffic Management (UTM) Concept of Operations v1.0
- Unmanned Aircraft Systems (UAS) Traffic Management (UTM) Concept of Operations v2.0
- In-time System-wide Safety Assurance (ISSA) Concept of Operations and Design Considerations for Urban Air Mobility (UAM)
- Urban Air Mobility Concept (OpsCon) Passenger-Carrying operations

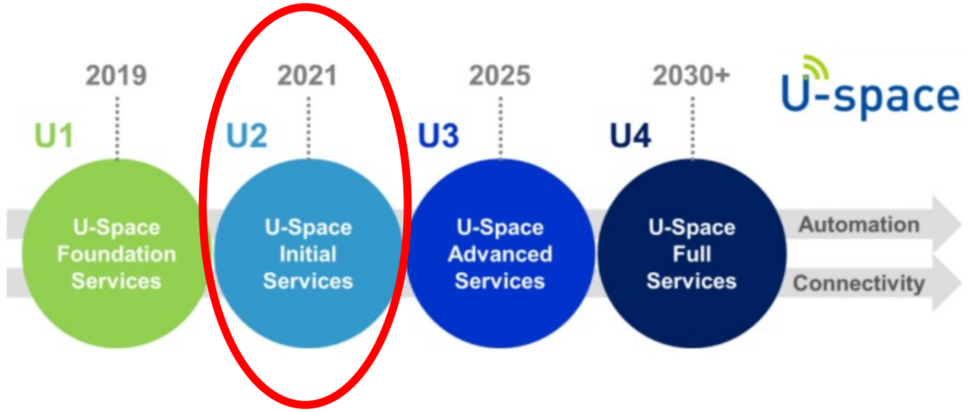


ARMD UAM-Related Projects



[AAM for FAA/NASA Research Roundtable]

Emerging challenges in Urban Air Mobility in near future



Phase		Service	
U1	Foundation Services	U1.1	e-Registration
		U1.2	e-Identification
		U1.3	Pre-tactical Geo-fencing
U2	Initial Services	U2.1	Tactical Geo-fencing
		U2.2	Flight Planning Management
		U2.3	Weather Information
		U2.4	Tracking
		U2.5	Monitoring
		U2.6	Drone Aeronautical Information Management
		U2.7	Procedural Interface with ATC
		U2.8	Emergency Management
		U2.9	Strategic De-confliction
U3	Advanced Services	U3.1	Dynamic Geo-fencing
		U3.2	Collaborative Interface with ATC
		U3.3	Tactical De-confliction
		U3.4	Dynamic Capacity Management
U4	Full Services	-	TBD

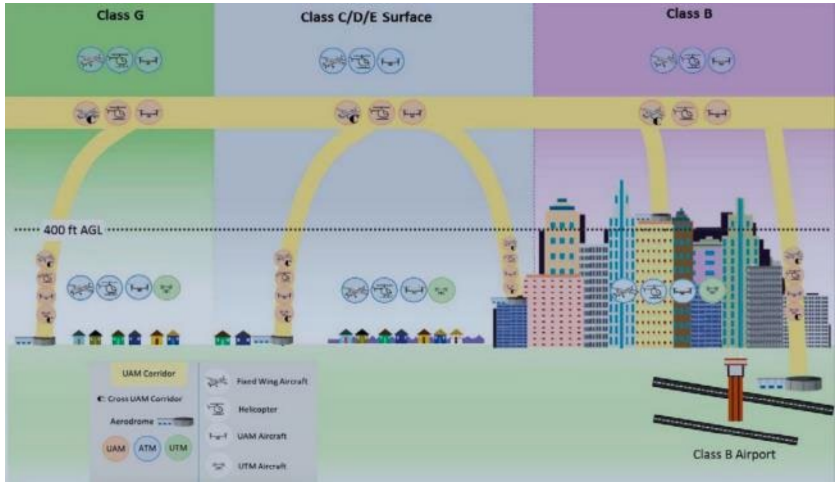
U-space is a set of new services relying on a high level of digitalization and automation of functions and specific procedures designed to support safe, efficient and secure access to airspace for large numbers of drones.

Documents

- U-space Blueprint
- European ATM Master Plan
- European Drones Outlook Study
- Initial view in Principles for the U-space architecture
- CORUS U-space Concept of Operations
- U-space Drone Operations Europe
- EASA Opinion No 1/2020
- EU Commission Delegated Regulation 2019/945
- EU Commission Implementing Regulation 2019/947, 2021/664, 2021/665, 2021/666

Airspace structures

FAA UAM Concept of Operations

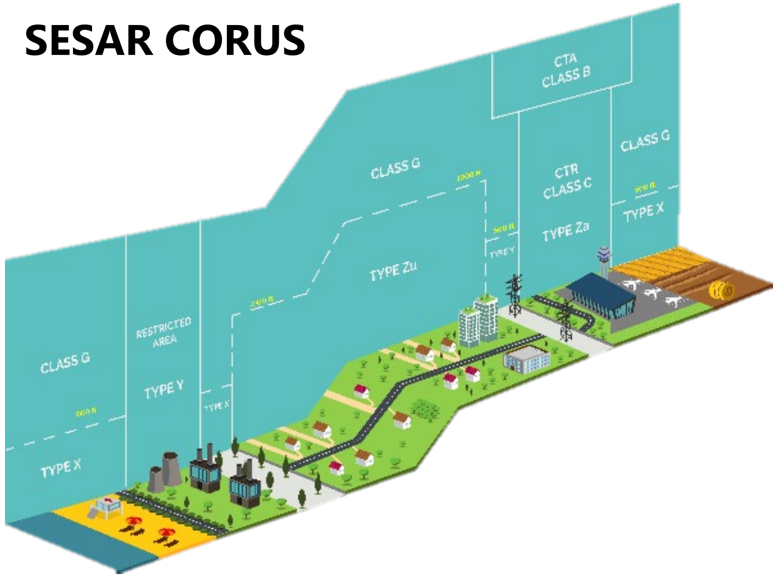


UAM operating environment
UAM operations are performed through the use of UAM corridors. Strategic deconfliction and tactical separation in UAM corridors occur without direct ATC involvement.

UTM operating environment
In uncontrolled airspace below 400ft AGL UTM provides a cooperative traffic management for UAS and other aircraft.

