

MUSE

Measuring UAM Social and Environmental Impact

Lessons learned from the MUSE project

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Introduction: The UAM challenge

The MUSE project



- **U-space will enable urban air mobility (UAM) on a wide scale**, facilitating a variety of use cases (e.g., medical and emergency transport, delivery of goods, passenger transport services).
- **Key barrier: Social acceptance and impact on citizens** is not completely understood in this growing scenario. Noise, visual pollution and privacy concerns are major obstacles.
- **The gap:** There is a **need for a better understanding of the interplay** between **UAM's concept of operations** (e.g., geofencing, route design, allowed traffic density), **drones' visual and noise footprint**, and **citizens' spatial behaviour** and use of public space. Existing assessments often rely on simplified assumptions or census data that overlook daily mobility patterns.

The **MUSE project** aims to address this gap by establishing the basis for a **future U-space service** supporting the **minimisation of UAM's negative social and environmental externalities**

Presentation objective



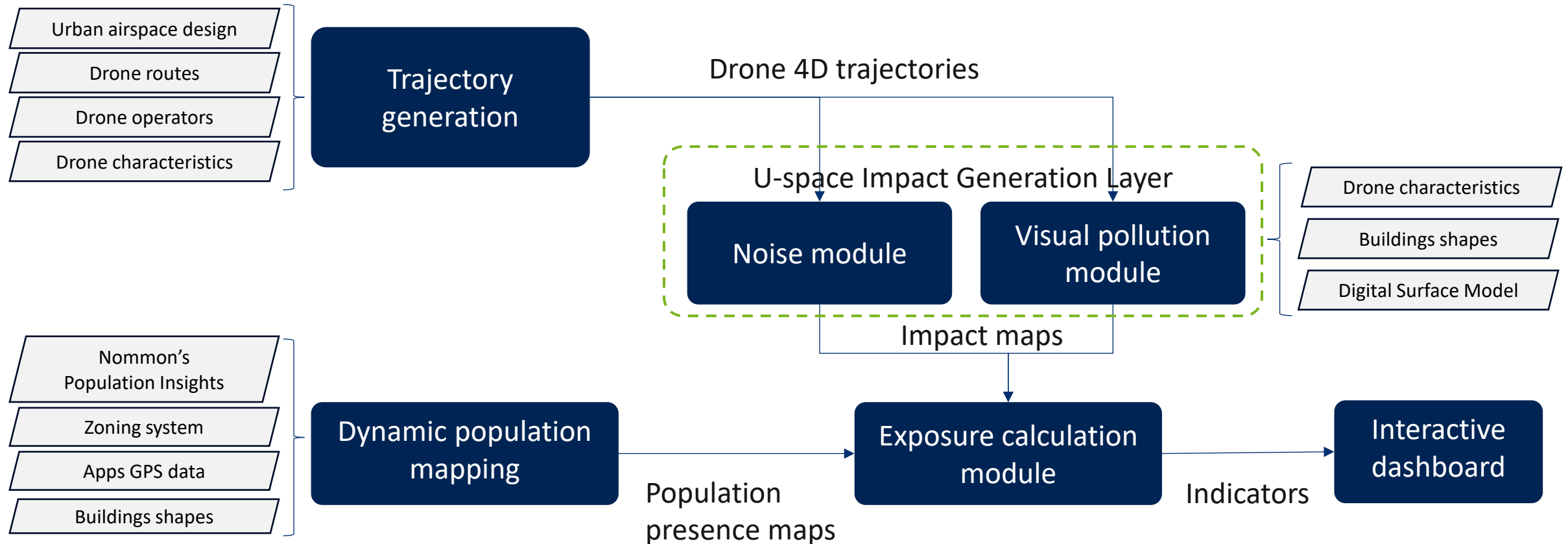
- This paper presents findings from case studies conducted within the MUSE project, distils lessons learned, and provides recommendations for policymakers, U-space regulators, U-space service providers (USSPs), and drone operators.
- We will discuss:
 - Methodology
 - Results of the case studies
 - Lessons learned and policy recommendations



- Indicators defined in the areas of noise, visual pollution, privacy concerns, access & equity, etc.
- Full list of indicators available in D3.1 U-space Environmental and Social Performance Framework

PIs	Unit	Measurement mechanism
NO-3: Trajectory-based people exposure to noise (SEL_A)	person	The amount of people exposed to a sound exposure level higher than a certain threshold in dBA, for a single drone operation, for a time period fixed by the drone trajectory, within an area.
NO-5: Area based people exposure duration to noise	D.person	A certain duration D of noise levels exceeding a certain threshold in dBA multiplied by the number of people exposed, over a fixed period of time (15 min), within an area.
VP-4: Trajectory based visual exposure	person.vp.h	Total visual pollution exposure perceived by the people exposed to a single drone operation.
PC-1: Trajectory-based people visually annoyed	person	Total amount of people annoyed by (presence of) a single drone operation.
PC-3: Area based people visually annoyed	person	Total amount of people annoyed by presence of UAs within an area, during observed time period.
AE-2: Reduced travel time for health care-related deliveries	seconds	The amount of time reduced for health care-related deliveries by UAs compared to the delivery by road transport.

