CORUS five

Traffic Synchronisation

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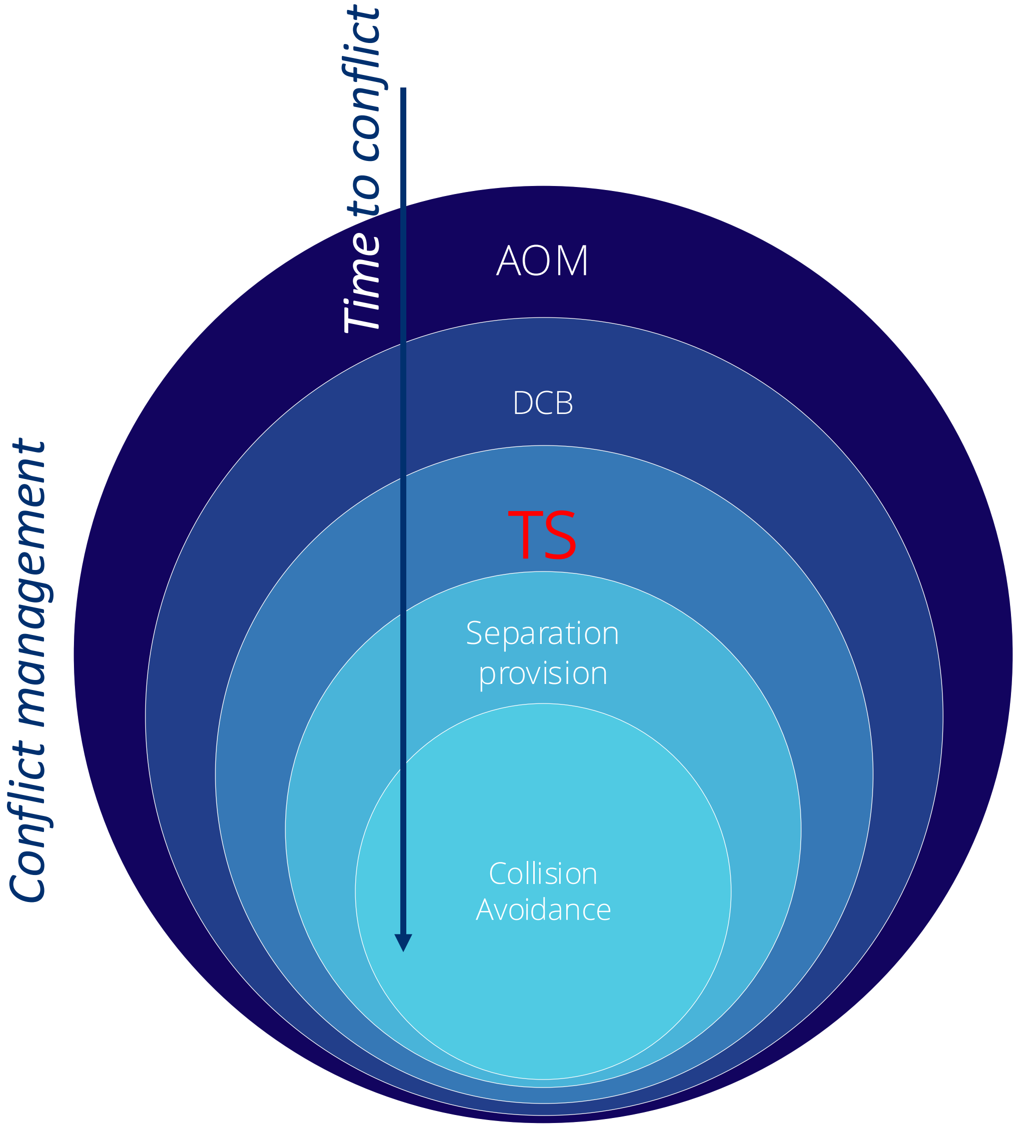
INTRODUCTION: TRAFFIC SYNCHRONIZATION

SHORT TERM HORIZON

MEDIUM/LONG TERM HORIZON

INTRODUCTION: Traffic Synchronization



Definition Global Air Traffic Management Operational Concept

Traffic synchronisation refers to the tactical establishment of a safely, orderly and efficient flow of air traffic.