ATM operating environment
Operations adhere to relevant ATM rules based on operation type, airspace class, and altitude.

SESAR CORUS

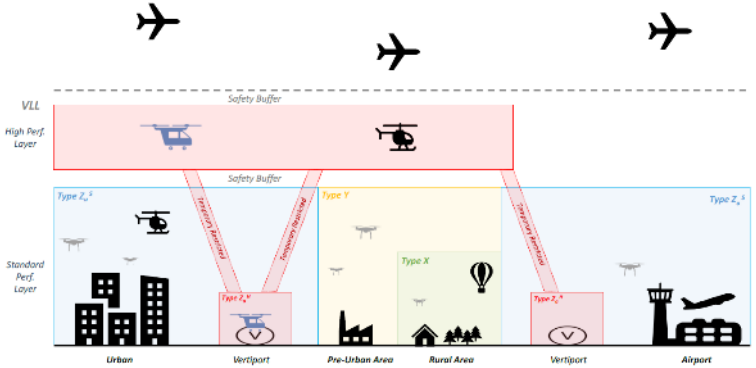


Type X:
No conflict resolution service is offered.

Type Y:
Only pre-flight conflict resolution is offered.

Type Z:
Pre-flight conflict resolution and in-flight separation.
Zu airspace controlled by UTM and Za controlled by ATM.

SESAR AMU-LED



Two layers within VLL:
- High performance layer
- Standard performance layer

Dynamic corridors

Airspace structures

Along with new airspace structure, suitable ground infrastructure for UAM needs to be developed.

- Small airports for eVTOLs
- Pickup & Drop-Off sites
- Charging facilities
- MRO operations
- Parking spaces for longer-haul eVTOLS

Even though new airspace concepts are designed specifically to enable safe unmanned operations, once large-scale operations begin, it might be necessary to further redesign the airspace to adjust it to various types of vehicles and operations.

Urban Air Mobility Traffic and control risks

MECHANICAL/ TECHNICAL

- Datalink loss
- Sensor failure
- Directional loss
- Flight controller failure
- Unintentional loss of altitude
- Total loss
- Loss of payload
- Erroneous data
- Latency
- Automation error

Understood as a random situation that will make UAV not following the desired path

ENVIRONMENTAL/ METEOROLOGICAL

- Animal collision
- Severe weather
- Icing
- Electromagnetic interference
- Corrosive environments
- Noise, pollution
- Sand or dust

Change the weather logical errors implemented to simulation:
i.e. wind 0 – 15 [m/s]

HUMAN/ OPERATIONAL

- Collisions
- VLOS loss
- Mission planning error
- Human error
- Insufficient understanding of advanced systems
- Obsolete equipment

Understood as loss of control and geofencing is not working

SECURITY

- Intentional collision
- Intentional interference
- Trespassing
- Cyberattack

Cyber security

UAM SERVICES

- Lack of transactional integrity
- Datalink loss
- Loss of data, processing error latency
- Lack of available infrastructure
- Inadequate ground crew training
- Degradation of ground control station capability

Maybe random trajectories

Potential solutions

Adapting solutions from manned aviation

Integration of UAS/UAM into the future aviation system is a challenge. Dynamic development of unmanned aviation industry is **outpacing existing regulations**. Maintaining the current level of safety in the aviation sector **is a priority**.

The idea is to identify scalable aspects of airspace operations that could potentially be addressed by adapting safety guidelines existing in manned aviation or non-urban UAV operations.

- Aircraft classification
- Airspace classes
- Pilot/operator training and licensing
- Certification/registration
- Security systems
- Weather, icing

Potential solutions

In some cases, it is not reasonable to adapt already existing solutions.

Advanced technologies are outpacing development of the necessary infrastructure.

Adapting existing solutions can cause new risks to emerge.

- First cars (environment was not ready)
- Traffics in old cities where the infrastructure is inefficient
- Capacity of public transport
- Uncontrolled expansion of some elements (cars, traffic, data transfer etc.)

It is necessary to search for new solutions to address the risks and needs of new technologies.

E.g., Tesla autopilot performance can be affected by:

- poor visibility (heavy rain, snow, fog)
- bright light (oncoming headlights, direct sunlight)
- narrow, high curvature or winding roads
- interference from other equipment that generates ultrasonic waves
- extremely hot or cold temperatures

New traffic approach:
tunnels providing stable conditions assuring high safety level

Roads suitable for horseback riding were too narrow for cars

Tesla tunnel under Las Vegas

UAV classifications: FAA, NASA

Table 1. FAA Categories of Permissible Operations over People

<table>
<tr><th rowspan="2">Category</th><th colspan="2">Performance-based requirements</th><th rowspan="2">Pilot Requirements</th></tr>
<tr><th>Weight</th><th>Injury upon impact</th></tr>
<tr><td>1</td><td>≤ 0.55 lb</td><td>Not required</td><td>Ensure aircraft weight</td></tr>
<tr><td>2</td><td>> 0.55 lb
≤ 55 lb</td><td>No more severe than from 11 ft-lb rigid object impact (AIS level 3)</td><td>Ensure aircraft is labeled for Category 2 operations</td></tr>
<tr><td>3</td><td>> 0.55 lb
≤ 55 lb</td><td>No more severe than from 25 ft-lb rigid object impact (AIS level 6)</td><td>Ensure aircraft is labeled for Category 3 operations. No operations over a moving vehicle or over open-air assemblies; over a closed- or restricted- access site with notification, no sustained flight over people.</td></tr>
<tr><td>4</td><td>-</td><td>-</td><td>Airworthiness Certificate
Operations over people performed in accordance with the operating limitations specified in the approved Flight Manual.</td></tr>
</table>

Table 2. FAA UAS Categorization by Weight

<table>
<tr><th colspan="2">Category</th><th>Weight</th></tr>
<tr><td rowspan="2">sUAS</td><td>Regular</td><td>MTOW > 0.55 lb (250 g) but ≤ 55 lb (25 kg)</td></tr>
<tr><td>Under 0.55 lb</td><td>MTOW ≤ 0.55 lb (250 g)</td></tr>
<tr><td colspan="2">Micro-/Ultra-Light UAS</td><td>MTOW > 55 lb (25 kg) but ≤ 330 lb (150 kg)</td></tr>
<tr><td colspan="2">Other UAS</td><td>MTOW > 330 lb (150 kg)</td></tr>
</table>

Table 3. NASA UAS Classification Matrix

Category	Type	Weight	Airspeed*
I	Model or sUAS	≤ 55 lb	≤ 70 kt
II	sUAS	55 - 330 lb	≤ 200 kt
III	UAS	> 330 lb	> 200 kt

* In Europe sometimes speed is changed into **kinetic energy** that is a parameter

UAV classifications: levels of autonomy

Table 4. Levels of autonomy by NATO [1]

Level	Description	Capability
1	Remote control	No tactical behavior.
2	High-level human input	Low-level tactical behavior in simple environment.
3	Mid-level human input	Multi-functional missions in moderate environment.
4	Low-level human input	Collaborative, high-complexity missions in difficult environment.
5	No human input	All missions in extreme environments.