Impact Assessment Toolset methodology



Case studies



Objectives of the case studies:

- To demonstrate the capabilities of the MUSE U-space Environmental and Social Impact Assessment Toolset to assess different scenarios and types of urban areas
- To assess UAM's impact and derive policy recommendations for the case study scenarios
- To derive conclusions and lessons learnt for the exploitation of the methods and tools developed by MUSE



Madrid (Spain)



Delivery and medical services

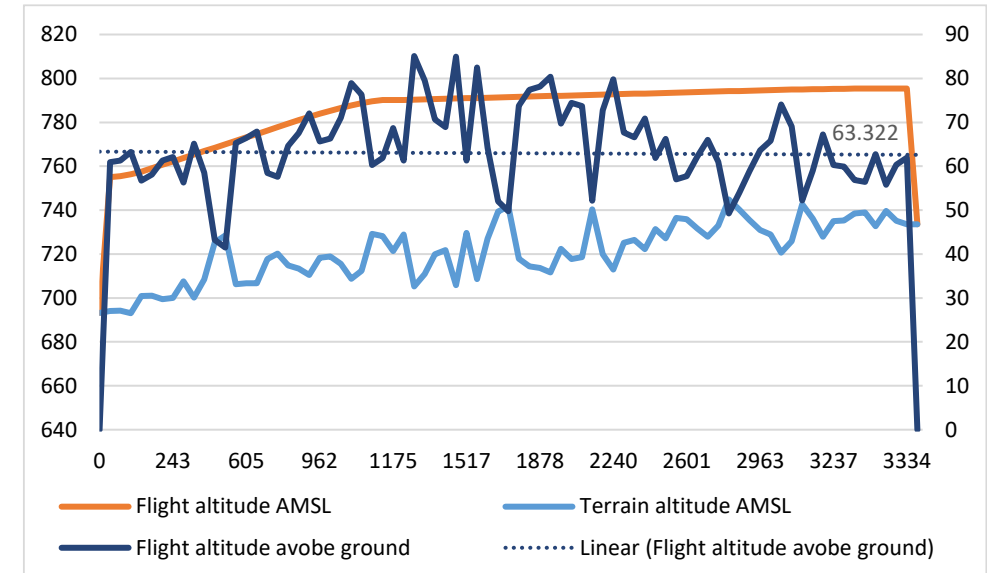
Case Study 1: Urban Parcel Delivery



Description

Parcel delivery

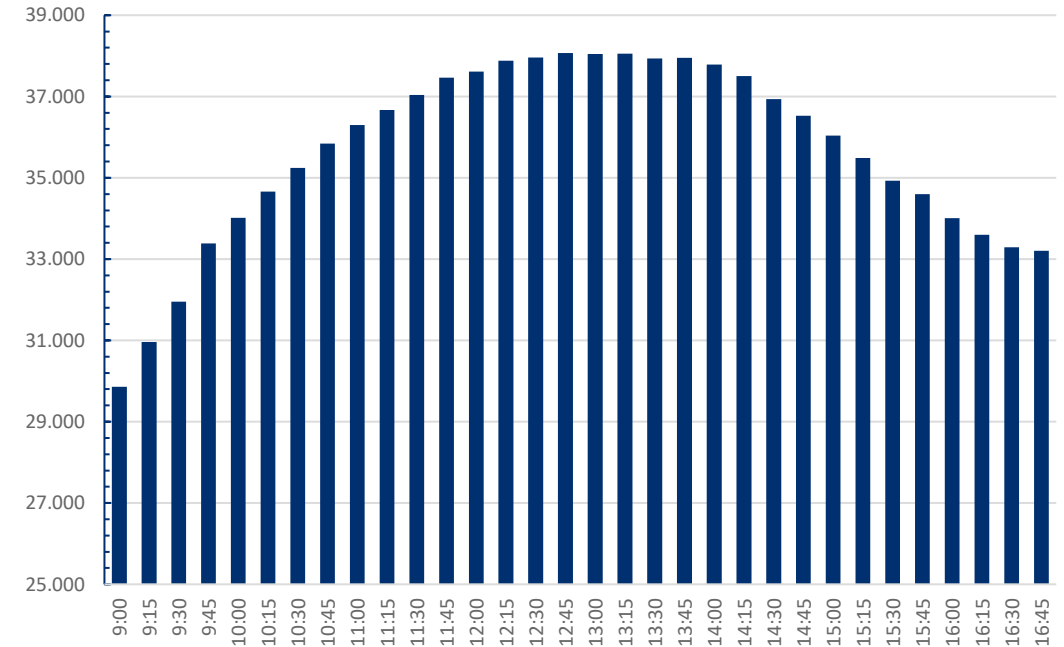
- **Growing urban interest** in drone-based delivery for small parcels due to speed, precision, and reduced environmental impact. Versatile payload capacity covering groceries, household items, etc.
- Flight altitudes in **the band 45–90 m AGL**. Each flight assigned a random altitude within this band; terrain-following trajectories introduce minor deviations from the target profile.
- Use of the **DJI Matrice 600**
- Distribution centres limited to a throughput of **60 operations per hour**.
- **Study area** restricted to a representative **5.9 km × 1.7 km zone in Madrid** containing residential districts, leisure areas, sensitive locations (e.g., Royal Palace), and hospitals.



Results

Population presence outside

- **Population presence is key** to analyse the indicators observed.
- We only look at population present in the **outside**.
- The data shows a peak between 12:30 and 14:30.



Results – Noise

NO-3: Trajectory-based people exposure to noise

Comparison of population exposure for identical ground tracks at different time of day

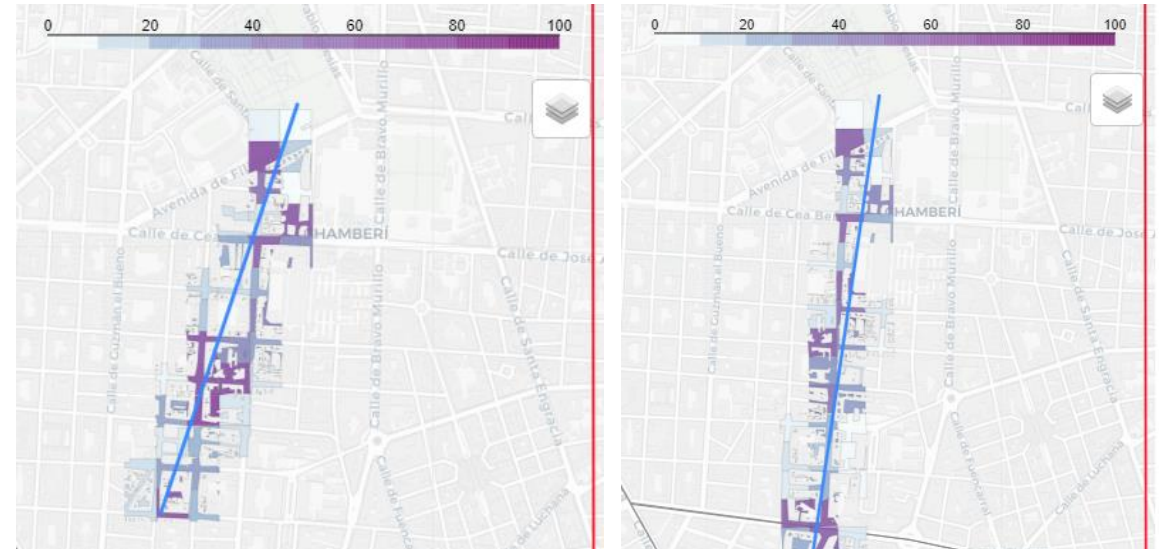
- We compared two flight paths with similar altitudes that flew over the same city area but at different times.
- The effect is roughly the same in both scenarios. Specifically, the morning flight affected 1,034 individuals, while the afternoon flight had a slightly smaller impact, affecting 951 people.
- Given the fact that the drone type is the same, any difference in this case is due to the population presence variation.

