



Enhancing Dynamic Airspace Configuration and Flight-Centric ATC through Clusterized Aircraft Early Handover

Towards a Cooperative Capacity-on-Demand Framework in Air Traffic Management

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Founding Members



ANTICIPATE

TABLE OF CONTENT

1. MOTIVATION AND BACKGROUND

2. THE EARLY DELEGATION METHOD WITH CLUSTERS

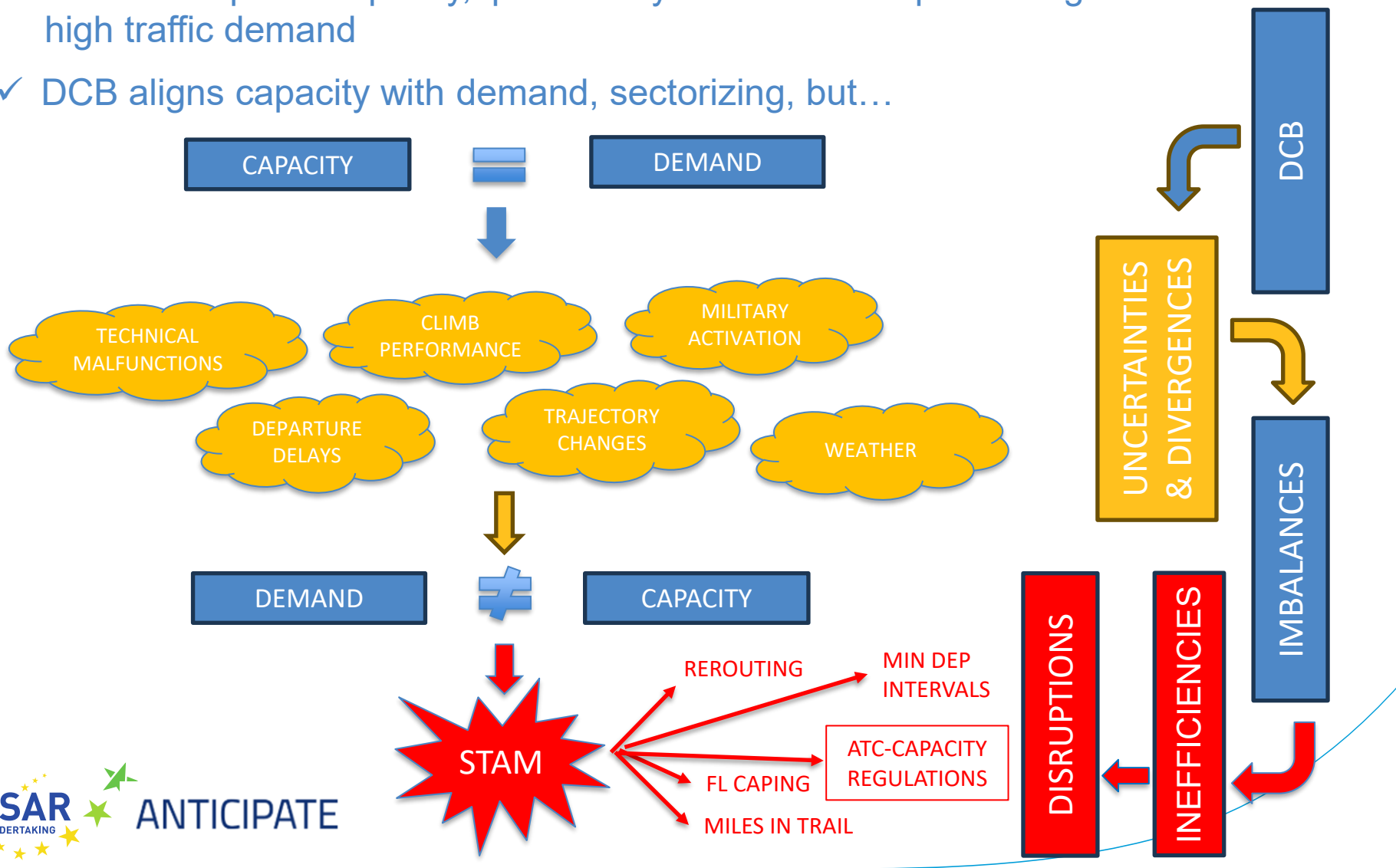
3. FIXED-AREA DELEGATION

4. COMPOSABLE-AREA DELEGATION

5. COMPATIBILITY WITH LETTERS OF AGREEMENT

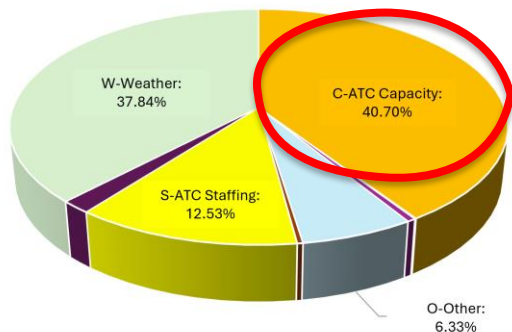
6. CONCLUSION AND FUTURE WORK

- ✓ ATM continues to face a central challenge in the ECAC area: limited airspace capacity, particularly in sectors experiencing high traffic demand
- ✓ DCB aligns capacity with demand, sectorizing, but...



122 ATC-CAPACITY REGULATIONS !!!

(27/07/2024)



ATC-capacity regulation triggering REASON?

