



Incorporating Optimisation in Strategic Conflict Resolution Service in U-space

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Founding Members



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Introduction

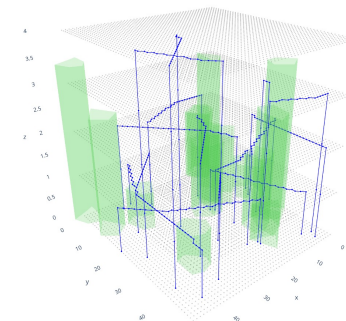
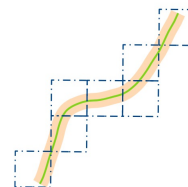
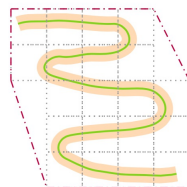
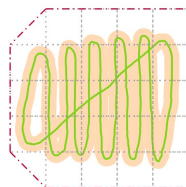
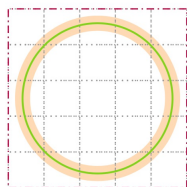


- According to the U-space Roadmap, a service of **Strategic Conflict Resolution** is proposed to realise at U2 stage.
- “The service provides **deconfliction assistance** to a drone operator at **strategic level** - when the flight plan is submitted, it is compared to other known flight plans and a **deconfliction in time or route** could be proposed.”
-- European ATM master plan: Roadmap for the safe integration of drones into all classes of airspace
- “The strategic conflict resolution service is invoked by the Drone operation plan processing service. It can be invoked because a **new operation plan** has been submitted or because an **already submitted operation plan** has changed.”
-- CORUS: U-space Concept of Operations
- “With the information about the **intended flight** and other information about the **type of the operations and its endurance**, as well as **aircraft performance**, the USSPs should be able to de-conflict the potentially conflicting flights before these flights take place.”

-- EASA Opinion No 01/2020

Type of operations*

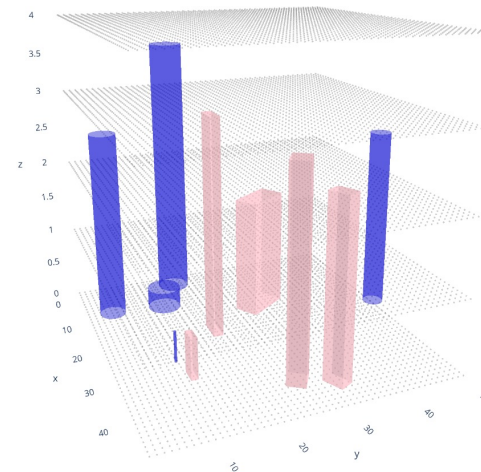
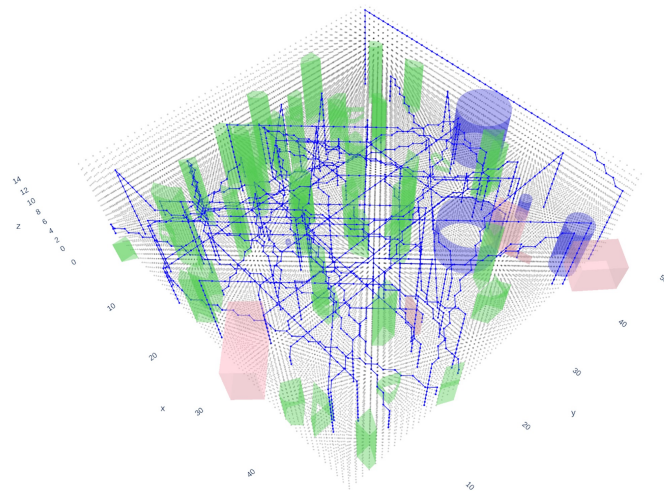
- *Linear flight*
 - UAS traverses each position (i.e., airspace volume in this case) for **only one time**.
 - The trajectory is included with a top of climb and a top of descent, assuming vertical take-off and landing phases and a constant cruise phase.
- *Area flight*
 - Certain positions may be revisited by the UAS for **multiple times**.
 - Its operational area is set with an upper bound of altitude, being the ground level as the lower bound.



* Tang, Y., Xu, Y., Inalhan, G. and A. Tsourdos. An Integrated Approach for Dynamic Capacity Management Service in U-space. 14th USA/Europe Air Traffic Management R&D Seminar, Virtual event, 20-24 Sep 2021.

Airspace modelling

- 3D airspace volume
 - Airspace is grided into a set of identical 3D volumes.
 - A volume is connected to its adjacent in 10 or 26 directions.
- Geographical zones and geo-fence
 - Geozone: strategic (long-term) measure - fixed geographic areas.
 - Geo-fence: tactical (short-term) measure - time-varying geographic areas.