Traffic synchronization will make use of integrated and automated assistance to surface, departure, arrival and en-route management to ensure an optimum traffic flow. The objective will be to eliminate chokepoints and, ultimately, to optimize traffic sequencing to achieve maximization of runway throughput.

Traffic synchronisation, conflict management and demand and capacity balancing are interrelated and will become fully integrated, leading to a continuous and organised flow of traffic.

Traffic Synchronization is like solving a packing puzzle

Note: throughout these slides we will continuously attempt to represent a four-dimensional problem using two-dimensional means, with varying degrees of success

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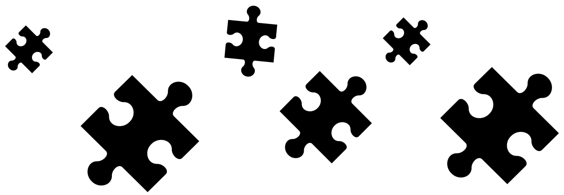
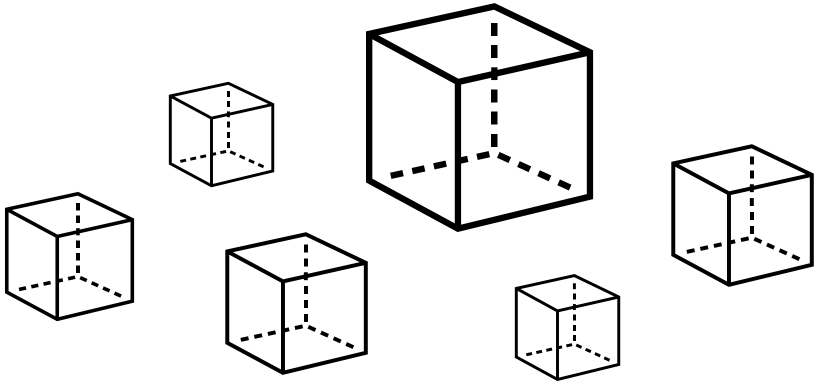
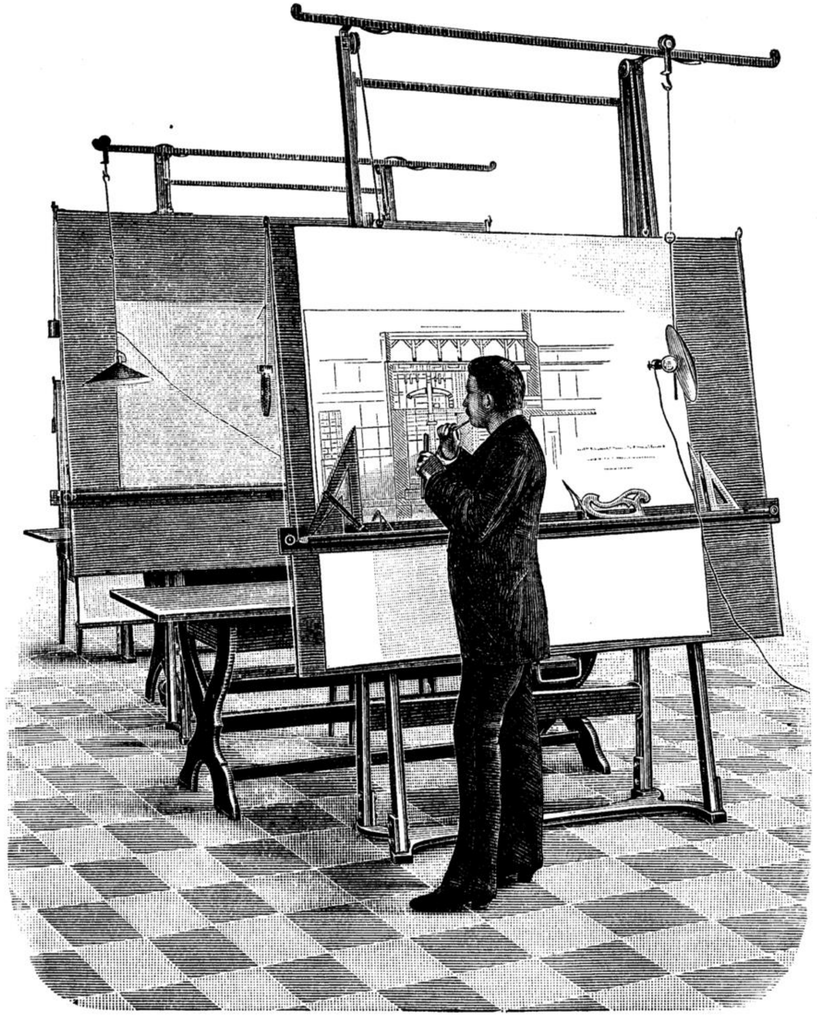
AOM is the game designer