OCCUPANCY COUNT



- ✓ ATC-capacity regulations were responsible for about 40% of the delays in the ECAC area during the 2024 summer season !!!

- ✓ ATC-capacity delays amounted to roughly 721 M€ in 2024 [1][2].



Effectiveness: remove the exceeding

Efficiency: avoid inefficiencies

Promptness: act quickly

Time responsiveness: brief time window

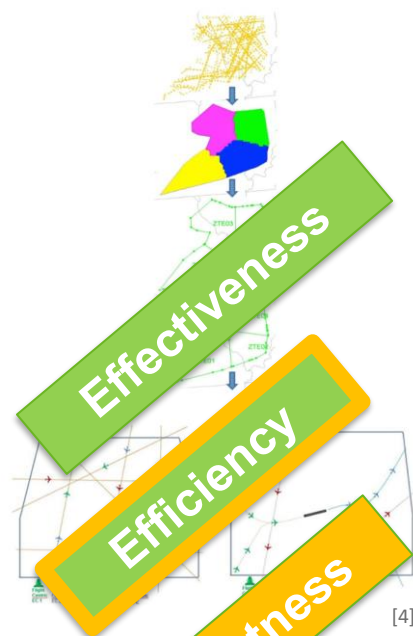


How?



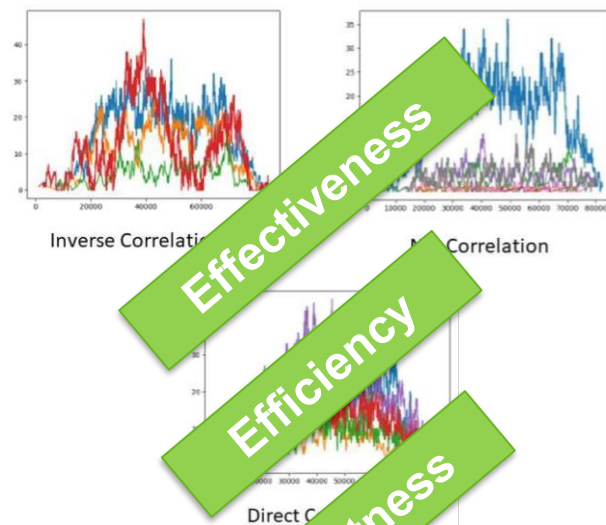
Continue striving to increase capacity, even though this generates inefficiencies. In some sectors overused and other underused

ACCEPT INEFFICIENCIES



New approaches to increase capacity by improving efficiency

DAC
FCA



Take advantage of the available capacity surrounding overloaded sectors

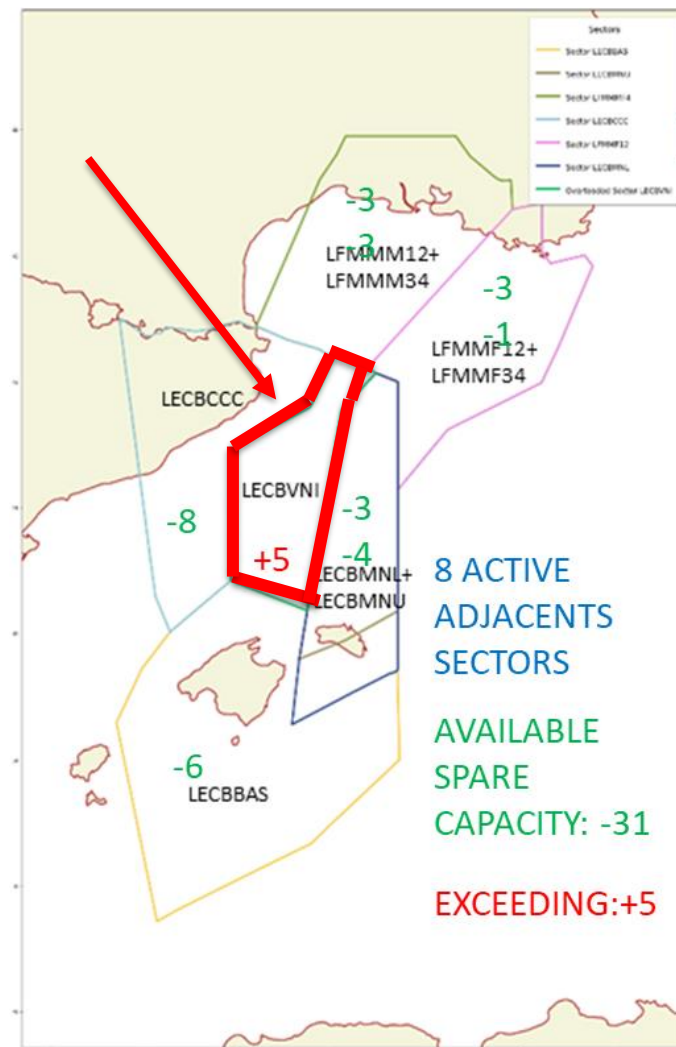
STERILIZED
AIRCRAFT
EARLY
HANDOVER
(CAEHO)

The Spare Capacity Concept. The core of the Early Delegation Method

Available Spare Capacity:

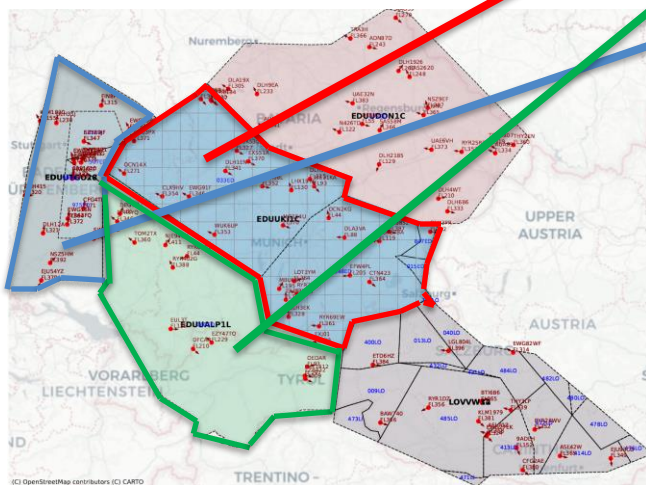
The amount of traffic (in aircraft counts) that a sector could still safely accept **before reaching its declared maximum capacity**.