Table 5. Levels of autonomy by National Institute of Standards and Technology [2]

Level	Description	Capability
1	Remotely controlled system	Actions depend on operator input.
2	Automated system	Actions depend on fixed built-in functionality (preprogrammed).
3	Autonomous non-learning system	Actions depend upon a fixed set of rules.
4	Autonomous learning system with the ability to modify rules	Actions depend upon a set of rules that can be modified for continuously improving goal directed reactions.

1. NIAG SG75, Pre-feasibility Study on UAV Autonomous Operations, 2004.
2. H.M. Huang, K. Pavek, B. Novak, J. Albus, E. Messina, A framework for autonomy levels for unmanned systems (ALFUS), in: AUVSI's Unmanned Syst. North Am. 2005 - Proc., 2005.

UAV classification implementation

Table 7. Proposed UAS classification

Level	Description
0	Full manual
1	Automatic Flight Control (waypoint navigation: A -> B)
2	Relatively small UAS: Automatic Flight Control + Collision Avoidance
3	Large cargo UAS: Automatic Flight Control + Collision Avoidance
4	Fully Autonomous

Table 8. UAS use cases

Level	Use cases
0	Hobby, personal usage, photography, video production
1	Small delivery (one task, one trajectory, e.g. package, food), media, surveillance operation, traffic monitring
2	Small delivery (package, food, post), multiple trajectory, inspections
3	Packages hub to Person H2P or H2H, multiple packages, larger cargo
4	Air taxi, medical transport

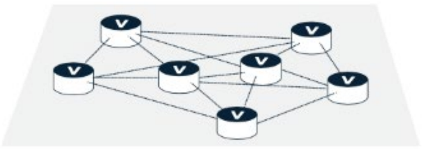
UAV classification implementation

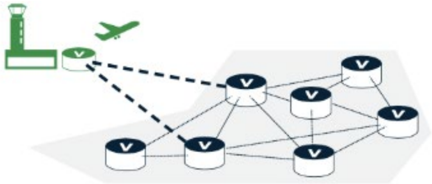
Table 9. Proposed UAS classification

Level	Description
0	Hobby, personal usage
1	Small delivery (package, food, medical supply) one task, one trajectory
2	Small delivery (package, food, post), multiple trajectory
3	Packages hub to Person H2P or H2H, multiple packages, lagrer cargo
4	Fully Autonomous, human taxi

Various UAV levels:

- different starting points/destinations:
  - L1 - from any place to any place
  - L3 - H2P, H2H
- different routes:
  - L3 - bypass not to disturb
  - L1 - need to deliver package to people
- different time of operating:
  - L3 - night shift opposite to daylife
  - L1, L2 - along the daylife
- different operating areas:
  - business district
  - commercial districts
  - residential area
  - parks/open fields
- on-demand & scheduled routes





Urban Air Mobility Traffic flight rules

Number of systems but all of them are centralized alike

Finland, Dubai, Italy, Canada, UAE, Colombia

But all of those solutions are short in future thinking.

Drone and pilot registration is crucial and important – such systems already exist and function – drone deploy i.e.

Most important common features:

- Operator and Drone Registries
- Flight Requests and Approvals
- Real-Time Traffic Monitoring
- SORA (Specific Operation Risk Assesment)
- Geofencing/restricted areas

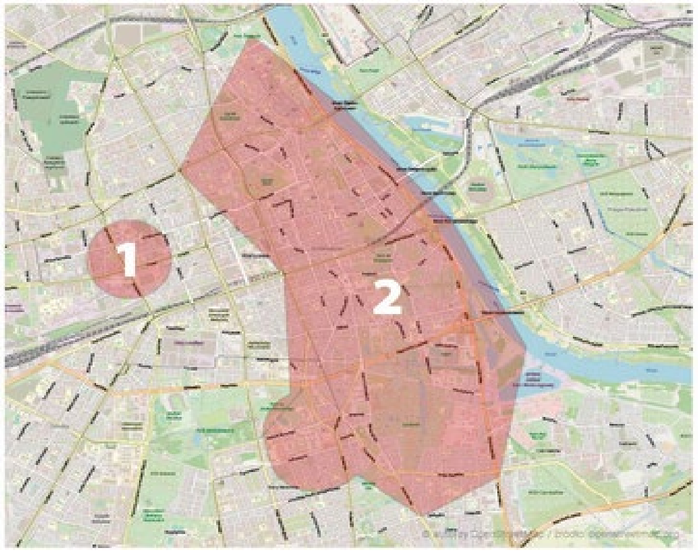
Urban Air Mobility Traffic Analysis Tool

Current status

- Simulations of drone traffic over specified area with defined no-fly-zones and restricted traffic zones
- UAV modeled as a point with no dynamics
  - Specified size (collision radius)
  - Limited range
  - Specified cruise speed
  - Division into UAV autonomy levels
  - Assigned waypoints
  - Families: commuters, parcel deliveries
- Departure and destinations points determined based on UAV type/application based on real world population density and hub locations

Close next steps (couple of weeks)

- Outcome of a close encounter based on UAVs' autonomy levels
  - two low autonomy level drones -> collision
  - at least one high autonomy level drone -> collision avoidance