- Defines the boxes (i.e. airspace structure)
- Describes how pieces can be (i.e. applicable rules)



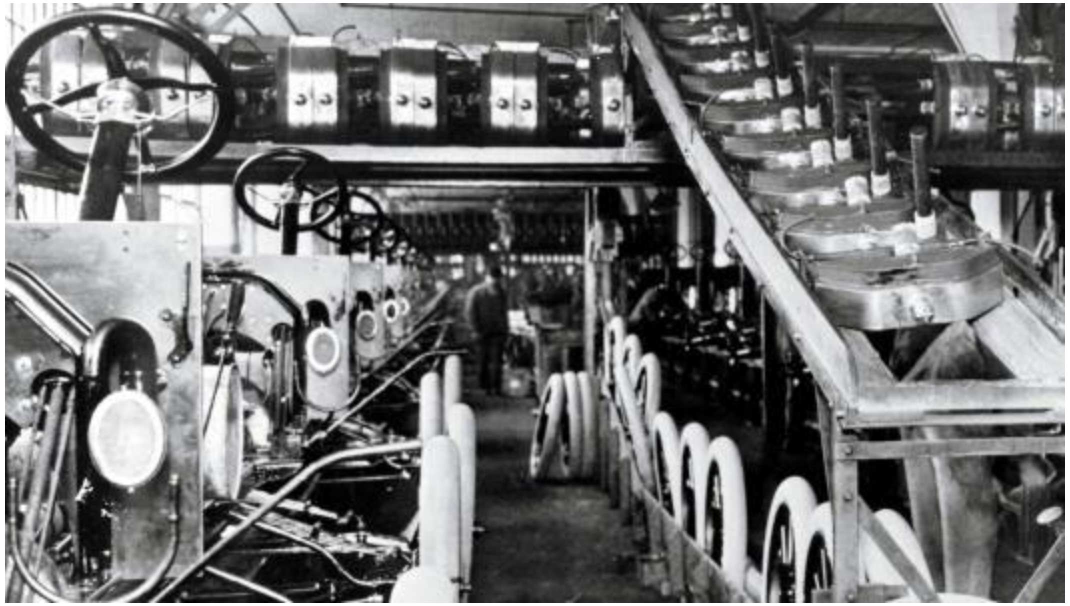


- It's a dynamic process (boxes can change!)



Airspace users are the manufacturing machines

- Create the pieces (i.e. airspace demand) according to dynamic needs and established rules