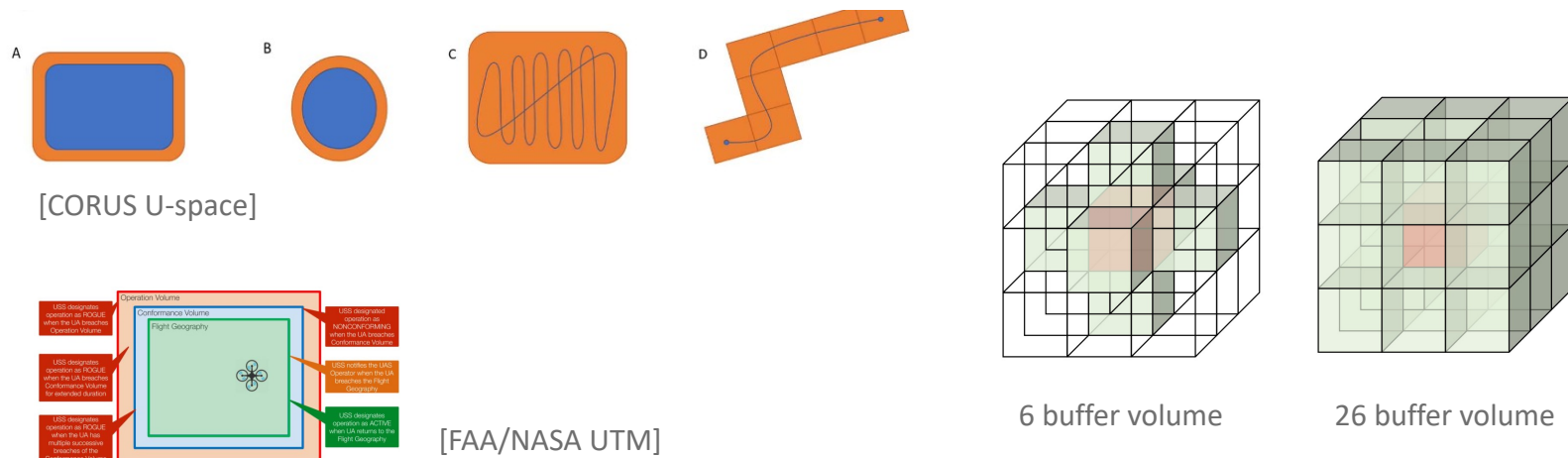


Background



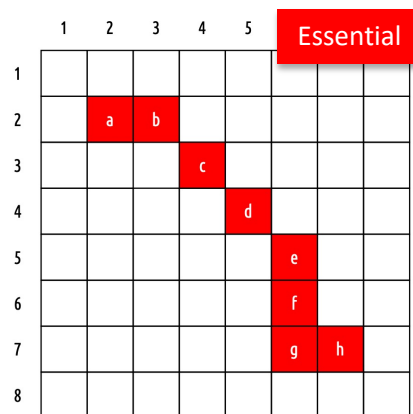
Uncertainty buffer space

- As stated in CORUS, to enable effective operations,
 - the Strategic Conflict Resolution service requires **precise operation plans** giving the 4D trajectory to be flown.
 - To use the airspace efficiently requires the amount of “**buffer space**” around flights to be minimised.
 - Some drone operations are not very precisely plannable – for different reasons.
- Typical ways of identifying uncertainty buffers

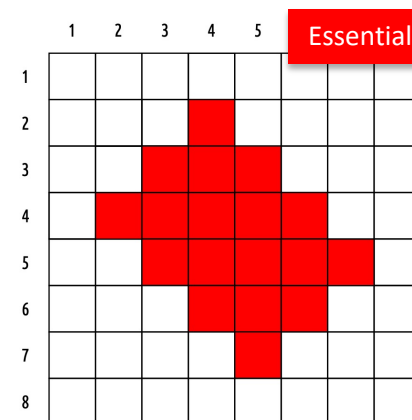
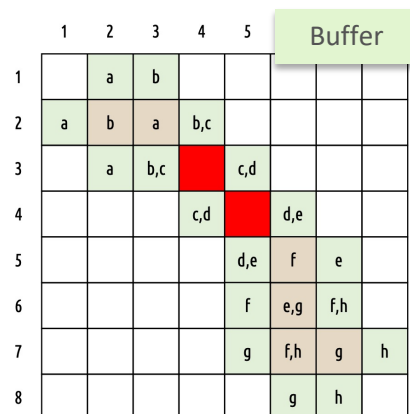


Uncertainty buffer space

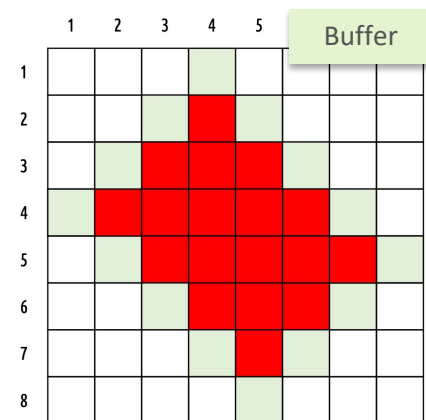
- Relationship between “essential” and “buffer” volumes
 - For *linear* operations, A specific volume can be an essential volume and a buffer volume **at the same time**.
 - The idea is to enforce the **timestamps** of the buffer volumes to **remain the same** as their corresponding “essential” volumes.
 - For *area* operations, the buffer volumes can be considered as a set of **extended essential volumes**.



Linear operation



Area operation



First-submitted, first served principle

- The flight plans are processed according to their **request/submission order**, rather than their scheduled take-off time.
- The flight plan submitted early will have an absolute **higher priority** to be processed than later ones.
- The fundamental of this algorithm is to have a **common information** to represent the **occupancy status** of the 3D airspace volumes.
- Once a group of volumes have been occupied by some early-submitted flights during the specific time periods (with **separation minima** included), they will be not available for the other flight plans submitted subsequently.
- Those flights will be **delayed iteratively**, until all their concerned airspace volumes have been cleared.