Flight A (8:00)

1,034 People Exposed

Flight B (16:30)

951 People Exposed



Trajectories of similar altitude at different time periods. Left: Trajectory IN10744-B, 65m at 8:07 a.m.. Right: Trajectory IN11162-B, 60m at 4.31 p.m.

Results – Noise

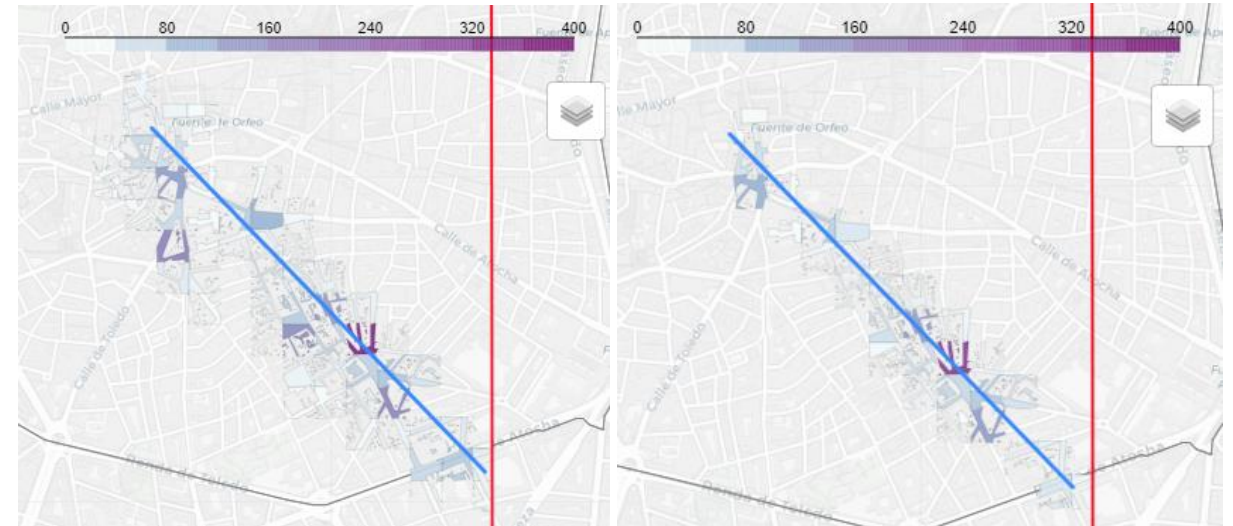
NO-3: Trajectory-based people exposure to noise

Comparison of population exposure for identical ground tracks at different altitudes

- In this scenario, a **9m increase in altitude** resulted in a **44% reduction in people exposed**
- The result seems reasonable with sound propagation effects

And yet, it is not always the case!

Flight A (49m AGL)	2,127 People Exposed
Flight B (58m AGL)	1,193 People Exposed



Similar trajectories at different altitudes (case 1). Left: Trajectory SO6388-F, altitude: 49 m. Right: Trajectory SO6388-B, altitude 58m.

Results – Noise

NO-3: Trajectory-based people exposure to noise

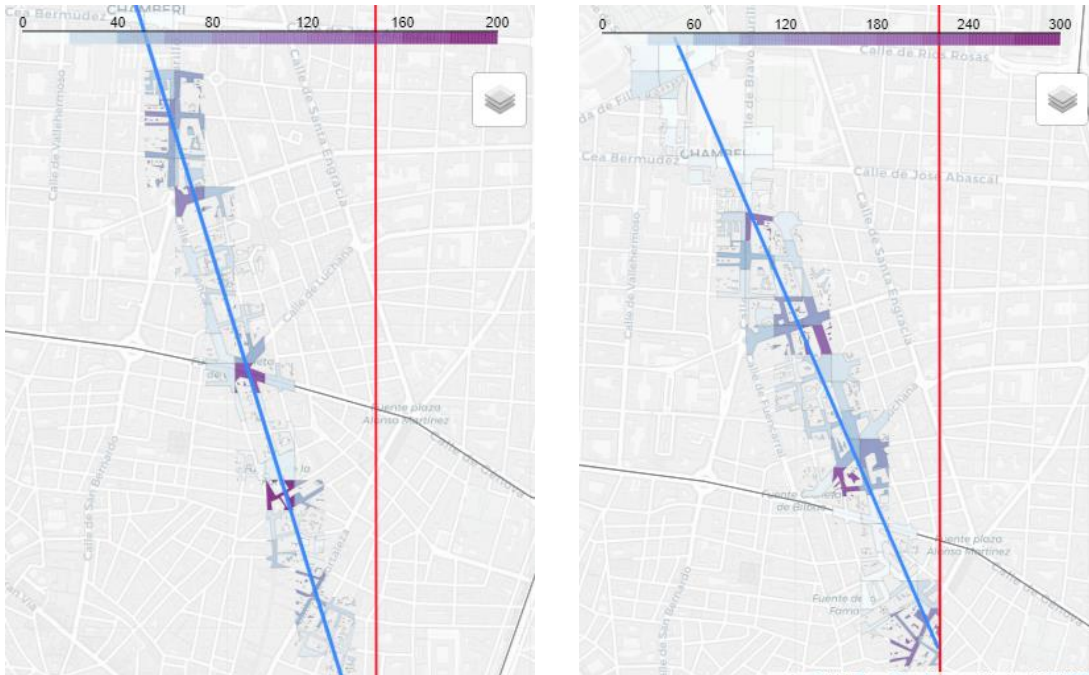
Comparison of population exposure for identical ground tracks at different altitudes