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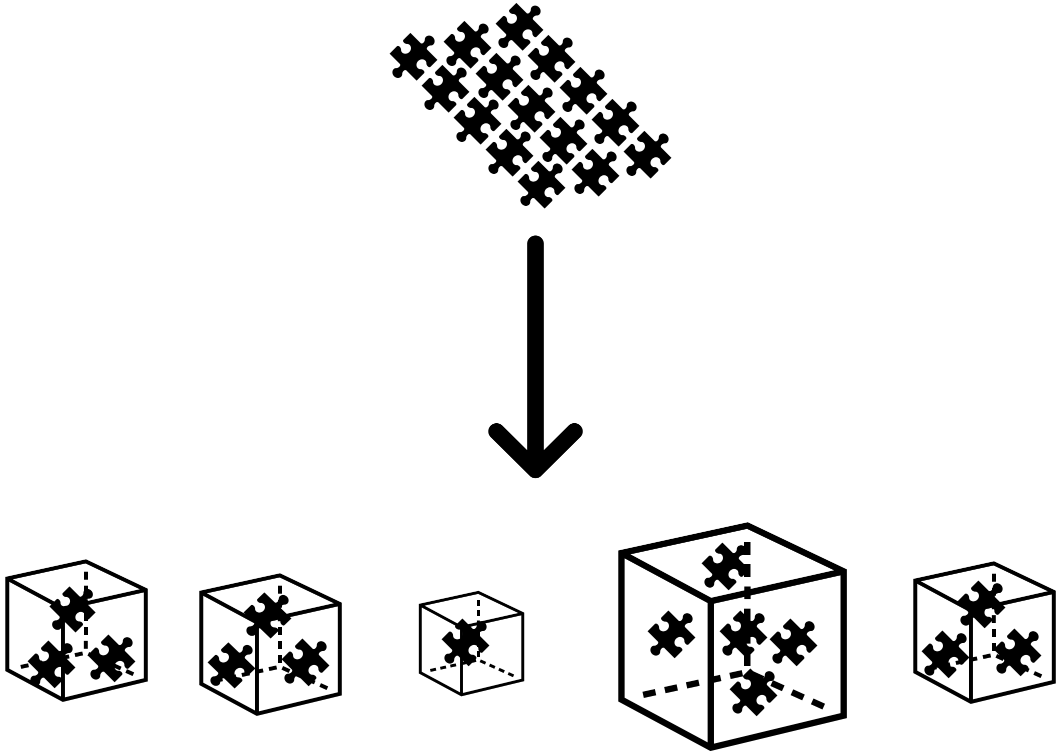
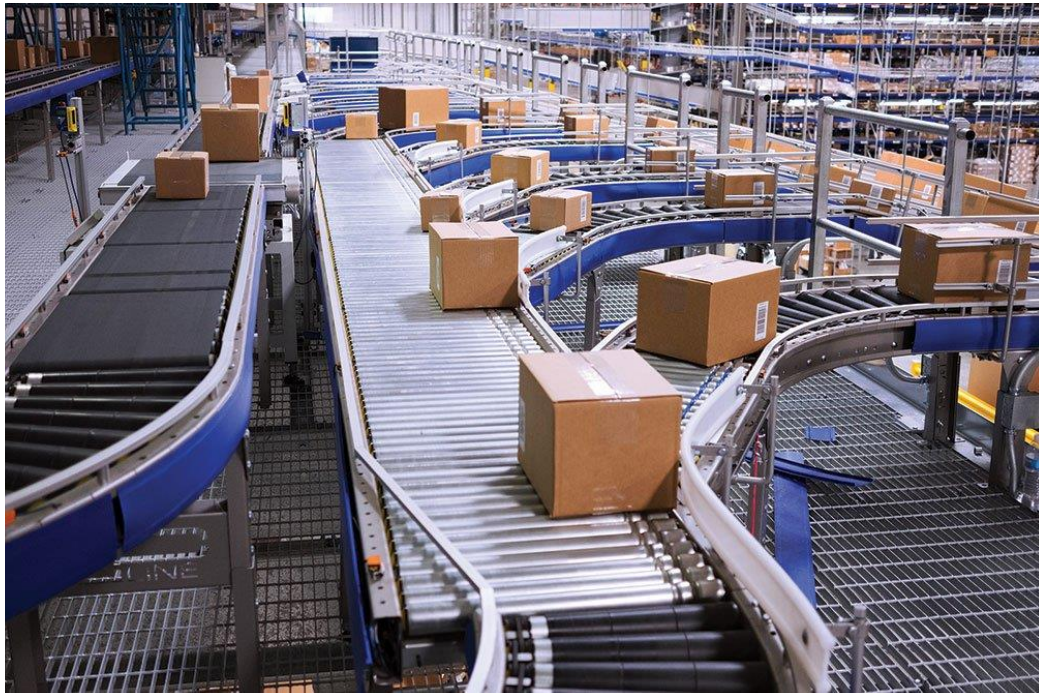
DCB are the sorting belts

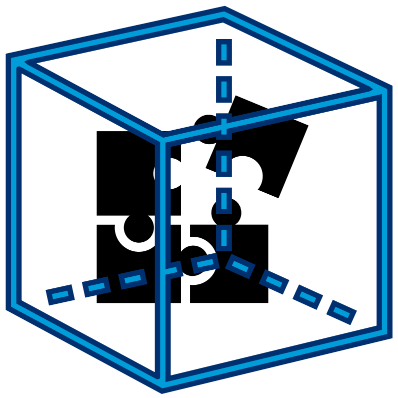
- Distribute demand in the available airspace
- Make more space available when needed