FCFS approach



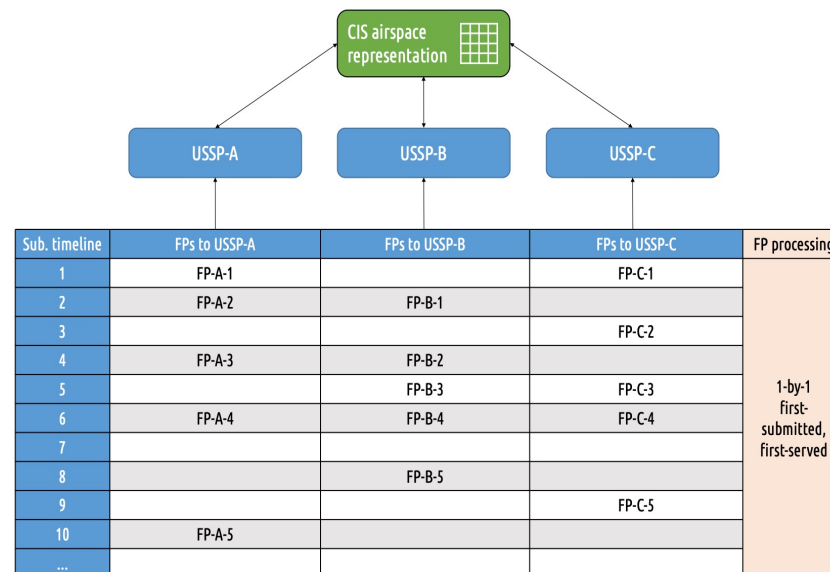
Pseudo algorithm

Algorithm 1 FCFS pseudo algorithm.

```

1: while  $f \in F$  do
2:   if  $f$  is linear flight then
3:     for  $(ess, t), (buff_{ess}, t) \in f_l$  do
4:       if  $(ess, t)$  or  $(buff_{ess}, t)$  is blocked then
5:         Delay  $f_l$  for 1 time unit
6:         Break
7:       else
8:         Insert  $(ess, t)$  and  $(buff_{ess}, t)$  to  $list_l$ 
9:       for  $(ess, t)$  and  $(buff_{ess}, t) \in list_l$  do
10:        Occupy  $(ess, t), (ess, t \pm sep)$ 
11:        Occupy  $(buff_{ess}, t), (buff_{ess}, t \pm sep)$ 
12:   if  $f$  is area flight then
13:     for  $(j, [t_{ini}, t_{end}]) \in f_a$  do
14:       if  $(j, [t_{ini}, t_{end}])$  is blocked then
15:         Delay  $f_a$  for 1 time unit
16:         Break
17:       else
18:         Insert  $(j, [t_{ini}, t_{end}])$  to  $list_a$ 
19:       for  $(j, [t_{ini}, t_{end}]) \in list_a$  do
20:        Occupy  $(j, [t_{ini}, t_{end}])$ 
21:        Occupy  $(j, [t_{ini} \pm sep, t_{end} \pm sep])$ 

```

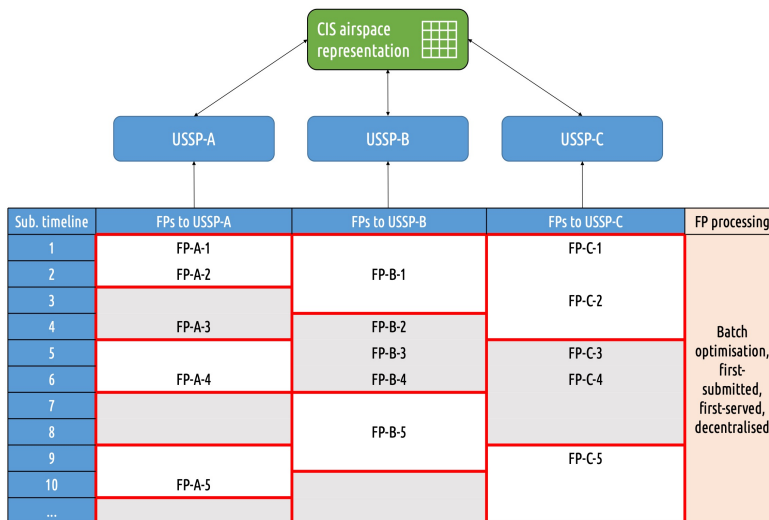


- CIS airspace representation.
- Flight plans are processed one by one.
- Run in parallel where as many USSPs as possible are involved.

Optimisation approach

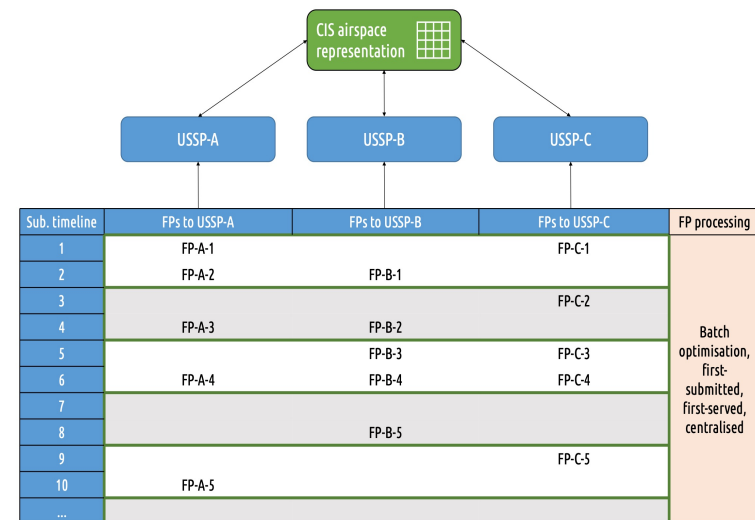


Operational scenarios



- **Batch optimisation**

- Deal with a batch of flight plans from each USSP.
- Produce the optimal delay allocation amongst selected flights.