- In the ECAC area
- On the 27/07/2024
- Strict available-spare-capacity criterion
- **Up to 97%** of the potential overloads could have been accommodated by adjacent sectors !!!



LECBVNI, 27/07/2024, 15:23

At sector level

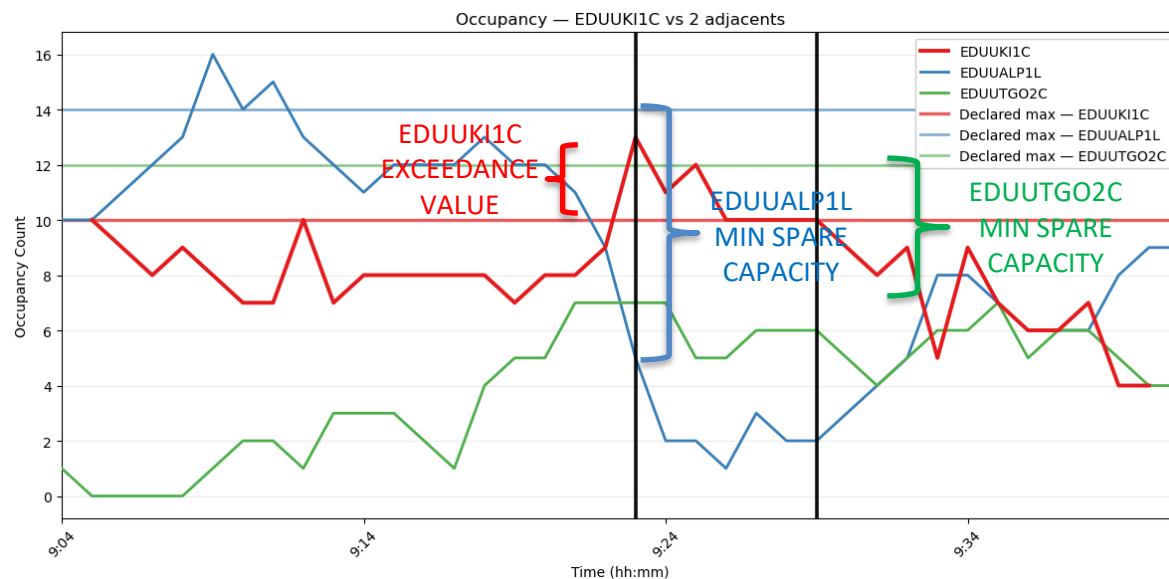


EDUUKI1C and some adjacent sectors

SECTOR	MAX DECLARED CAPACITY	OCCUPANCY COUNT	SPARE CAPACITY
--------	-----------------------------	--------------------	-------------------

EDUUKI1C	10	13	-3
EDUUALP1L	14	5	9
EDUUTGO2C	12	7	5

EDUUKI1C and some adjacent sectors key spare capacity values on the 27/07/2024 at 9:23



EDUUKI1C and some adjacent sectors occupancy count evolution on the 27/07/2024 from 9:04 to 9:44

Introducing the Early Delegation: Control and Communications

The control and communication of a **cluster of aircraft** is early delegated to downstream sectors

Only conflict-free flights

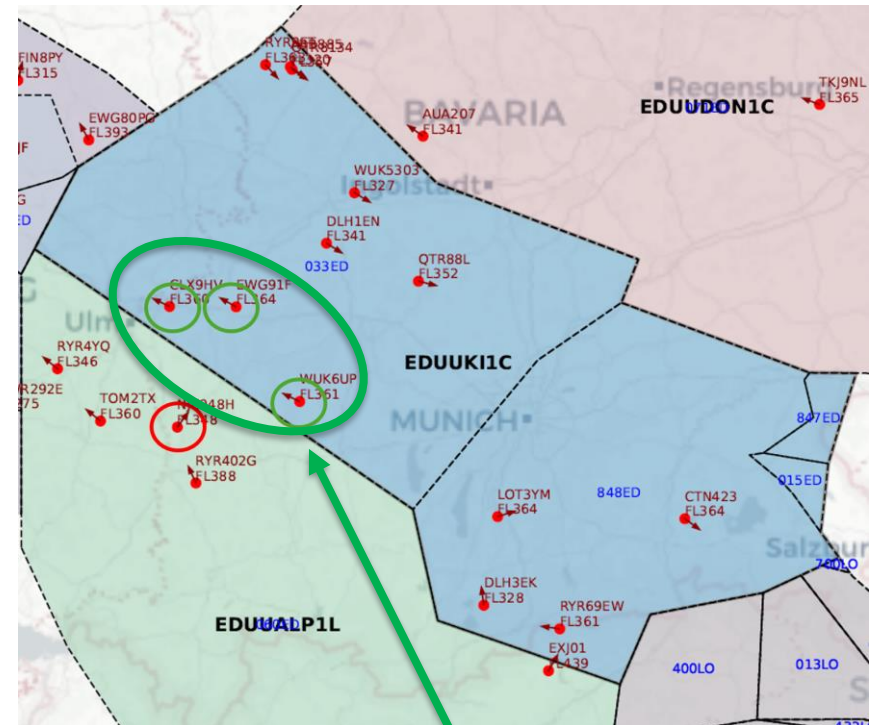
Before they get to the edge

Only dealing with **clusters**, not single aircraft

Only **en-route** aircraft (FL > 240)

2 min < Remaining dwell time < 7 min

No changing trajectories or imposing delays.