Flight A (38m AGL)

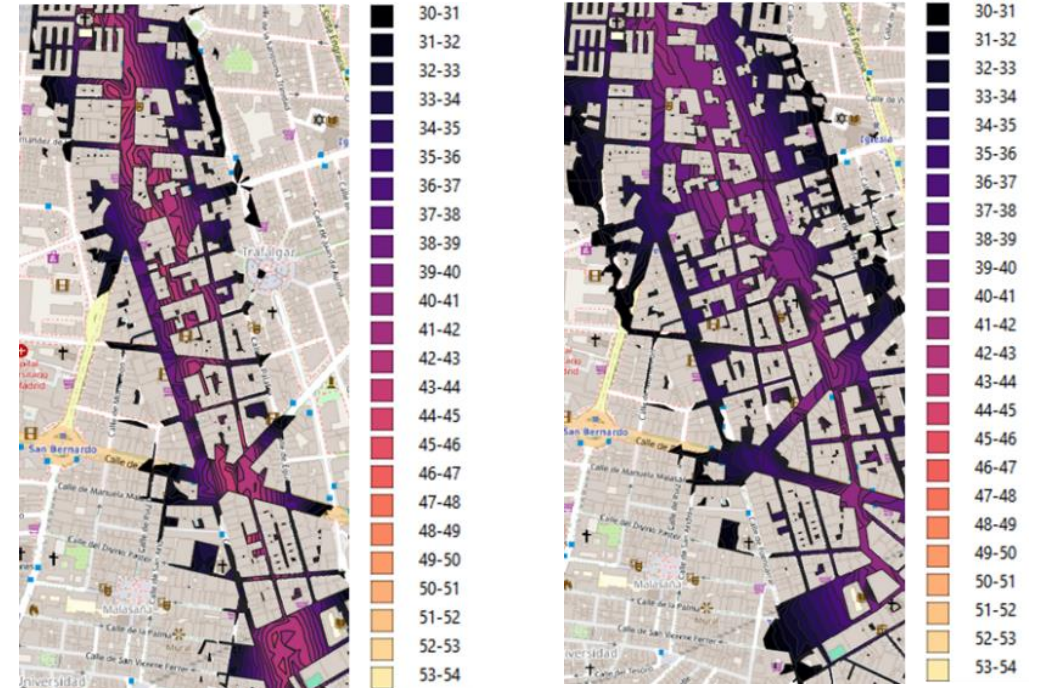
1,317 People Exposed

Flight B (73m AGL)

2,244 People Exposed



Similar trajectories at different altitudes (case 2). Left: Trajectory IN9596-B at 9.03 a.m., altitude 38m. Right: Trajectory IN8351-B at 8.32 a.m., altitude 73m.



Noise map of NO-3 indicator (SELA, [dBA]) for similar trajectories at different altitudes.

Results – Noise

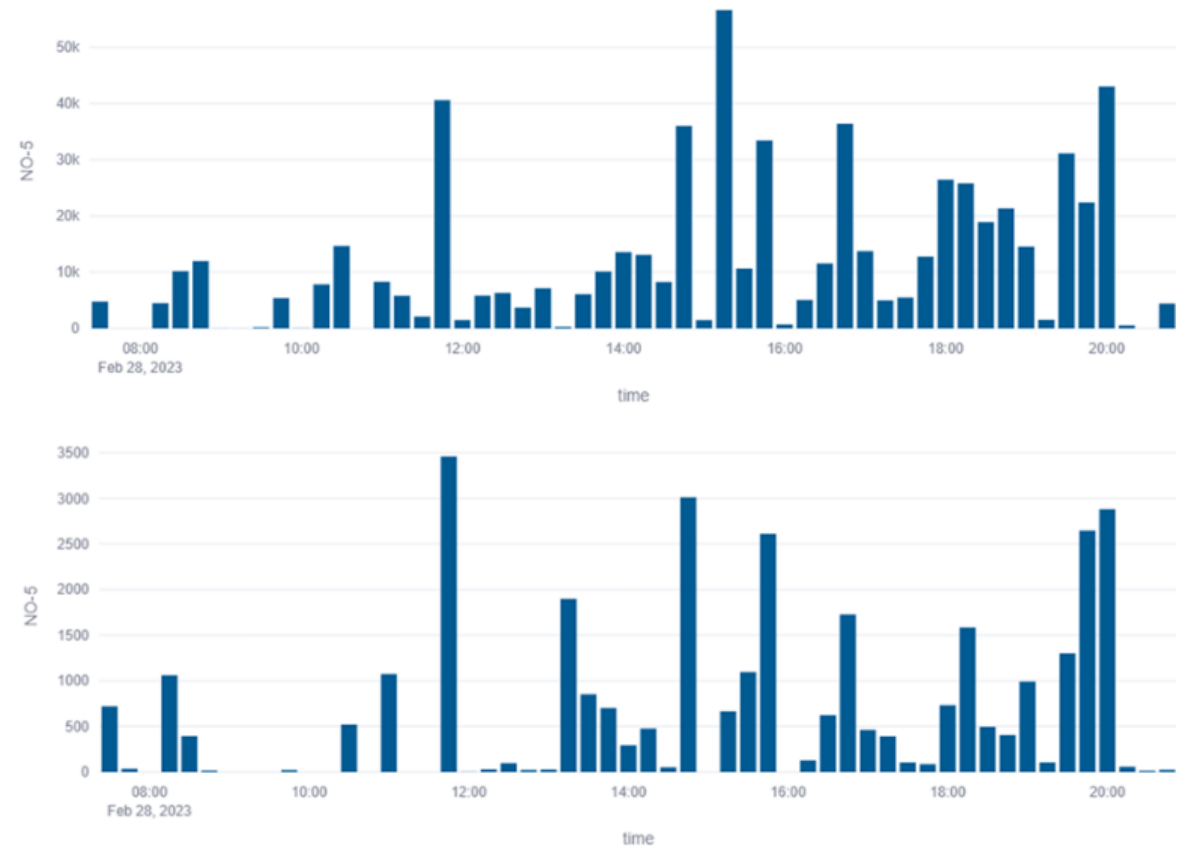
NO-5: Area based people exposure duration to noise (D-persons)