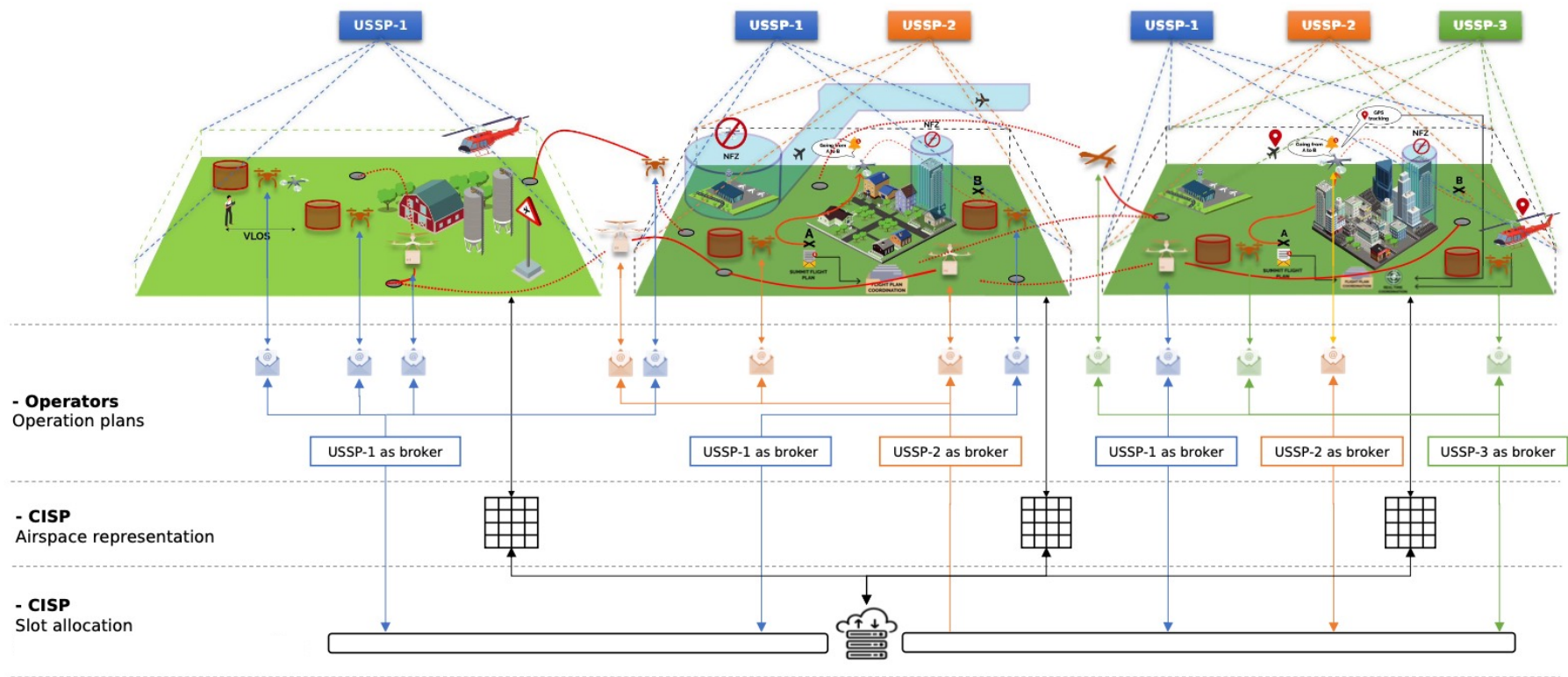
- **Centralised optimisation**

- Flight plans from various USSPs are processed together.
- Run periodically to synchronise the solutions.