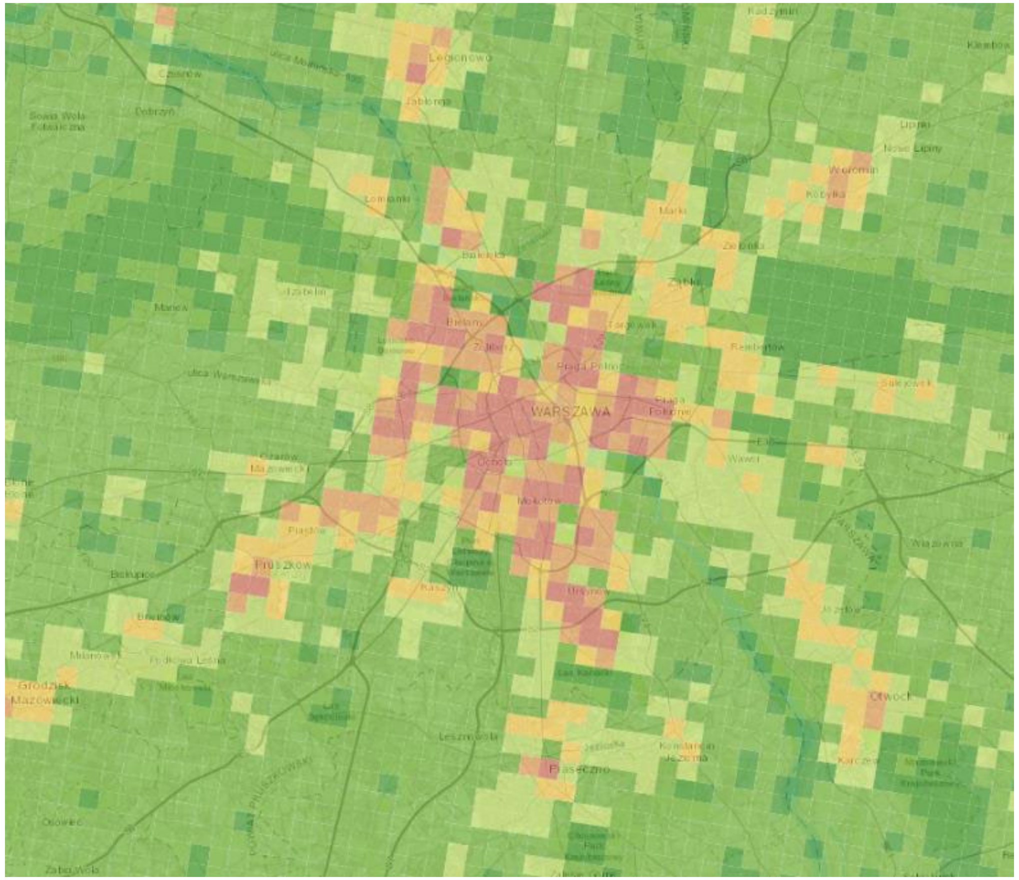


Long perspective

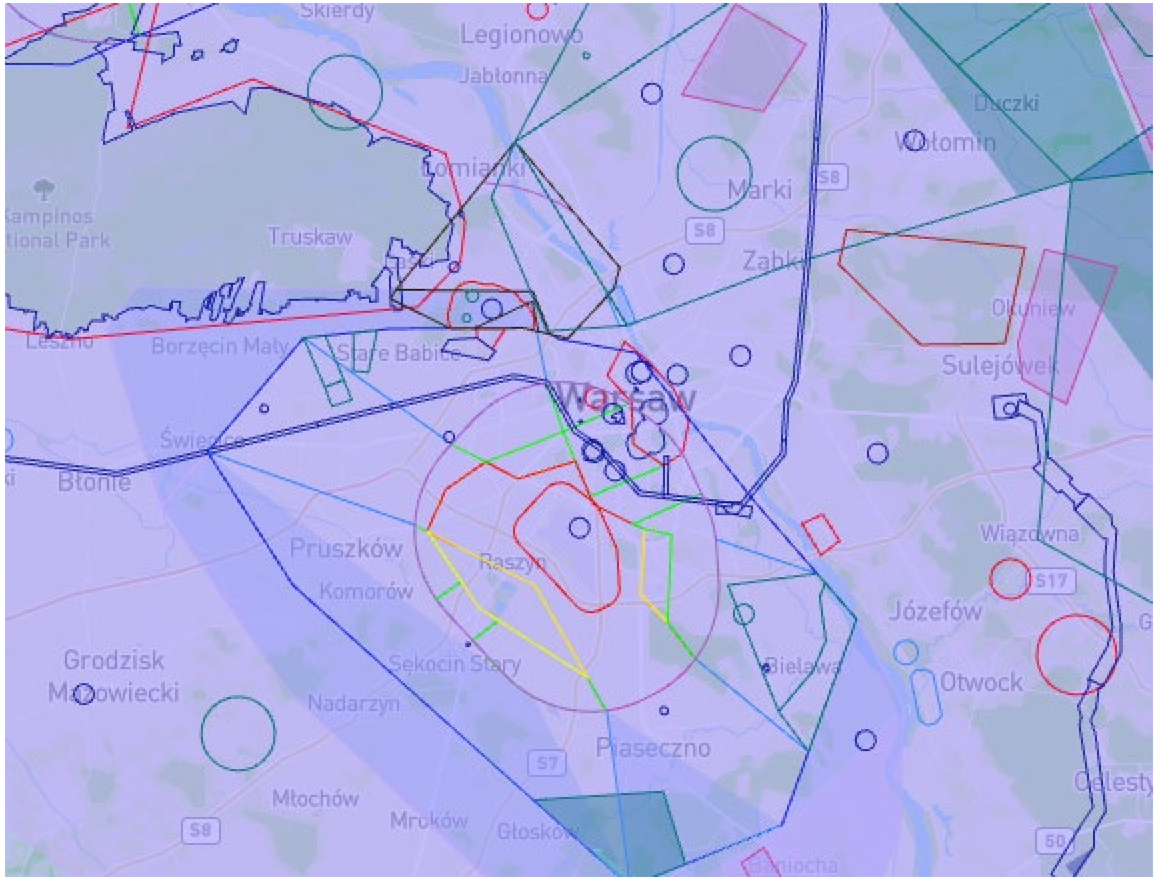
- Additional done families
  - Recreational/loiter
  - Food (ad-hoc) deliveries
- More realistic modelling of deliveries destination selection (multipoint destinations within the same area)
- More advanced start and landing modelling
- Risks and managing the risks by different class of UAVs
- Traffic rules
  - Corridors, zones, etc.