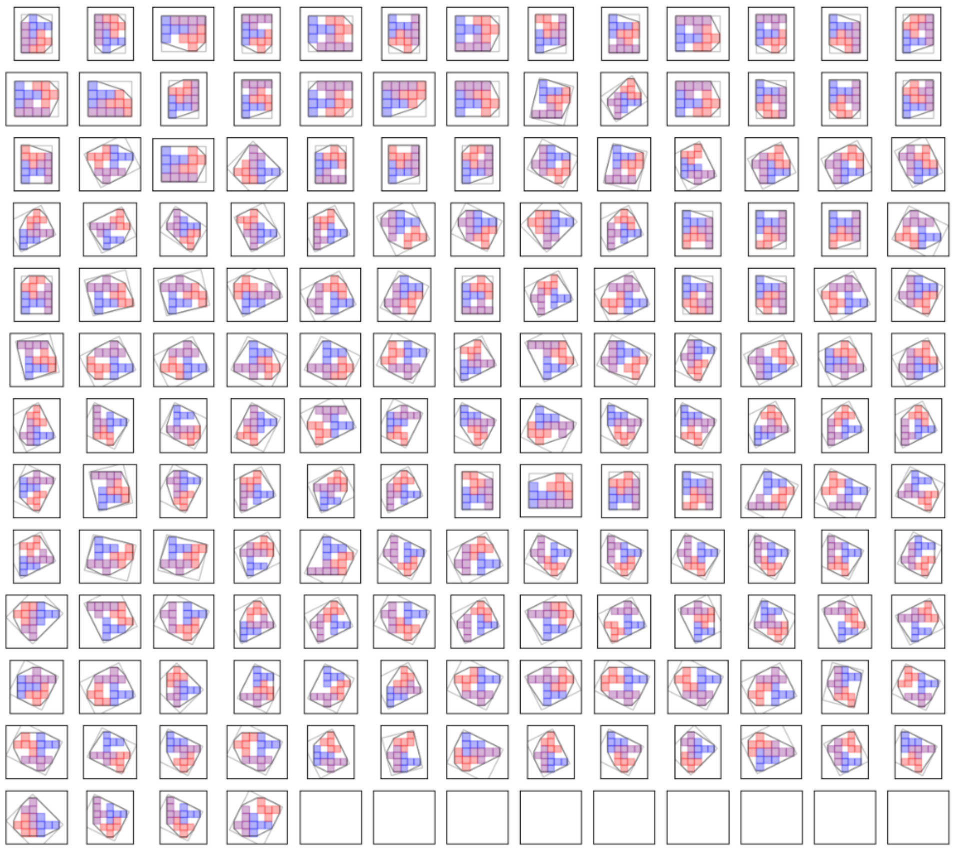


TS is the person attempting to solve the puzzles

- TS finds the proper way to arrange the pieces into each box



Each box is in 4D!



- DCB is in place to ensure the puzzle can be solved!

SHORT TERM HORIZON

In the STH, traffic synchronization is materialised via the strategic deconfliction of U-plans, expressed as 4D trajectories, to ensure U-plans are free of conflicts in time and space.

- The strategic deconfliction process searches for overlaps in the 4D trajectories (+deviation thresholds) to detect conflicts.
- The prioritisation scheme is first-come first-served: the U-plan that has been submitted earliest has priority.
- Otherwise, special UAS operations may have higher priority than regular UAS operations, so these can be accepted even if in conflict with a previously submitted UAS operations, which will have to be amended or withdrawn.
- There is no requirement about how to resolve a strategic conflict other than rejecting the U-plan, but the USSP may propose an alternate to the operator, involving a change to the 4D trajectory.