Optimisation approach



Centralised optimisation → Decentralised coordination scheme

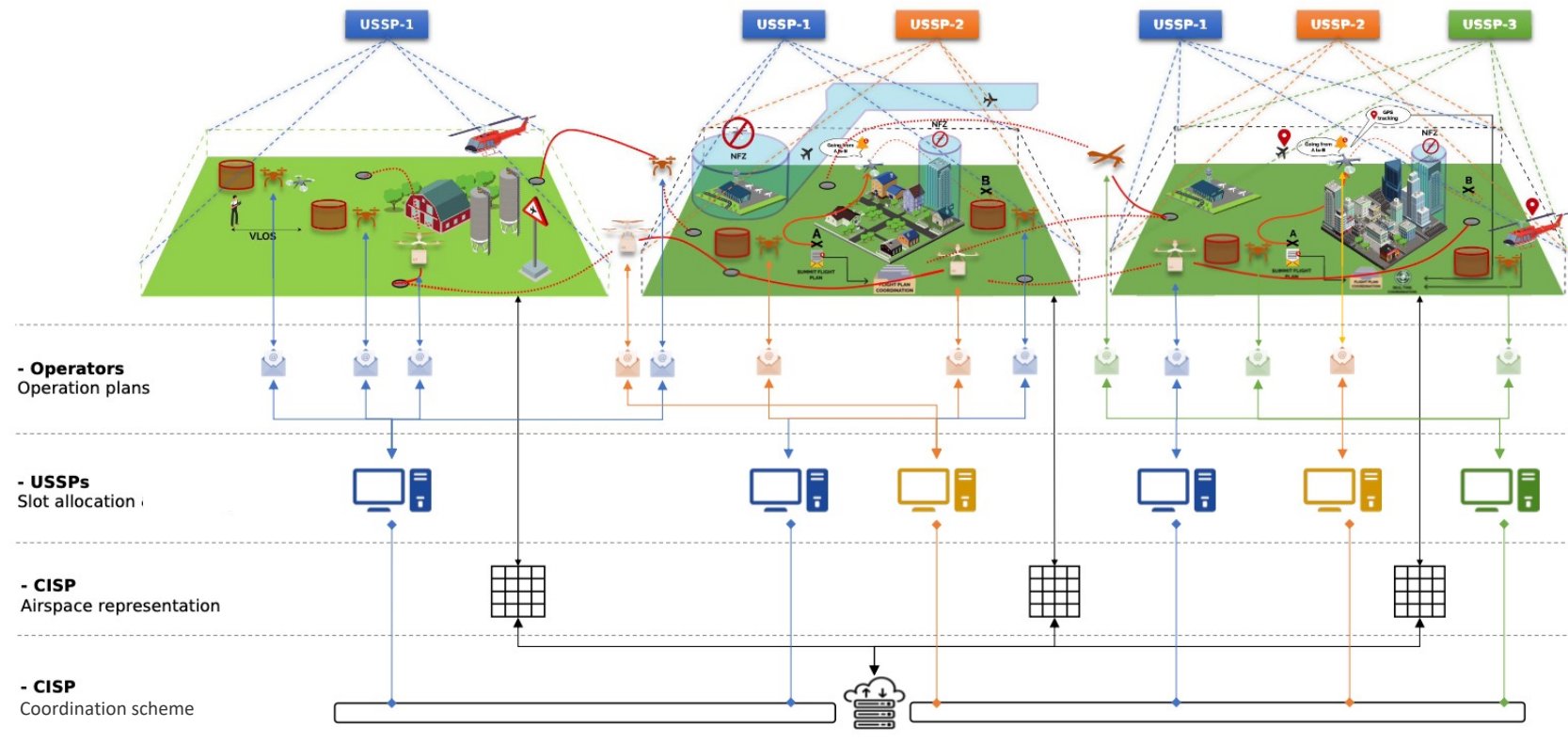


Optimisation approach



Centralised optimisation → Decentralised coordination scheme

- Break down the single (potentially large-scale) problem concerning multiple USSPs, to further allow a decentralised coordination scheme, with a view to retaining the **same global optimum** as if in the centralised way.



Optimisation approach

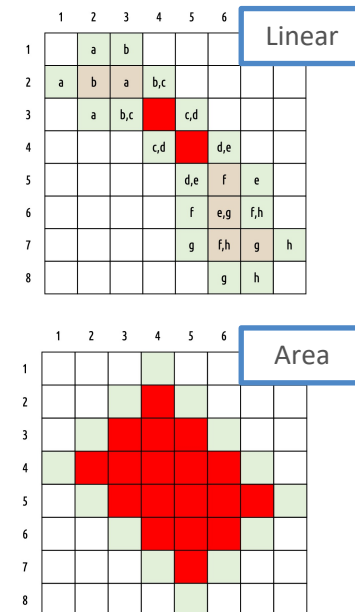


Optimisation model formulation

- Objective function
 - Minimise the **overall delay costs** for all linear and area flights.
 - Weighted costs** can be specified for individual flights to reflect priority.

Priority	Type of operation
1 (max)	Emergency – Air ambulance, Search and rescue, catastrophe...
2	Hospital (Hospital transport)
3	Authorities (Police, other)
	Military
4	Urgent Transport
	Passenger transport
5	Agriculture
	Inspection
	Infrastructure
	Science
	Weather
6	Transport
7	Video, Filming, TV
	Empty flight (ferry flight)
8 (min)	Leisure, Sports

Possible prioritisation
[CORUS U-space]



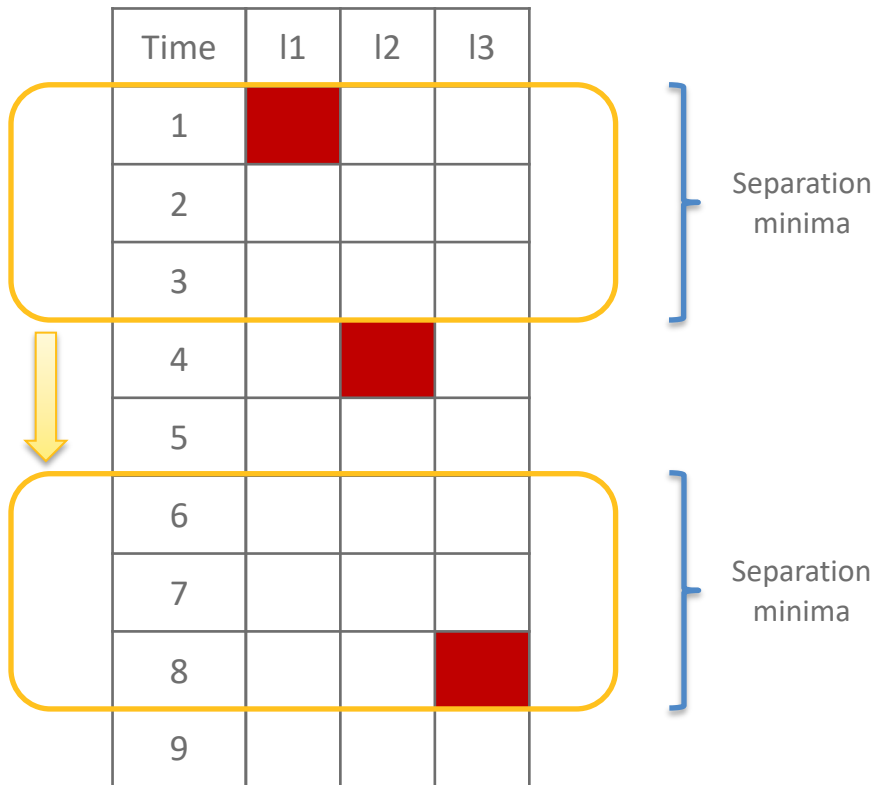
- Operational constraints (based on submitted flight plans):
 - Different for linear and area flights.
 - Segment flight duration, timeline continuity, essential-buffer points correlation, etc.