Three aircraft (CLX9HV, EWG91F, WUK6UP) are delegated early from **EDUUKI1C** to the downstream sector **EDUUTGO2C** **before boundary crossing**.

Operational Benefits and Constraints of the Early Delegation

Delegation Flexibility

Only targeted aircraft are included to be delegated



Constrained selection

Operational and conflict-free requirements

Balanced workload

Several clusters can be delegated to different adjacent sectors based on spare capacity



Coordination complexity

Broader use requires multi-sector synchronization

No Geometry Changes

Keeping sector boundaries unchanged facilitates immediate operational deployment



Multi-controller coordination

Some ATCOs sharing the same area of responsibility

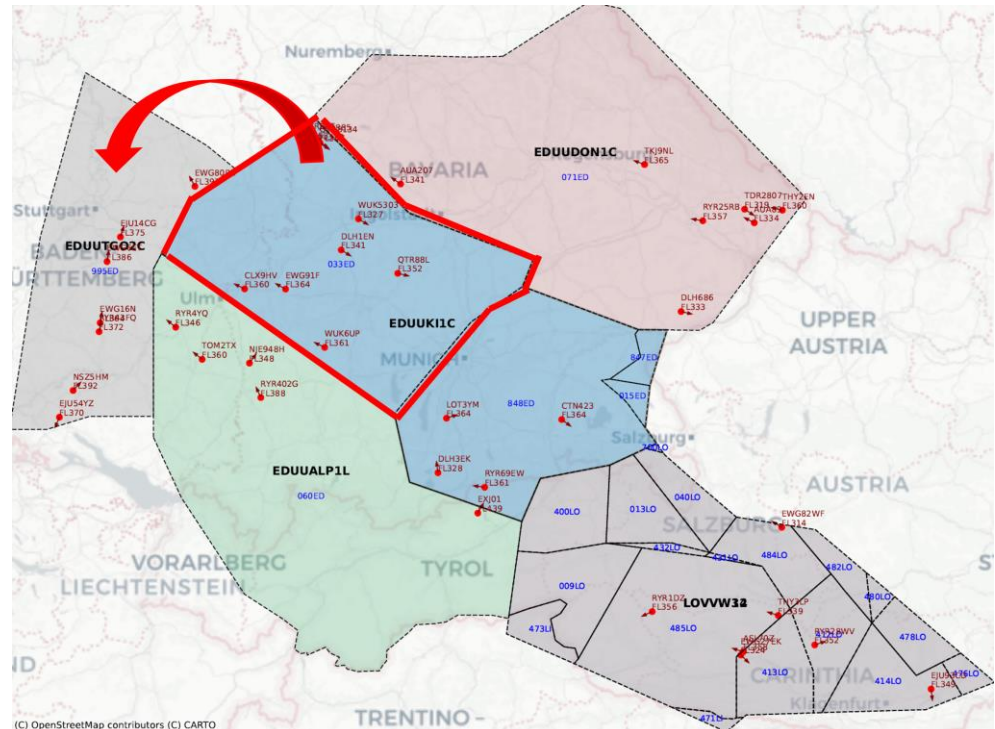


Operational
context

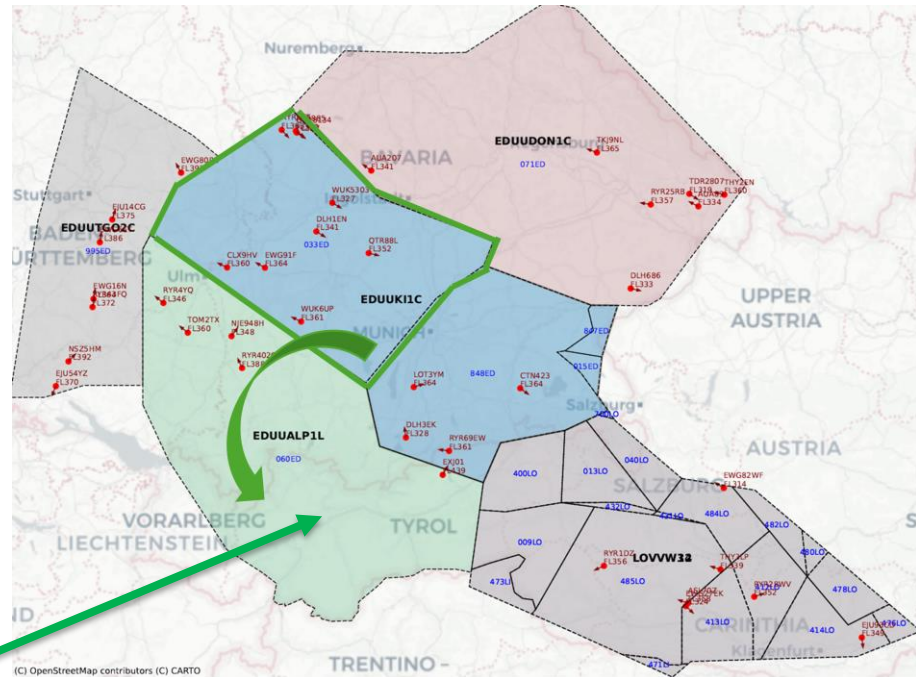
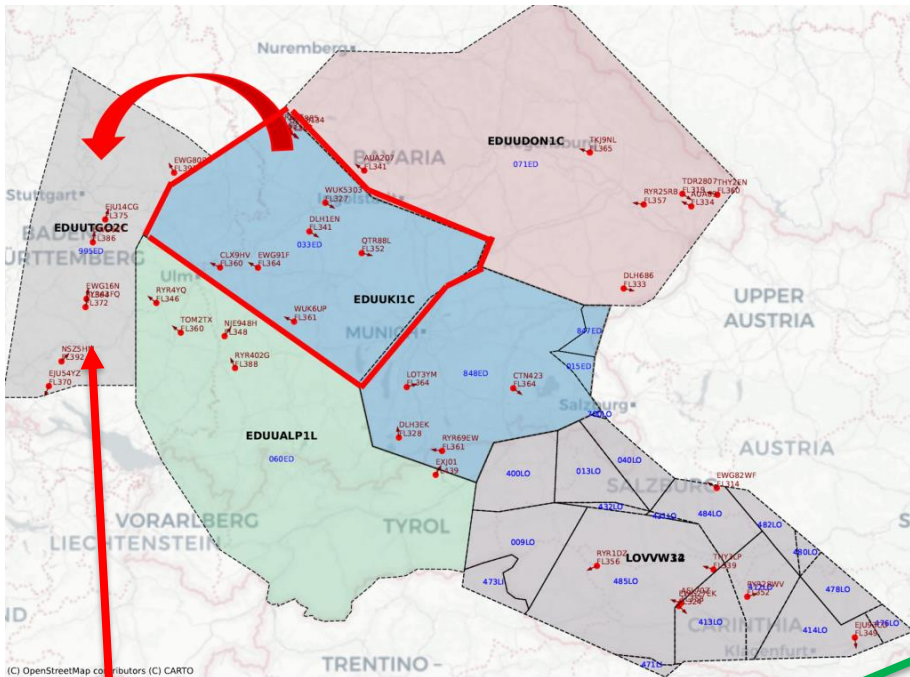
Fixed-area
variant

Fixed-area variant

- Transfers airblocks instead of clusters of aircraft. The full responsibility of the area is delegated
- The issue of shared ATCO responsibility is eliminated
- No conflict-freeness constraints apply → more candidates → more available spare capacity
- More candidates require more spare capacity in the receiving sector → **performance issues???**



EDUUKI1C sector is composed of 4 airblocks. The control of the 033ED airblock is expected to be delegated



SECTOR	MAX DECLARED CAPACITY	OCCUPANCY COUNT	TRANSFERRING	SPARE CAPACITY
EDUUKI1C	10	13	9	-3
EDUUALP1L	14	5	-	9
EDUUTGO2C	12	7	-	5

Operational Benefits and Constraints of the Fixed Area Delegation

Full responsibility transfer

Receiving ATCO assumes complete responsibility inside the active area. NO sharing the same AoR

Procedural simplicity

A single predefined region is activated as a unit, reducing coordination and geometry decisions

Predictable boundaries

Stable shapes and transfer points support training and standard operating procedures

Area
Rigidity



Geometry mismatch

Aircraft can not be targeted

Potential inefficiency

One sector may stay underloaded while the receiving sector operates near maximum capacity

Over-delegation

Entire area is transferred, which may exceed the receiving sector's spare capacity