Road traffic background noise daily average (Lday) provided by the Madrid City Council for 2021.

40 dBA

Road traffic noise



NO-5 indicator time distribution along the day. Top: 40 dBA threshold. Bottom: threshold corresponding to the background noise (Lday).

Results – Visual pollution

VP-4: Trajectory based visual exposure (person·vp·h)

- This compound indicator measures not only the visual pollution concentration (VP), but also the number of people exposed and the duration of their exposure.
- Higher altitude -> Lower VP
- When altitude is similar, the direction of the flight becomes a key factor:

Landing phases (inbound) generate 60% higher cumulative visual pollution exposure than take-off phases due to lower velocities in the phases closer to the observers

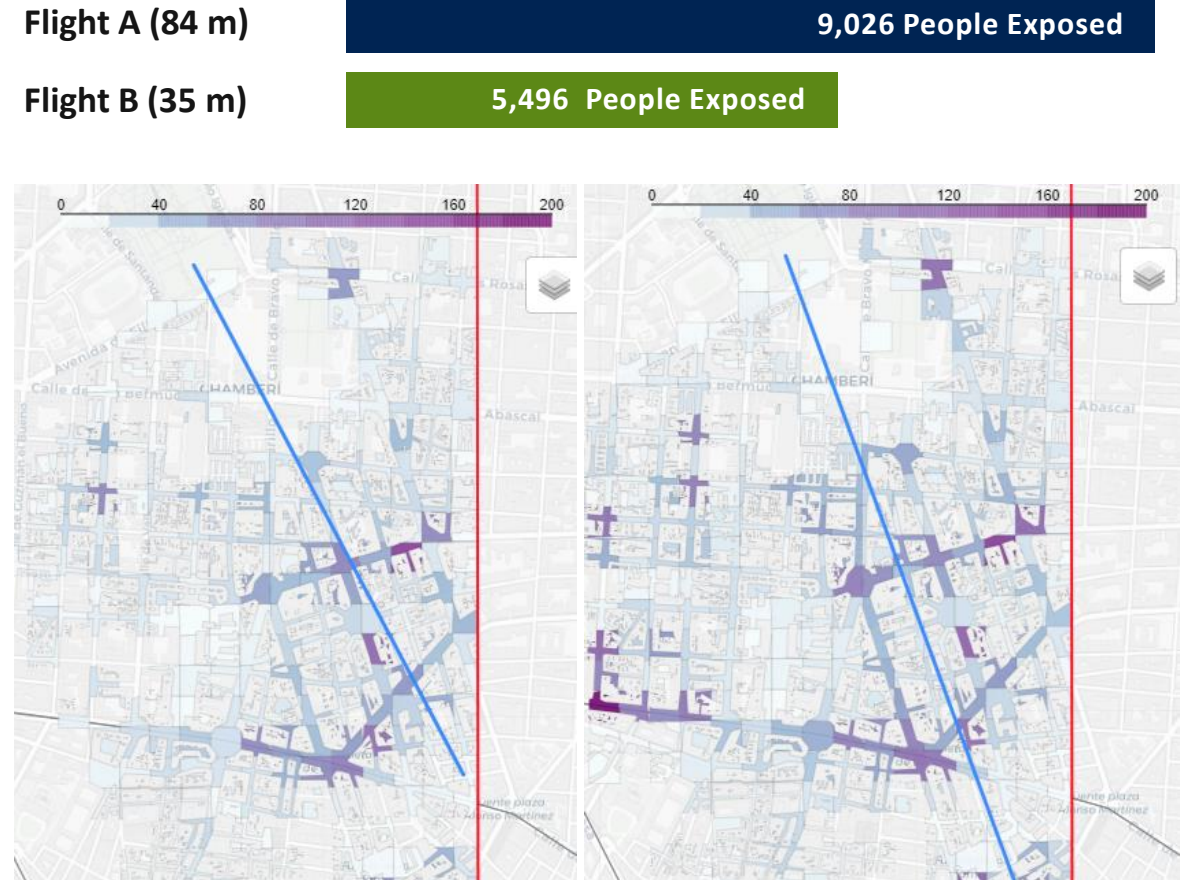
Inbound flight	1,281 person·vp·h
Outbound flight	808 person·vp·h



Results – Privacy concerns

PC-1: Trajectory-based people visually annoyed

- Two comparable flights were analysed to isolate the effect of altitude on privacy-related visual annoyance (PC-1).
- This corresponds to a 64% increase in the number of exposed individuals at the higher altitude.
- The primary driver is the **expanded visibility radius at greater heights**, which enlarges the population potentially experiencing visual disturbance.
- Effect of distance not analysed: how far away a drone stops concerning you, even if it is visible?