Optimisation approach



Optimisation model formulation

- Separation assurance constraint
 - At each (valid) **airspace volume**, it can be only occupied by **one flight** within a (valid) **sliding time window** (length of separation minima):



Optimisation approach



Optimisation model formulation

- Separation assurance constraint
 - Added complexity from **buffer volumes** and **area flight** plans

Linear flights (essential volumes)

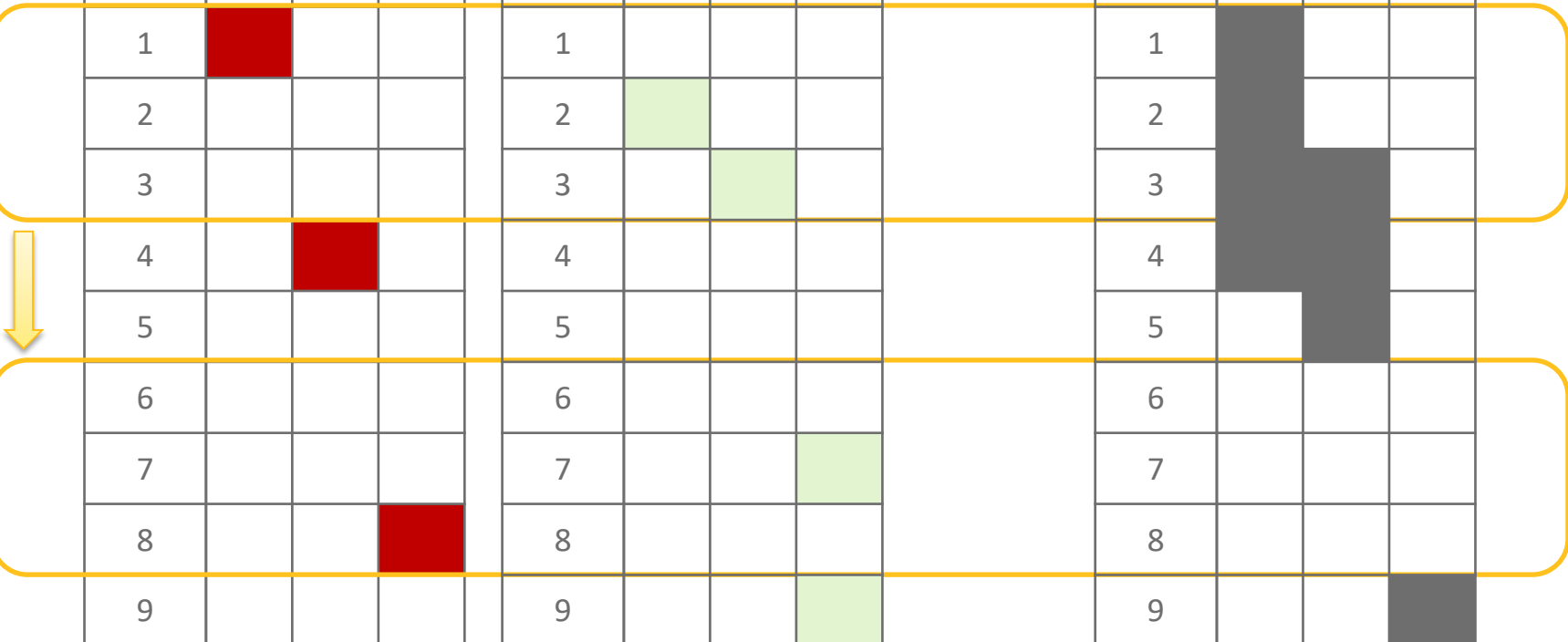
Time	l1	l2	l3
1			
2			
3			
4			
5			
6			
7			
8			
9			

Linear flights (buffer volumes)

Time	l1	l2	l3
1			
2			
3			
4			
5			
6			
7			
8			
9			

Area flights (essential + buffer volumes)

Time	a1	a2	a3
1			
2			
3			
4			
5			
6			
7			
8			
9			

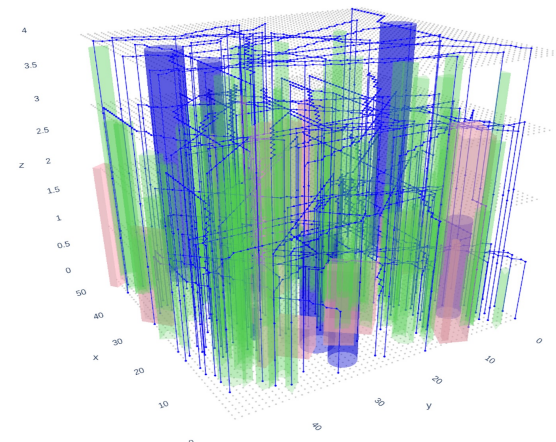


Illustrative examples



Experimental setup

- The airspace of interest covers a 3D space of $2.5 * 2.5 \text{ km}^2$, with 150 m height.
- It is divided to $50*50*5$ identical airspace volumes, leading to each volume of $50*50*30 \text{ m}^3$ size.
- 200 flights (100 linear and 100 area) throughout 24 hours' duration.
- The speed of linear flights are randomly set between 10-15 m/s.
- The duration of area flights are randomly set between 5-30 minutes.
- Each linear flight's essential volume is associated to 6 surrounding buffer volumes.
- A time-based separation minima is assumed to be 15 min.
- 5 min unit time step.
- 15 geographical zones, 15 geo-fences.



Illustrative examples



Case studies

- Case-1: Full FCFS
- Case-2: Full optimisation
- Case-3: Hybrid (50% optimisation followed by 50% FCFS)
- Case-4: Batch optimisation (4 hours per batch)

KPI	Case-1	Case-2	Case-3	Case-4
Delay (min) - linear	890	550	650	830
Delayed flights (a/c) - linear	35	37	32	34
Max delay (min) - linear	80	55	80	80
Delay (min) - area	325	185	350	275
Delayed flights (a/c) - area	11	11	13	10
Max delay (min) - area	75	45	75	75
Total solution time (sec)	5	1320	310	180

Illustrative examples



Additional experiments

- Fairness factor (deviation to FCFS solution)
- Optimisation percentage
- Batch size
- Separation minima