Rigidity
constrains

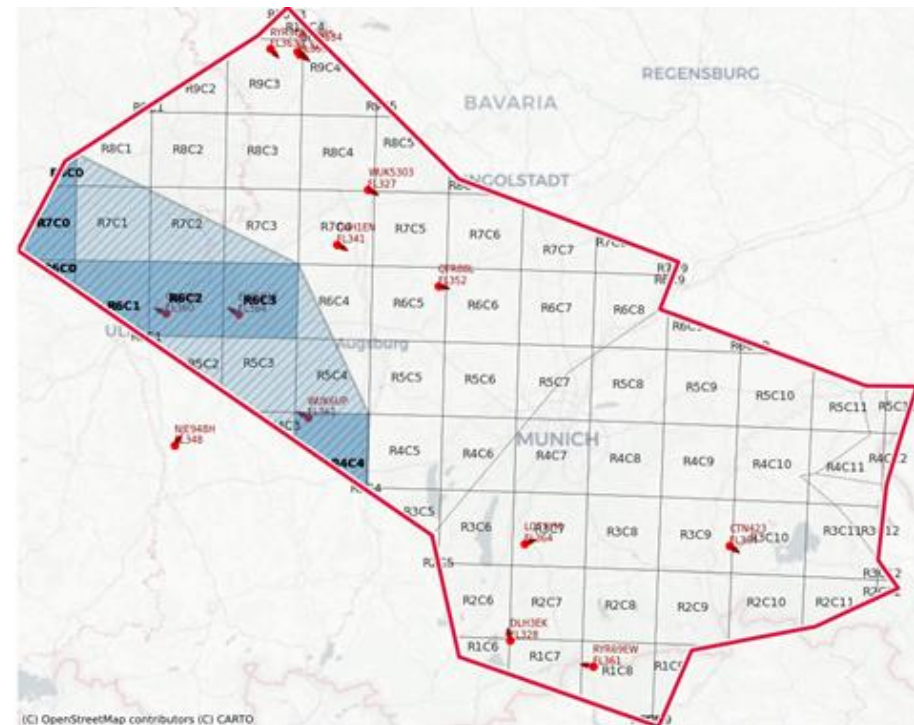


Composable
area variant

Composable-area variant

- A unified approach combining Early delegation approach, DAC, and FCA, supported by DAS
- A flexible area is built around the selected cluster, as in early handover
- The control of the area is delegated
- No conflict-freeness required, which increases the performance

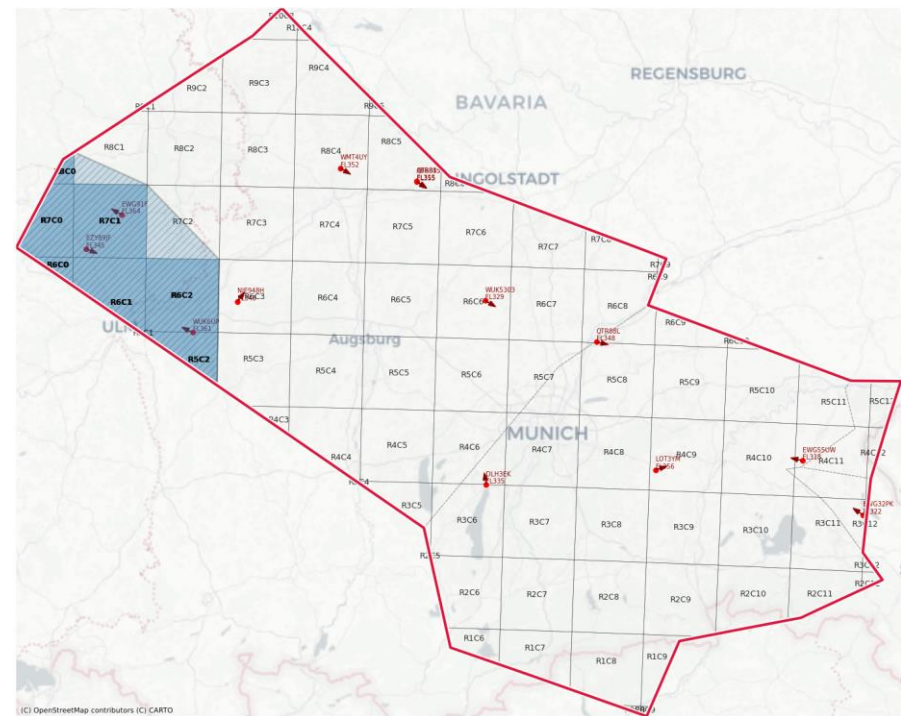
1st phase: building the composable area according to the cluster



2nd phase: the area follows the traffic

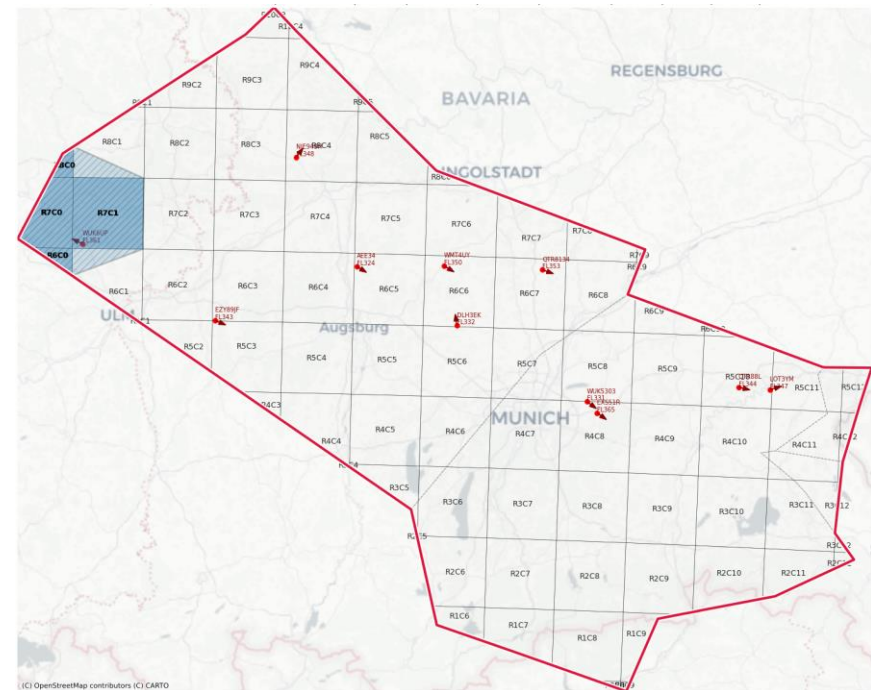
- The delegated volume evolves with the trajectories of the selected aircraft and shrinks as each aircraft exits the sector.

$$CH(P) = \left\{ \sum_{i=1}^n \lambda_i \mathbf{p}_i \mid \lambda_i \geq 0, \sum_{i=1}^n \lambda_i = 1 \right\}$$



3rd phase: vanishing the area as the traffic leaves the sector

- Delegation concludes automatically when the last selected aircraft leaves the sector, ensuring continuous adaptation to real-time conditions.