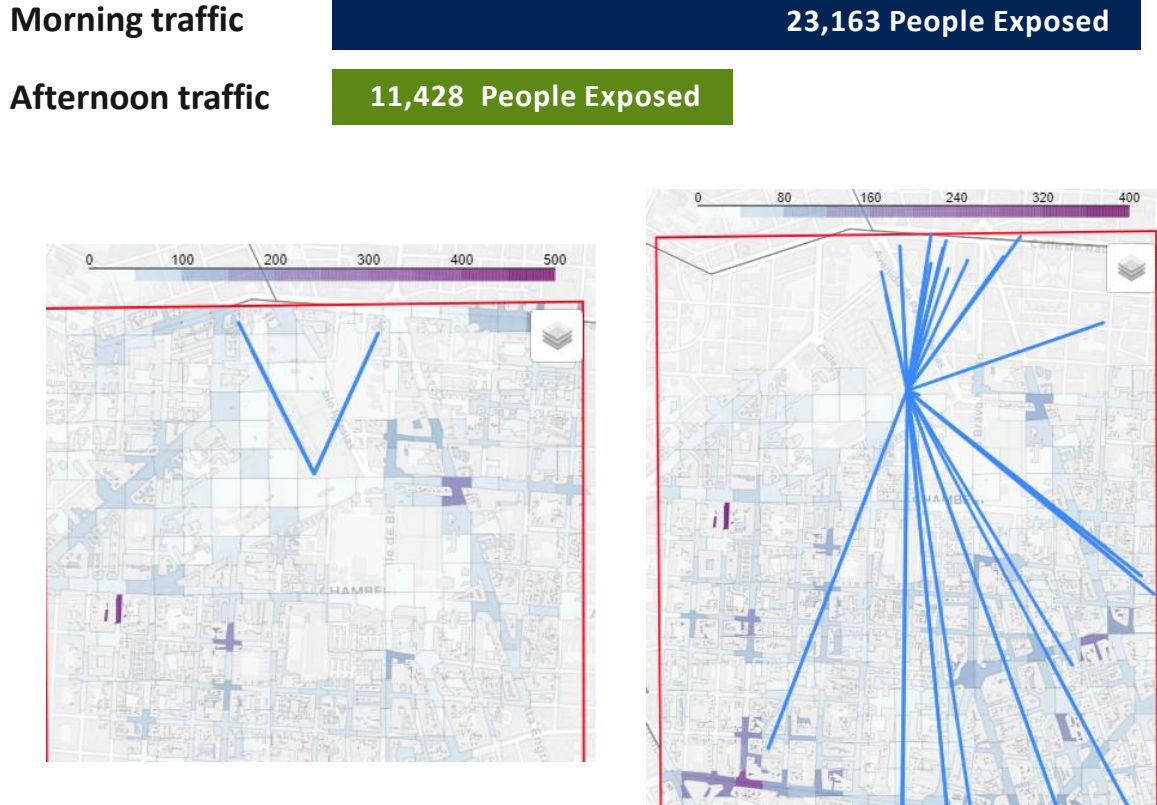


Results for PC-1 indicator. Left: Low-altitude trajectory (IN10226-B at 35m).
Right: High-altitude trajectory (IN10481-F at 84m).

Results – Privacy concerns

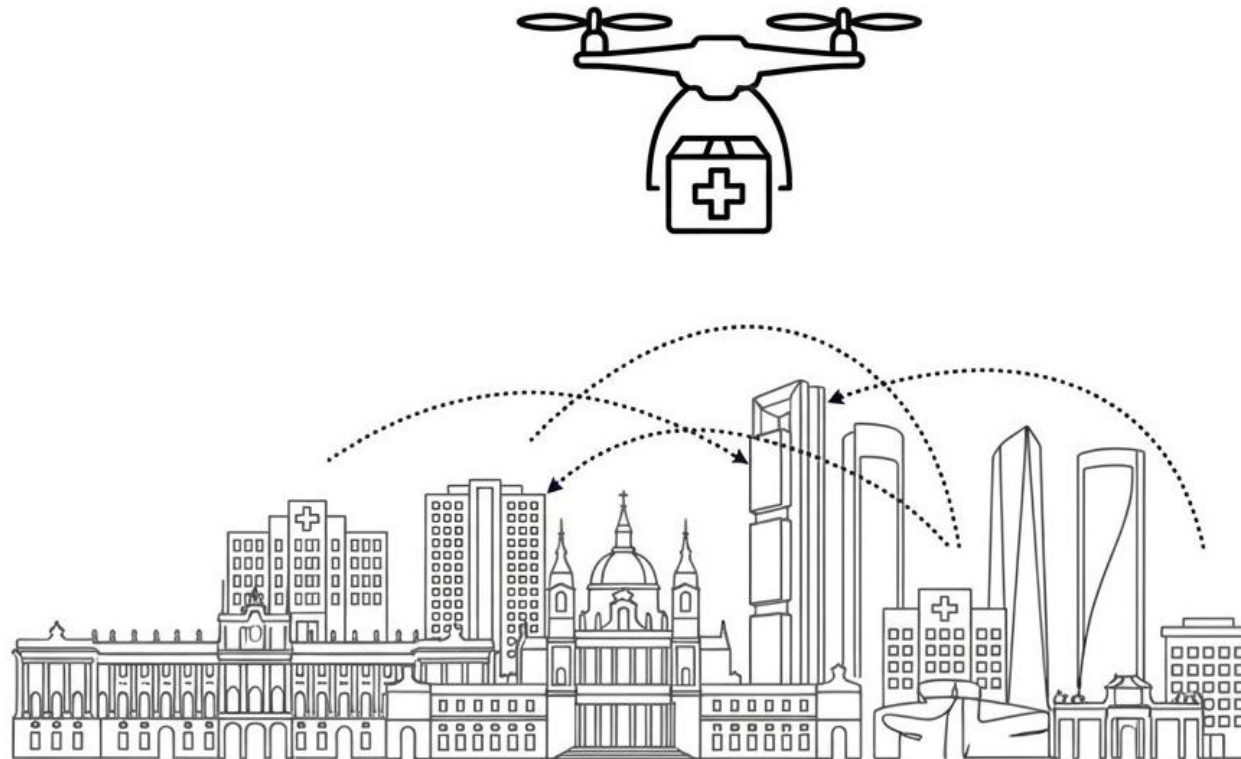
PC-3: Area based people visually annoyed

- PC-3 quantifies the total number of people visually annoyed by drone operations within a defined area over a given time window.
- Traffic intensity strongly influences this indicator:
 - Afternoon (high traffic): 23,163 people affected.
 - Morning (low traffic): 11,428 people affected.
- The afternoon value is roughly double the morning value, showing that increased drone activity significantly amplifies privacy-related visual annoyance.