Urban Air Mobility Traffic Analysis Tool

Population density distribution
Statistics Poland (Central Statistical Office)

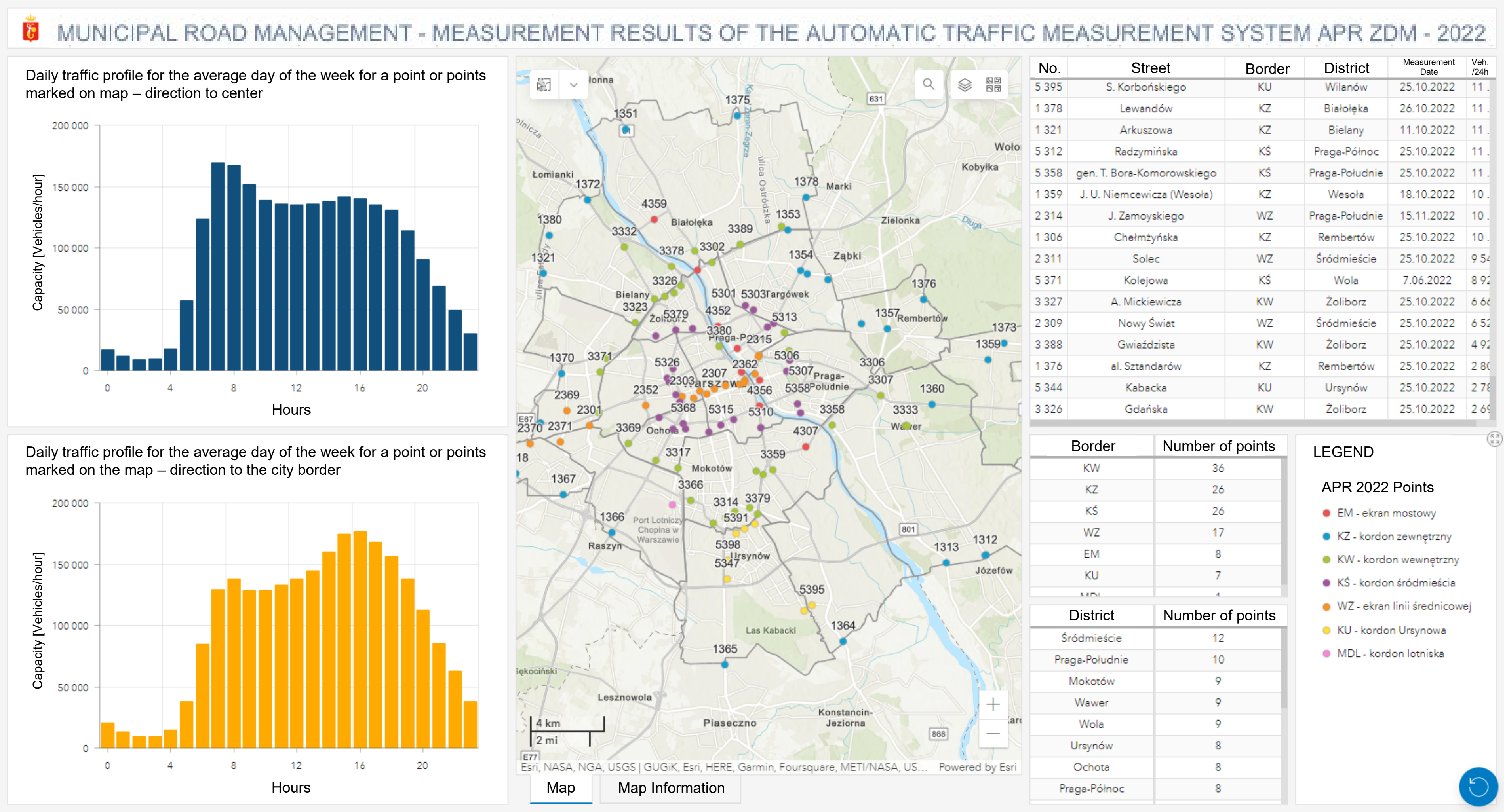


Airspace restrictions
Polish Air Navigation Services Agency



Urban Air Mobility Traffic Analysis Tool

Daily traffic distribution – Municipal Road Administration



No.	Street	Border	District	Measurement Date	Veh. /24h
5 395	S. Korbońskiego	KU	Wilanów	25.10.2022	11 .
1 378	Lewandów	KZ	Białołęka	26.10.2022	11 .
1 321	Arkuszowa	KZ	Bielany	11.10.2022	11 .
5 312	Radzymińska	KŚ	Praga-Północ	25.10.2022	11 .
5 358	gen. T. Bora-Komorowskiego	KŚ	Praga-Południe	25.10.2022	11 .
1 359	J. U. Niemcewicza (Wesoła)	KZ	Wesoła	18.10.2022	10 .
2 314	J. Zamoyskiego	WZ	Praga-Południe	15.11.2022	10 .
1 306	Chełmżyńska	KZ	Rembertów	25.10.2022	10 .
2 311	Solec	WZ	Śródmieście	25.10.2022	9 54
5 371	Kolejowa	KŚ	Wola	7.06.2022	8 92
3 327	A. Mickiewicza	KW	Żoliborz	25.10.2022	6 66
2 309	Nowy Świat	WZ	Śródmieście	25.10.2022	6 52
3 388	Gwiaździsta	KW	Żoliborz	25.10.2022	4 92
1 376	al. Sztandarów	KZ	Rembertów	25.10.2022	2 80
5 344	Kabacka	KU	Ursynów	25.10.2022	2 78
3 326	Gdańska	KW	Żoliborz	25.10.2022	2 69

Border	Number of points
KW	36
KZ	26
KŚ	26
WZ	17
EM	8
KU	7
MDL	1

District	Number of points
Śródmieście	12
Praga-Południe	10
Mokotów	9
Wawer	9
Wola	9
Ursynów	8
Ochota	8
Praga-Północ	8

Source: Warsaw Municipal Road Administration, https://zdm.waw.pl

Urban Air Mobility Traffic Analysis Tool

UAV population definition

- Drone families and their parameters (e.g. cruise speed, range, level of autonomy, daily traffic distribution, hubs)
- Population density
- Route/waypoints assignment

Route planning

- Airspace restrictions
  - No-fly zones
  - Restricted fly zones (drones may only enter the zone if its departure or destination point lies within that zone, drone must fly along shortest path)
- Assignment of flight altitude