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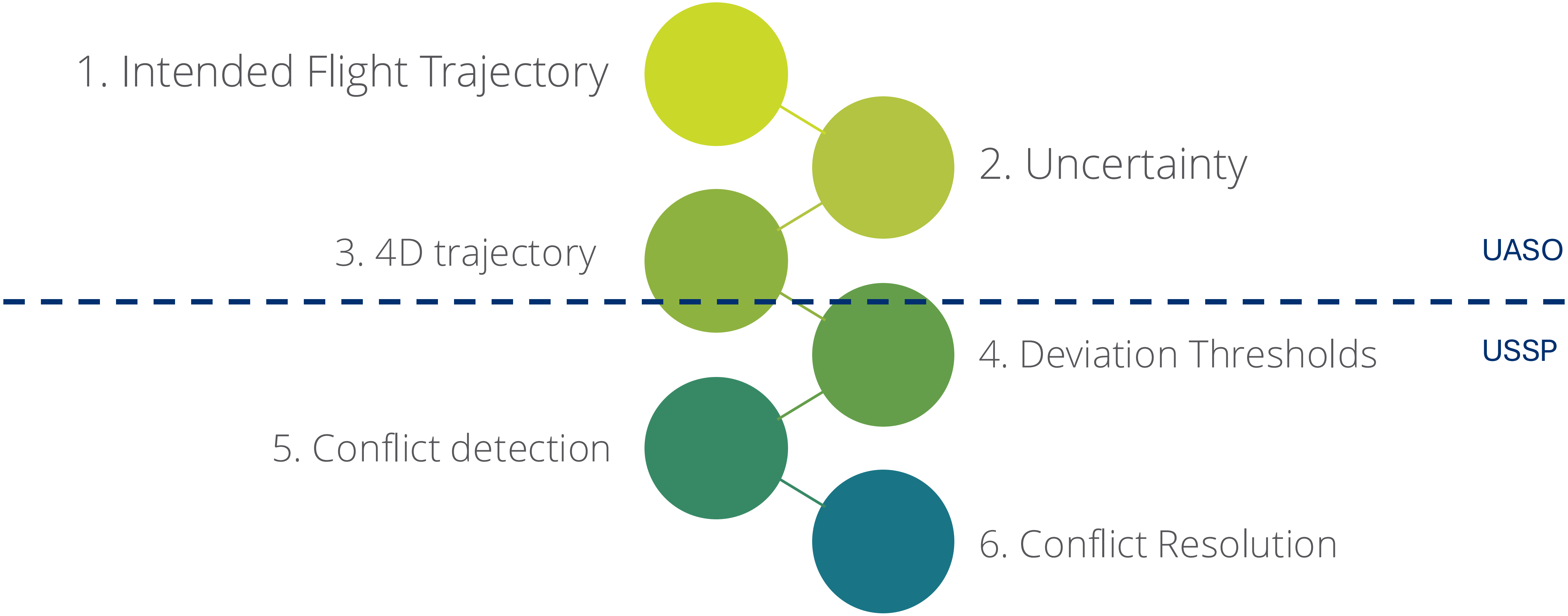
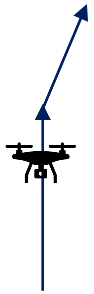
Strategic deconfliction in the STH

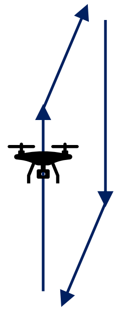


1. Intended flight trajectories and areas

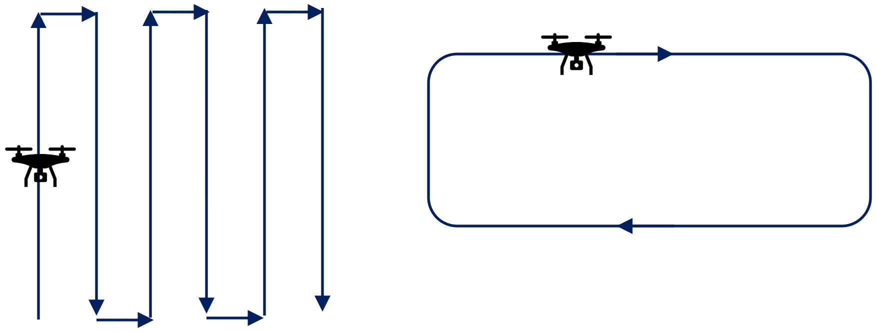
The **intended flight trajectory** is the path expected to be flown by the autopilot (or remote pilot) based on the definition of the trajectory given by a sequence of 4D waypoints, leg types and transitions; defined by the operator according to the mission objectives