Results for PC-3 indicator. Left: morning period. Right: afternoon period.

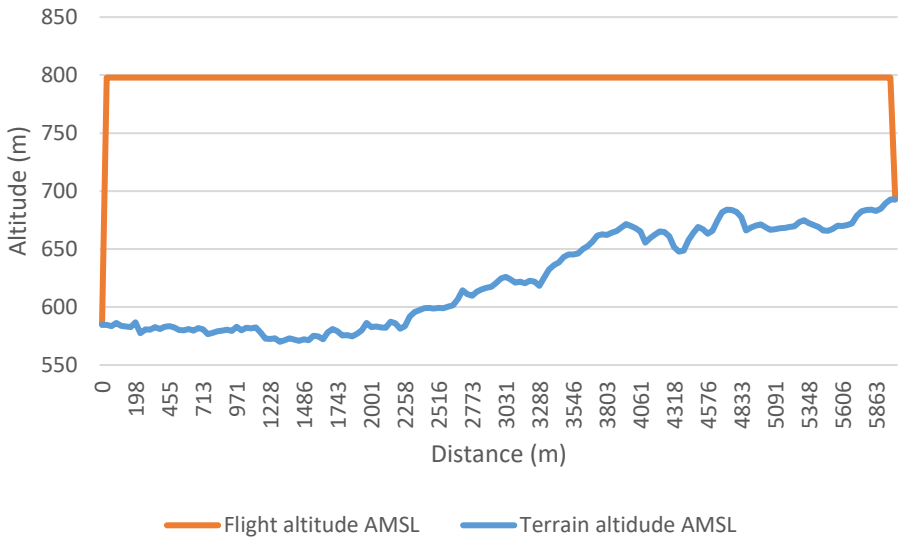
Case Study 2: Emergency Medical Logistics



Description

Emergency delivery

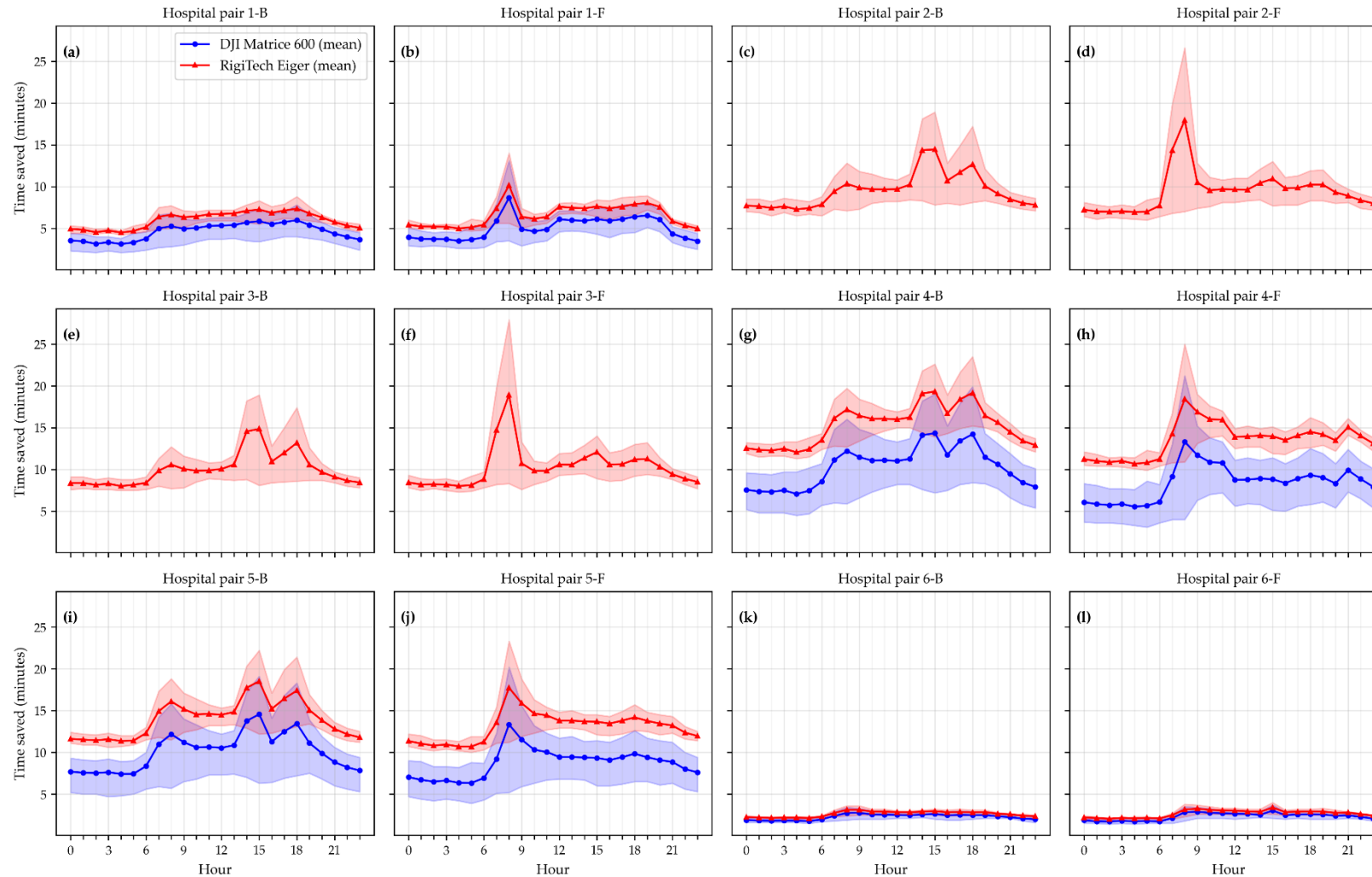
- Medical applications are emerging as a **leading driver of societal trust** in drone technology (medications, blood samples, organs, and other critical supplies).
- Medical deliveries demand **higher urgency**, prompting direct hospital-to-hospital routes and **dedicated airspace layers** (105 m for south–north, 120 m for north–south operations).
- The MUSE project assesses time savings by **comparing drone flight durations** (via GEMMA) against **road transport times** (via Google Routes API).
- **Traffic variability** addressed by analysing one week of road-travel data (4–10 May 2026), covering both weekdays and weekends.
- **Ground-handling tasks excluded** for both modes due to lack of consistent data; such procedures are expected to become faster and more automated for drones.
- **Other concerns** (noise, visual impact, privacy) **were negligible** due to limited operations and higher flight altitudes relative to parcel delivery scenarios.