Traffic simulation

- Simulation of air traffic
- Each drone flies to its destination(s) via waypoints specified during route planning
- Detection of required collision avoidance manoeuvres (traffic advisories) and collisions (in case of non autonomous drones)

Traffic report

- Traffic animation
- Traffic density map
- Collisions density map
- Traffic advisories density map
- Number of collisions per drone
- Number of traffic advisories per drone

Urban Air Mobility Traffic Analysis Tool

Loiter drones

550 000 UAV operations in 2022 in Poland
- 0.01456 UAV operations per capita (per year, assuming population of 37.766M)
- 95 UAV operations per day in Warsaw area (assuming population of 2.384M)

Source: https://www.pansa.pl/co-moze-grozic-za-naruszanie-przepisow-okreslajacych-zasady-wykonywania-lotow-dronami/

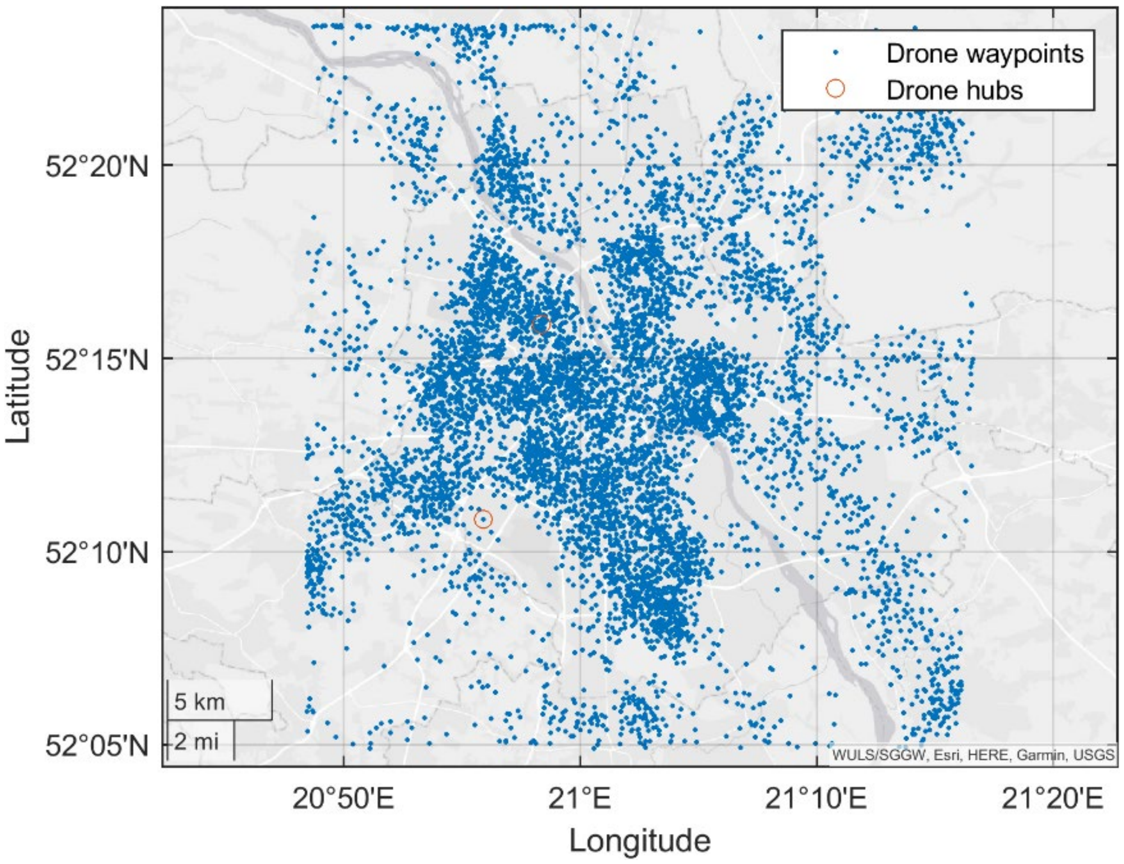
Commuter drones (taxi)

111.5M taxi rides in 2022 in Poland (app based)
- 2.95 taxi rides per capita (per year, assuming population of 37.766M)
- 19270 taxi rides per day in Warsaw area (assuming population of 2.384M)

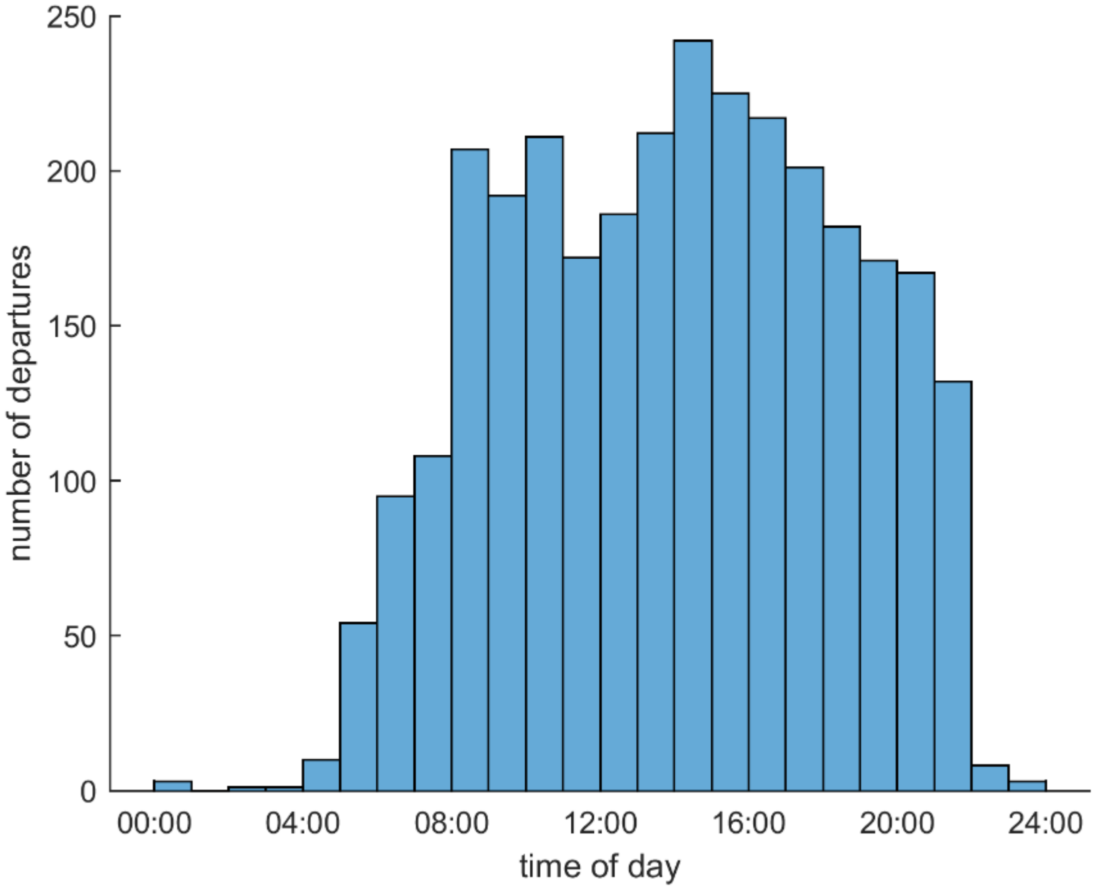
Source: https://www.transport-publiczny.pl/pdf/TAXI_raport_CS6-min.pdf