Simple trajectory



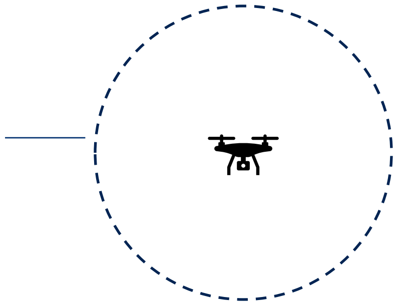
Simple trajectory with return



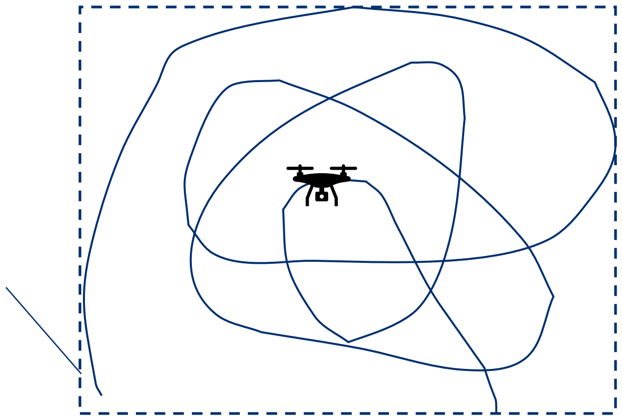
Area sweep with different geometry and defined path

Intended flight areas can be used instead when there is no predefined path

Intended flight area (centre + radius + min&max altitudes start and end time)



Intended flight area (2D boundaries + min&max altitudes + start and end time)