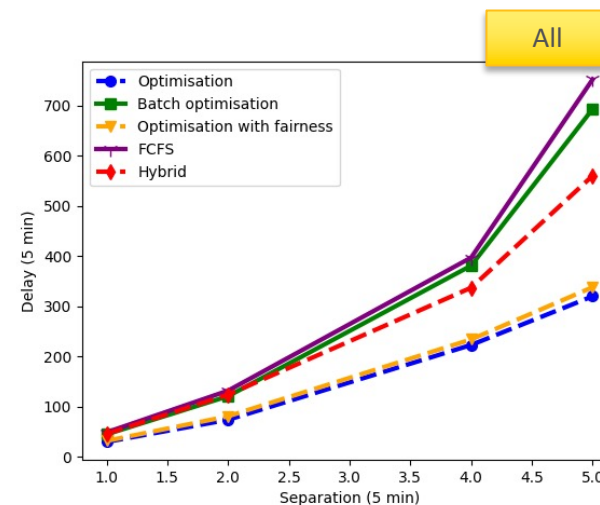
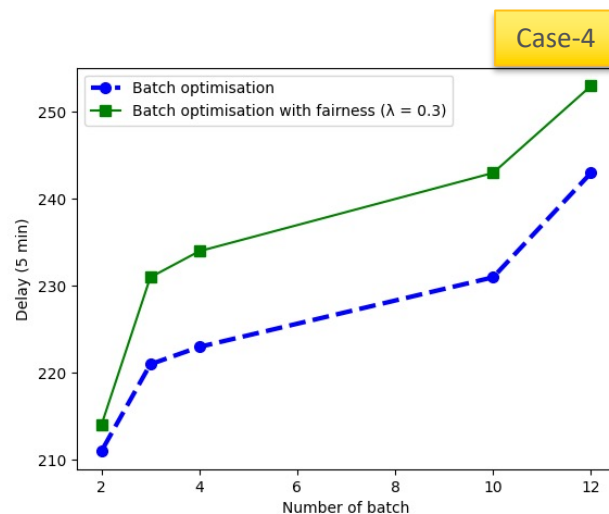
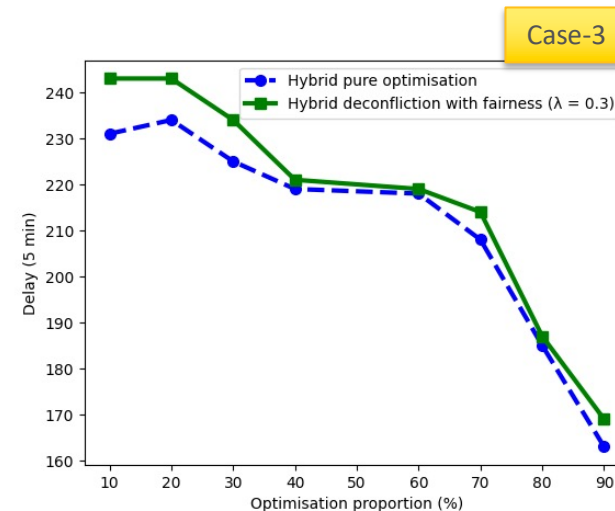
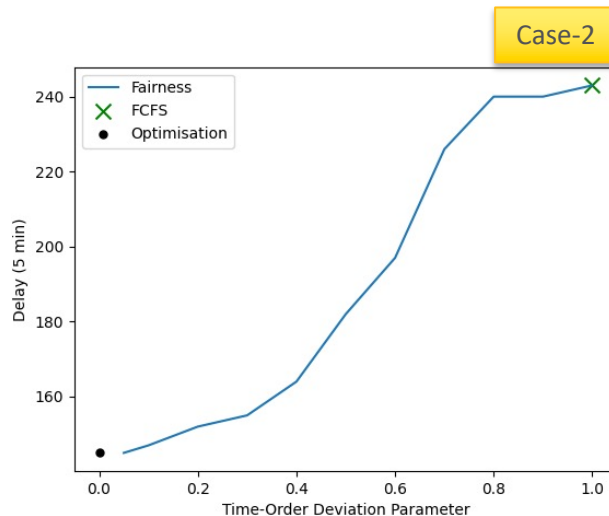
Experiment Theme	Parameter
Case-3 Hybrid Optimisation proportion (%)	10%
	20%
	30%
	40%
	50%
	60%
	70%
	80%
Case-4 Batch optimisation Batch size (min)	90%
	120
	144
	360
	480
Separation minima (min)	720
	5
	10
	15
	20
	25

Experiment Theme	Parameter	
Case-2 Optimisation Fairness factor (λ)	0.1	
	0.2	
	0.3	
	0.4	
	0.5	
	0.6	
	0.7	
	0.8	
	0.9	
Case-3 Hybrid Optimisation proportion (%)	Fairness factor $\lambda = 0.3$	10%
		20%
		30%
		40%
		50%
		60%
		70%
		80%
		90%
Case-4 Batch optimisation Batch size (min)		120
		144
		360
		480
		720