Urban Air Mobility Traffic Analysis Tool

Departure, destination and waypoints selection

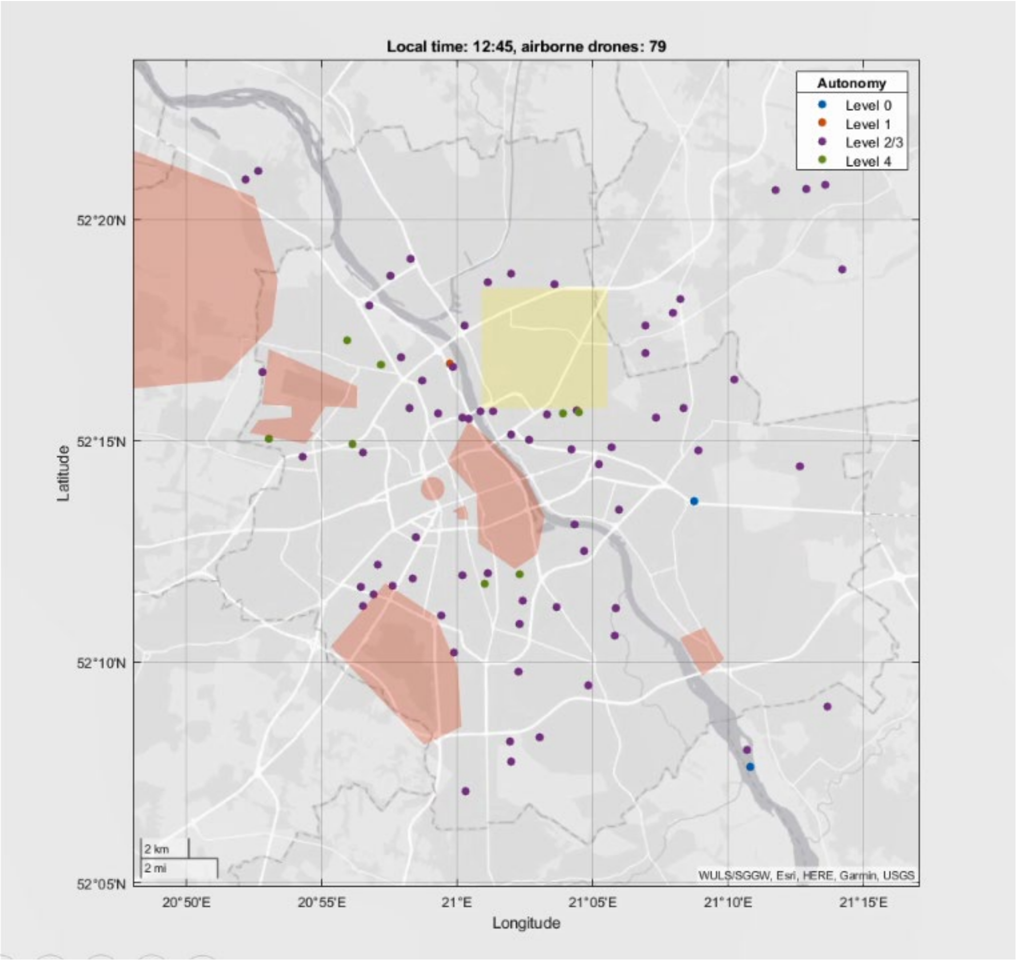


Departure times distribution

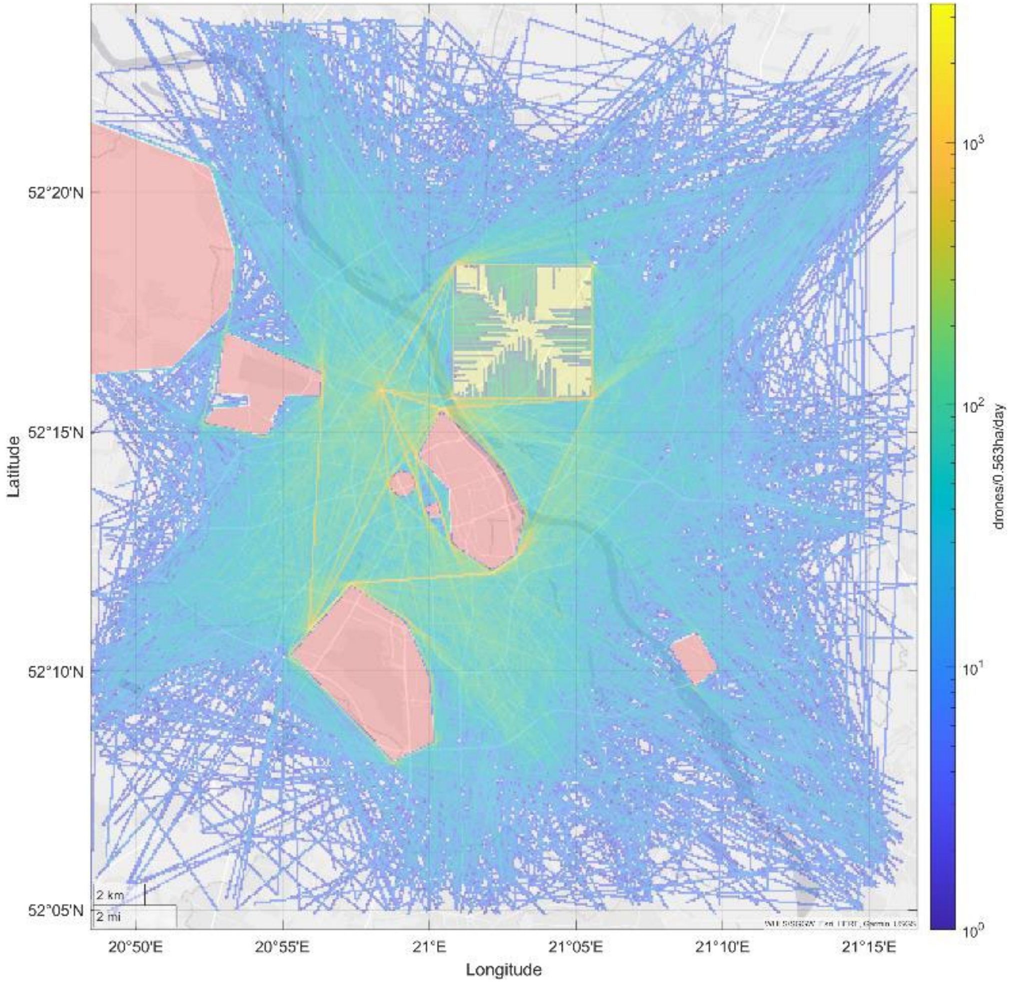


Urban Air Mobility Traffic Analysis Tool

Traffic simulation

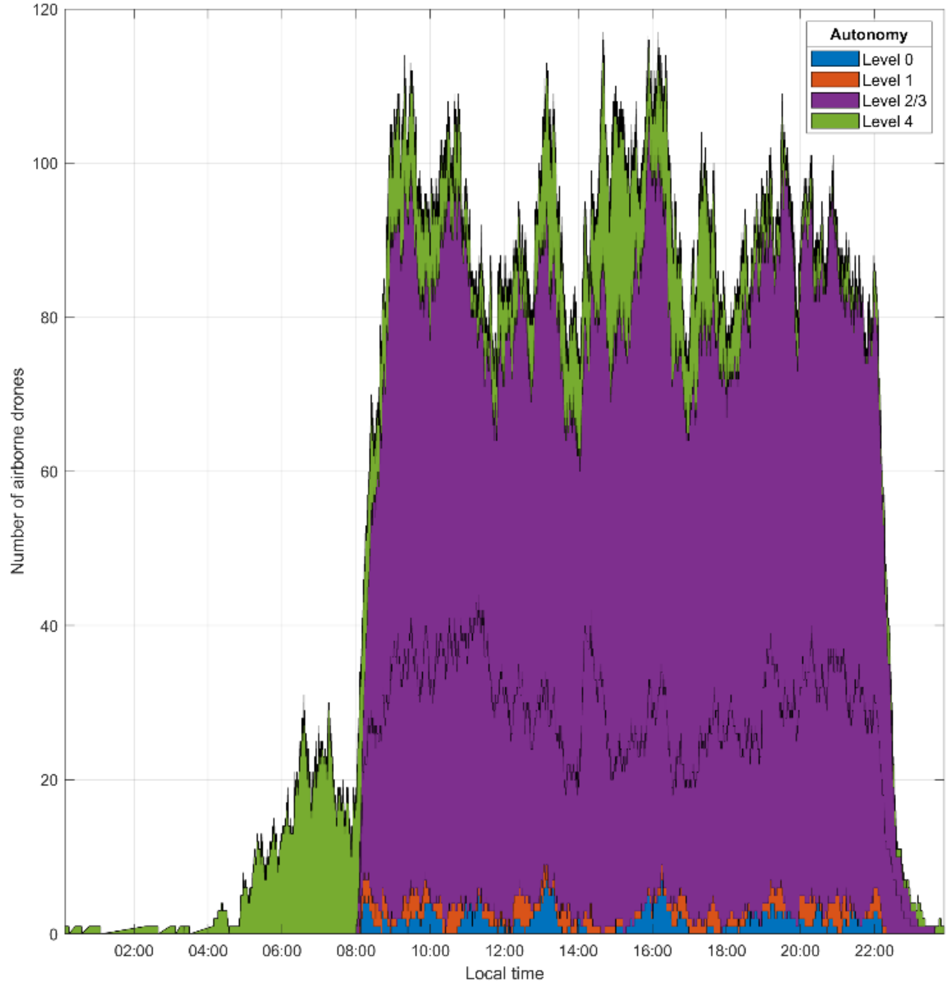


Traffic density map



Urban Air Mobility Traffic Analysis Tool

Traffic distribution



Simulation report

```
================================================================================
888     888        d8888 888b     d888    88888888888        d8888 88888888888
888     888       d88888 8888b   d8888        888           d88888     888
888     888      d88P888 88888b.d88888        888          d88P888     888
888     888     d88P 888 888Y88888P888        888         d88P 888     888
888     888    d88P  888 888 Y888P 888        888        d88P  888     888
888     888   d88P   888 888  Y8P  888        888       d88P   888     888
Y88b. .d88P  d8888888888 888   "   888        888      d8888888888     888
 "Y88888P"  d88P     888 888       888        888     d88P     888     888
================================================================================
Simulation was started at: 2023.04.28 09:50:16.

Simulation time at the start was: 00:00:00.
Simulation duration was: 24:00:00.

Total number of drones in the simulation was: 3000, including:

Autonomy        Number
------------------
Level 0         100
Level 1         100
Level 2         600
Level 3         1200
Level 4         1000

Total number of collided drones was: 18.
Total number of collision avoidances was: 2076.
```

UAV classification implementation

Simulation tool allows to:

- Drones’ data generation:
  - each drone is assigned with randomly drawn speed, take-off and landing points’ location and time,
- Hub locations and numbers
- Drone population generator
- drone’s path is adjusted in such a way that it avoic restricted airspaces
- Air traffic simulation based on the generated data the traffic simulation is conducted taking into account the drones’ parameters
- Data analysis:
  - traffic animation
  - traffic density map generation
- Heat map of airborne
- Heat map of drones’ Collision
- Heat map of collision avoidance