Characteristic	DJI Matrice 600	RigiTech Eiger
Maximum Take-Off Weight	15.5 kg	21 kg
Maximum Payload	2.7 kg	3 kg
Cruise velocity (min-max)	12 – 18 m/s	23 – 35 m/s

Results – Access and equity (time savings)

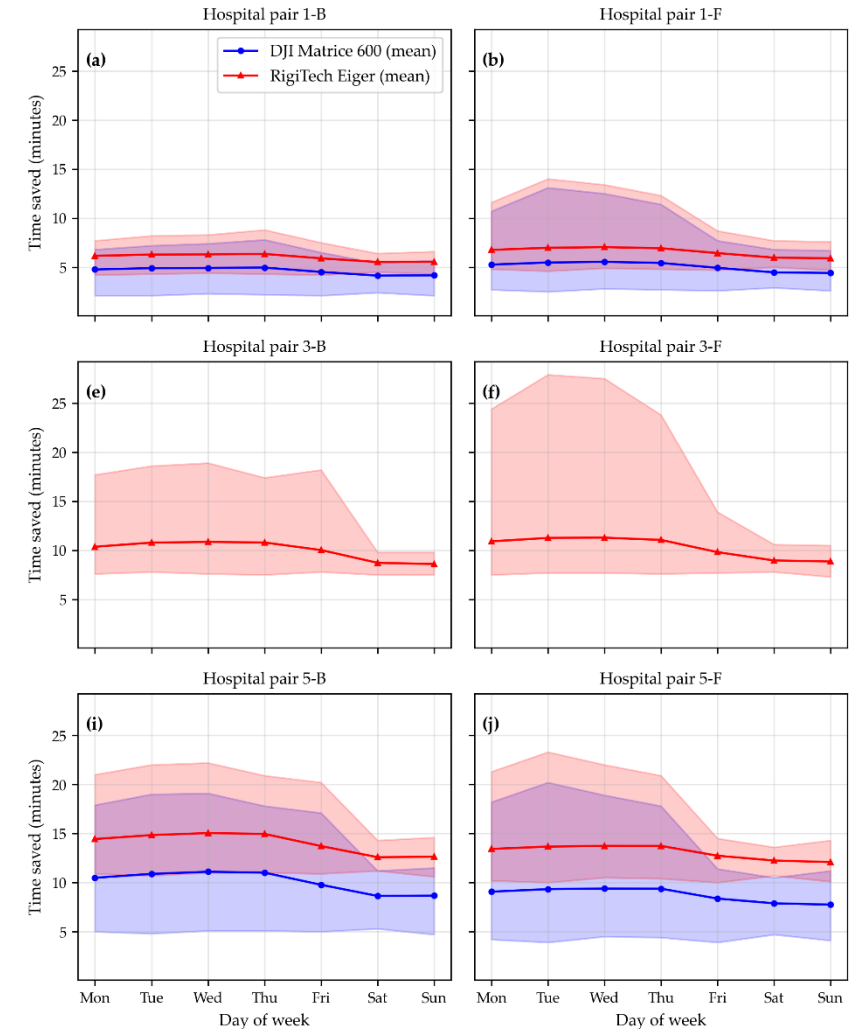
Time of the day



Results – Access and equity (time savings)

Day of the week

- The largest reduction was 25 minutes, recorded at 8:00 a.m. on a Tuesday—during the morning rush hour—with the Eiger drone on Hospital Pair 3-F (from Hospital 12 de Octubre to HU Carlos III) (6.0 km). This highlights the significant advantage drones offer when urban roads are most congested.
- The total time saved for all flights conducted in a single day was 1502 minutes (or 25 hours) – enough for around 100 extra drone deliveries!
- Additional analyses on estimating time savings and predictability of drone emergency deliveries are presented in a companion paper [20].



Recommendations and lessons learnt



Technical insights

- MUSE provides an integrated framework combining environmental and social indicators for UAM; innovative but still requires broad validation (surveys, interviews, and scenario-based testing).
- Noise assessment remains technically demanding. High-fidelity source models are needed for absolute comparisons, whereas simplified models can support trend analyses. In addition, robust background data, and refined thresholds are needed.
- Visual perception is highly context-dependent and non-linear; improved baselines will need VR studies and larger behavioural datasets.
- Accurate, granular population mapping is critical for credible exposure estimate. Progress is needed in integrating satellite data, mobility traces, and statistical models, while correcting for biases from underground transport.

Recommendations and lessons learnt



Political implications

- UAM operations directly impact urban residents; environmental and social assessments must be integrated into ConOps, involving authorities, operators, planners, and citizens.
- Case studies indicate trade-offs: Privacy, visual pollution, and noise are interconnected; low-altitude flights increase discomfort, especially when drone purpose is unclear. Sensitivity varies by location and population demographics.
- Access and equity are essential for the fair development of UAM systems. Policy frameworks should not only focus on the equitable distribution of services but also on While service availability receives much attention, the equity in exposure to negative environmental and social impacts
- Advancing UAM demands integrated frameworks, validated indicators, participatory governance, and operational concepts that balance efficiency, environmental protection, and social acceptance.

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