Illustrative examples



Additional experiments



Conclusions and future work



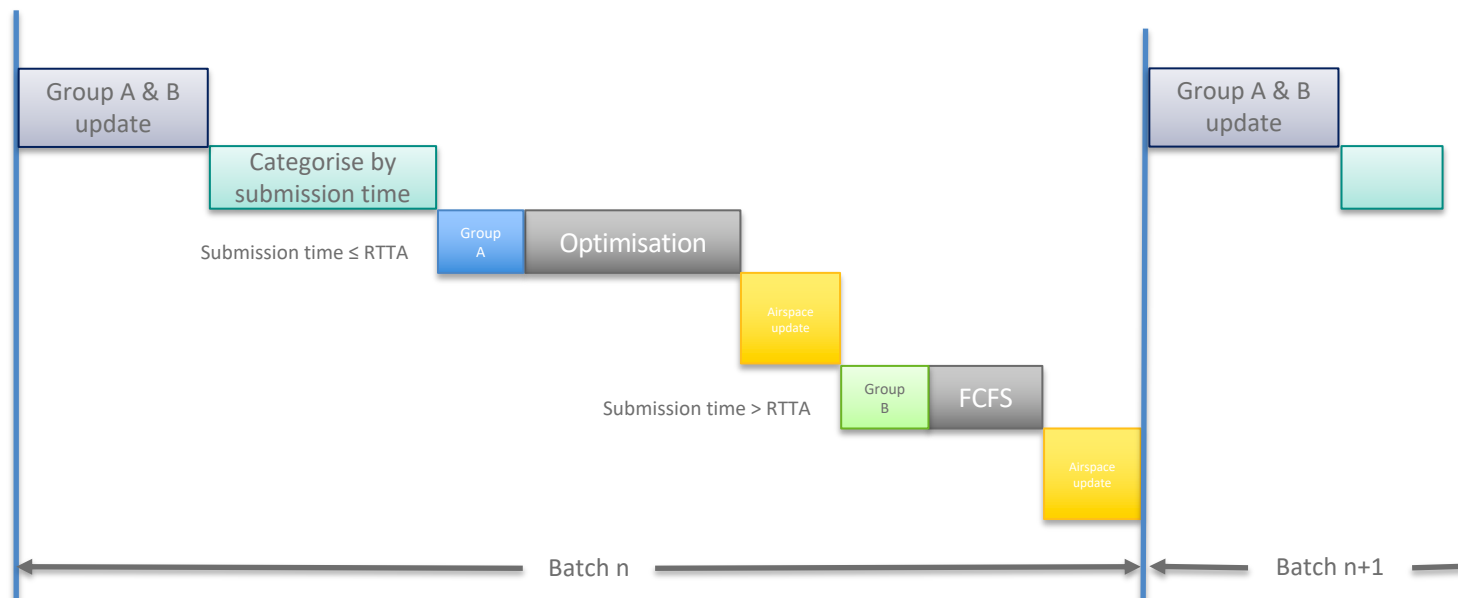
- An optimisation model for strategic conflict management is proposed, with a view to addressing the inefficiency of the existing FCFS approach.
- Depending on the **availability of flight plans** at the time when decisions need to be made, the optimisation approach can be customised jointly with the FCFS approach, or it can be realised through batch execution.
- Both approaches are tested and incorporated, where **four case studies** are performed through illustrative examples, including:
 - full FCFS
 - full optimisation
 - hybrid, and
 - batch execution
- Results suggest that, compared to FCFS, a notable delay reduction can be achieved with the optimisation approach incorporated.
- Some critical questions still remain open, in particular with the **priority issue** and the **fairness concern**.

Conclusions and future work



Reasonable-Time-To-Act (RTTA)

- There is a time period far enough before flight that a disturbance to the operation has minor repercussions. After that time the effect of change becomes harder to accept.
- RTTA impacts how the flight is treated in processes like strategic conflict resolution and dynamic capacity management.

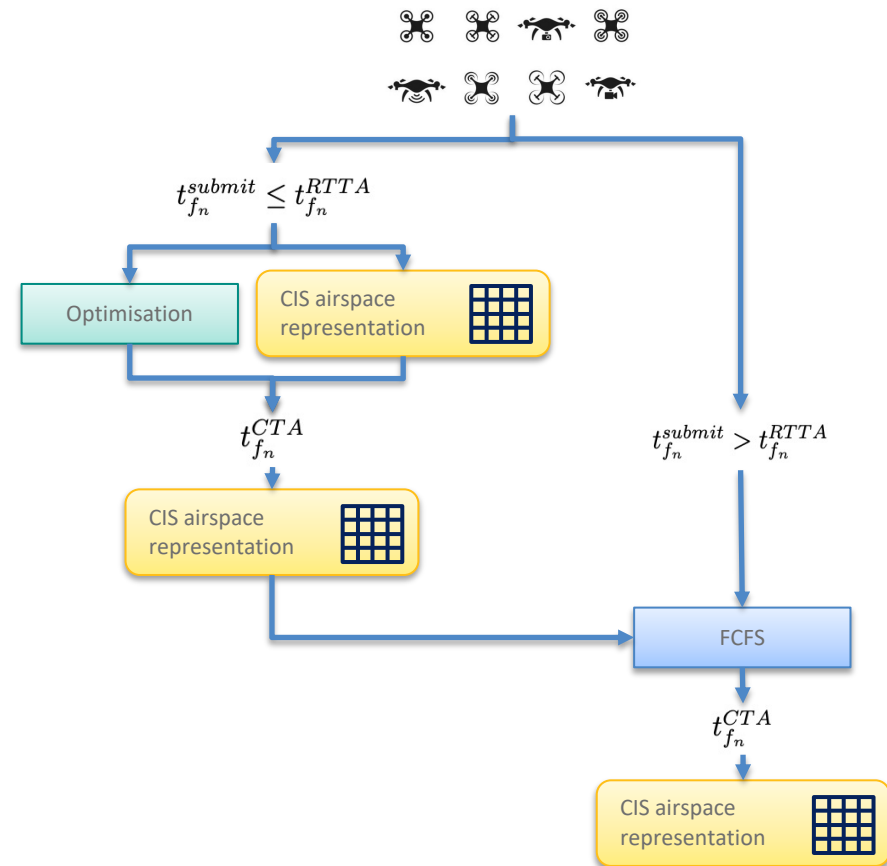


Conclusions and future work



Required-Time-To-Act (RTTA)

- If an operation plan has been submitted **before its RTTA**, then from RTTA until take-off U-space will protect that flight from any further change in all but the most extreme situations.
- If an operation plan is submitted **later than its RTTA** then that flight will be **processed at a disadvantage** in strategic conflict resolution and dynamic capacity management.





Incorporating Optimisation in Strategic Conflict Resolution Service in U-space

Thank you very much for your attention!



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Founding Members



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