Operational Benefits and Constraints of the Composable Area Delegation

Flexibility

Breaks the rigidity of the fixed areas. Targeted adaptation to traffic



Possible inclusion of non-target aircraft

Although **less frequent** than with fixed-area delegation.

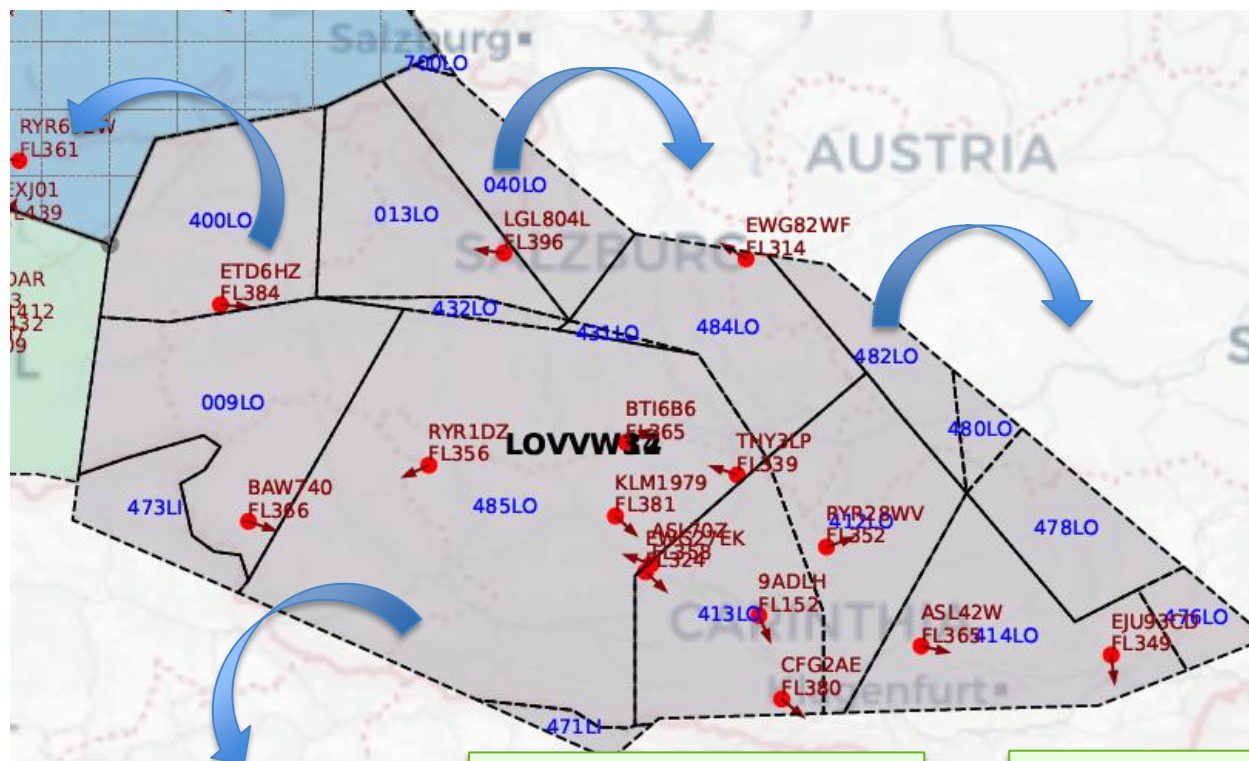
Spatial-awareness sensitivity

Frequent boundary changes may complicate situational understanding compared to static delegation

Full responsibility transfer

Receiving ATCO assumes complete responsibility inside the active area. NO sharing the same AoR

Is fixed area delegation = DAC with airblocks



- Aligned with early delegation, selecting airblocks according to the desired clusters
- Several clusters to several adjacent sectors ≈ several airblocks to several adjacent sectors

FAST RESPONSE

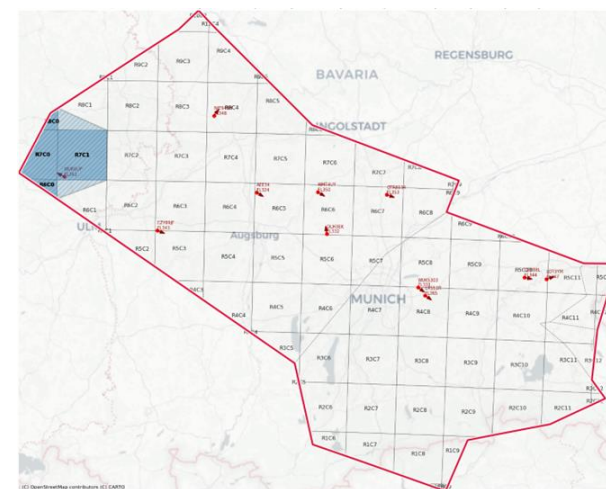
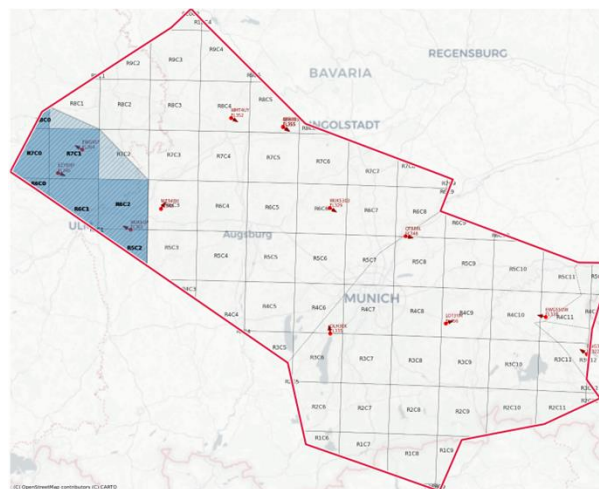
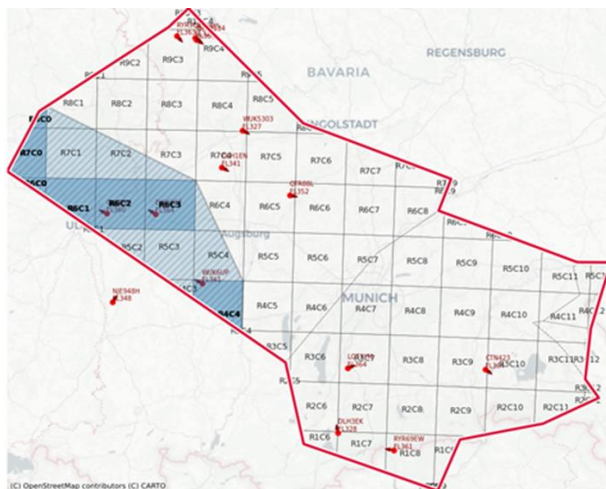
OCCUPANCY-COUNT INDICATOR

SPARE CAPACITY DRIVEN

Is composable area delegation



DAC with flexible
boundaries



1) Promptness

2) Flexibility



Flows followed structures;
structures followed flow (DAS) [5];
now they follow the cluster

Letters of Agreement

- LoAs may provide the mechanism for formalizing early handover, requiring no new legal instruments.
- Delegation options within the LoA framework
 - Fixed-area delegation aligns naturally but lacks flexibility.
 - Clusterized CAEHO is operationally effective and efficient yet diverges from current structures.
 - Composable-area delegation offers a balanced, reconfigurable LoA-compatible alternative.

Overflights

ATS Route	COP	Receiving Sector	FLA	Special Conditions
DCT	MICOS	HOL	All	
	PIBUL			
	ELKIM			
	BUMAB		Even if Westbound	
	RAXLU			
	TUGDU		Odd if Eastbound	
	DEGUL			
	GINIM			
	GIKOG			
	DEXAV	JEV	Even if Westbound	
	LUTIR			
	TUSKA			
	KUGAL		Odd if Eastbound	
	DOROR			
	OMIMA			
	AMADA			
	GREFI			
	SUTEB			

Departures

Departure	Routing	COP	Receiving Sector	FLA	Special Conditions
EKCH, EKRK, ESMS	DCT	MICOS	HOL	max. 340	Note 1
EKBI, EKEB, EKSP, EKOD	DCT	-	HOL	max. 280	Via Alsie Area
EKBI	DCT	-	JEV	max. 280	

Note 1 – Traffic from EKCH to EDDV, max FL 290

Arrivals

Destination	Routing	COP	Receiving Sector	FLA	Special Conditions
EDDW, EDDV, EDVE	DCT	-	JEV / HOL	max. 340	

D.2.2.1 General Directs

The following directs may be used without coordination, above FL285:

LoA between Maastricht UAC and Copenhagen ACC. REV N/A

Only for Simulation Purposes on IVAO Network – NOT VALID FOR REAL OPERATIONS

Page D4

Conclusions and Future Work

Comparative characteristics:

- **Early delegation with clusters:** flexible, precise targeting; constrained by conflict-freeness and shared ATCO responsibilities.
- **Fixed-area delegation:** clear roles; rigid and may shift surplus traffic.
- **Composable-area delegation:** mid-level flexibility; frequent changes may affect awareness.

Performance under realistic demand

- **Early delegation with clusters:** performs best
- **Fixed-area delegation:** underperforms
- **Composable-area:** balanced compromise with supporting tools

Future work will focus on AI-based clustering, benchmarking fixed-area delegation, and developing flexible geometries, with ANTICIPATE extending assessments through fast-time simulations and socio-technical modeling.

References

- [1] EUROCONTROL. (2024, May). *Standard inputs for economic analyses* (Edition 10). <https://www.eurocontrol.int/sites/default/files/2024-05/eurocontrol-standard-inputs-economic-analyses-ed-10.pdf>
- [2] EUROCONTROL. (n.d.). *All-causes delay analysis interactive dashboard*. Retrieved 23/11/2025, from <https://www.eurocontrol.int/dashboard/all-causes-delay-analysis-interactive-dashboard>
- [3] Clancy, D. (2014, February 3). *Dynamic Airspace Configuration*. Mosaic ATM. Retrieved November 26, 2025, from <https://mosaicatm.com/2014/02/03/dynamic-airspace-configuration/>
- [4] SESAR Joint Undertaking. (n.d.). *Flight-centric air traffic control (ATC)*. Retrieved November 26, 2025, from <https://www.sesarju.eu/sesar-solutions/flight-centric-air-traffic-control-atc>
- [5] I. Gerdes, A. Temme, and M. Schultz, “Dynamic airspace sectorisation for flight-centric operations,” *Transportation Research Part C: Emerging Technologies*, vol. 95, pp. 460–480, 2018

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Thank you very much
for your attention!



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