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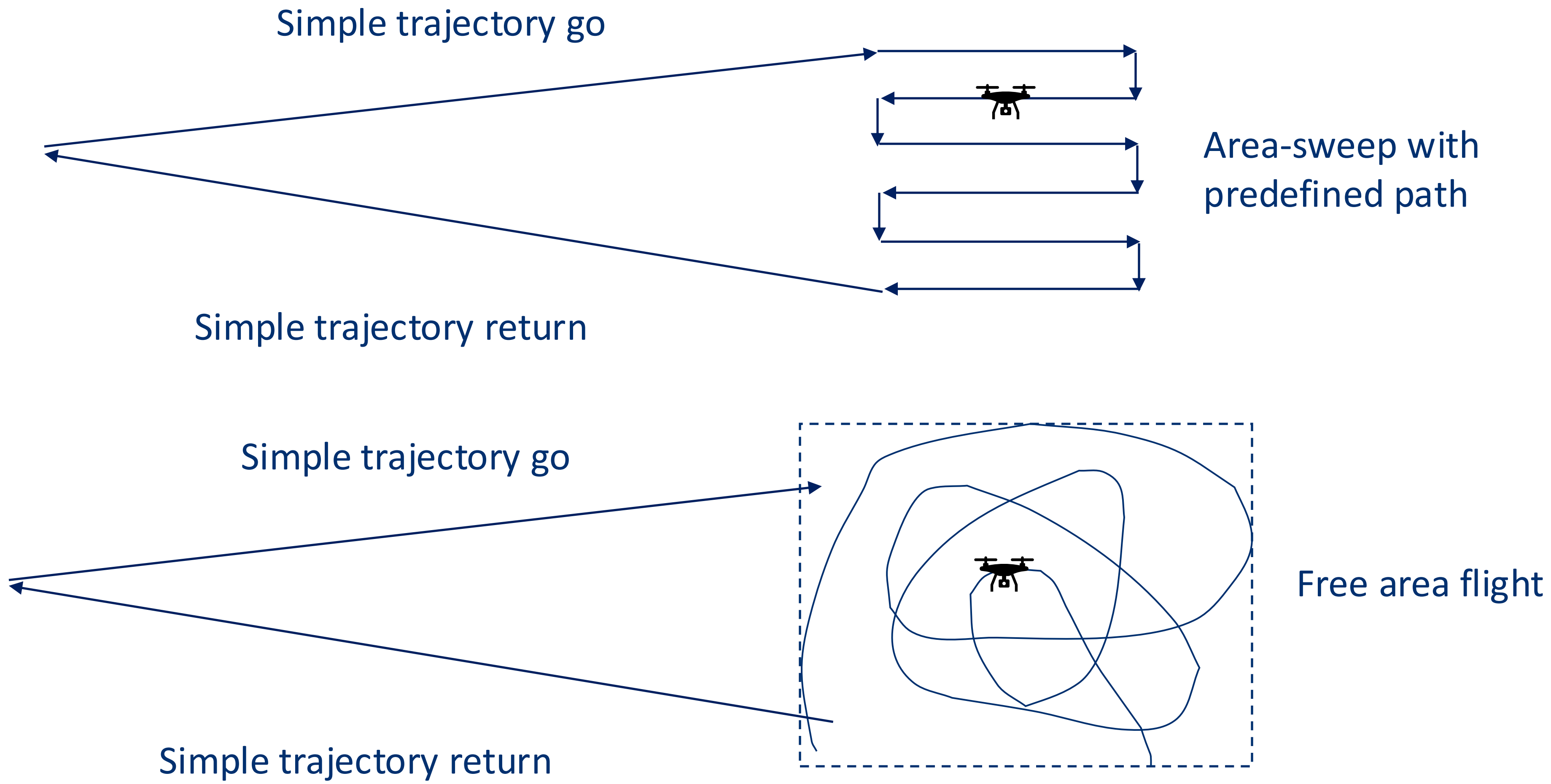
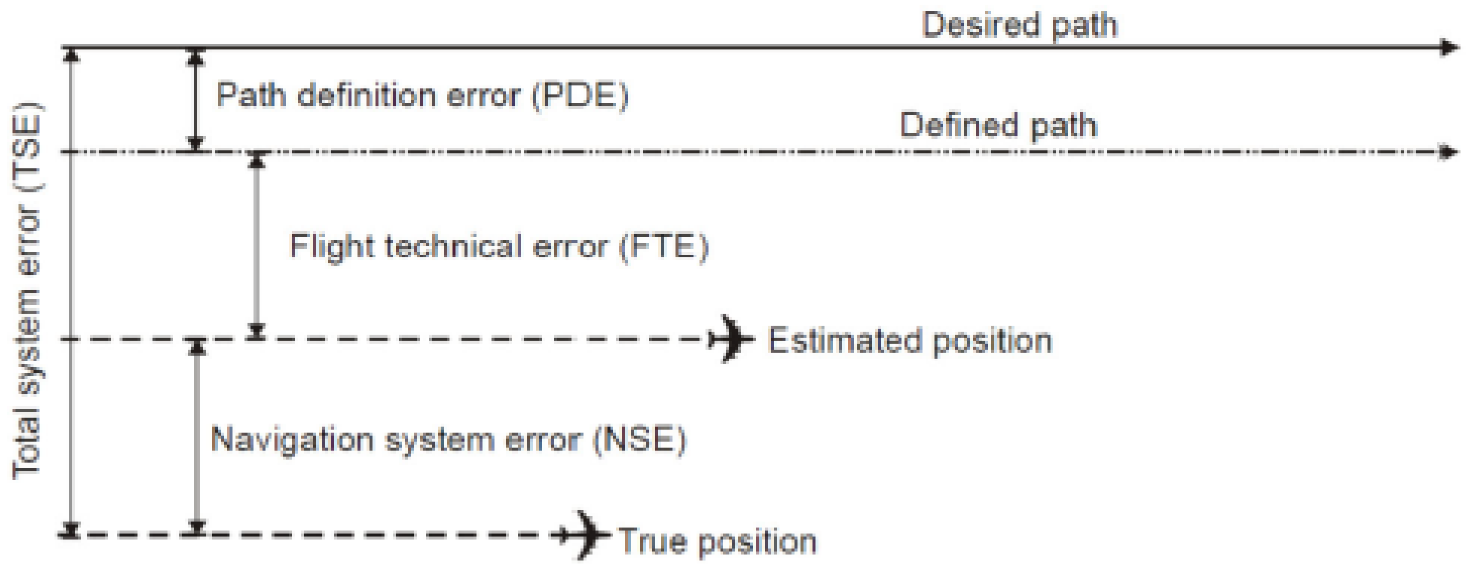
1. Combining trajectories and areas



Any combination is possible as long as consecutive legs are connected (in time AND space!)

2. UNCERTAINTY

- Every mission inherently involves both spatial and temporal uncertainty. This uncertainty originates from the Navigation System Error (NSE), Flight Technical Error (FTE), and Path Definition Error (PDE). Together, these components determine the outer boundary of the operational intent (F3548-21).



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2. Simple 4D trajectories with uncertainty

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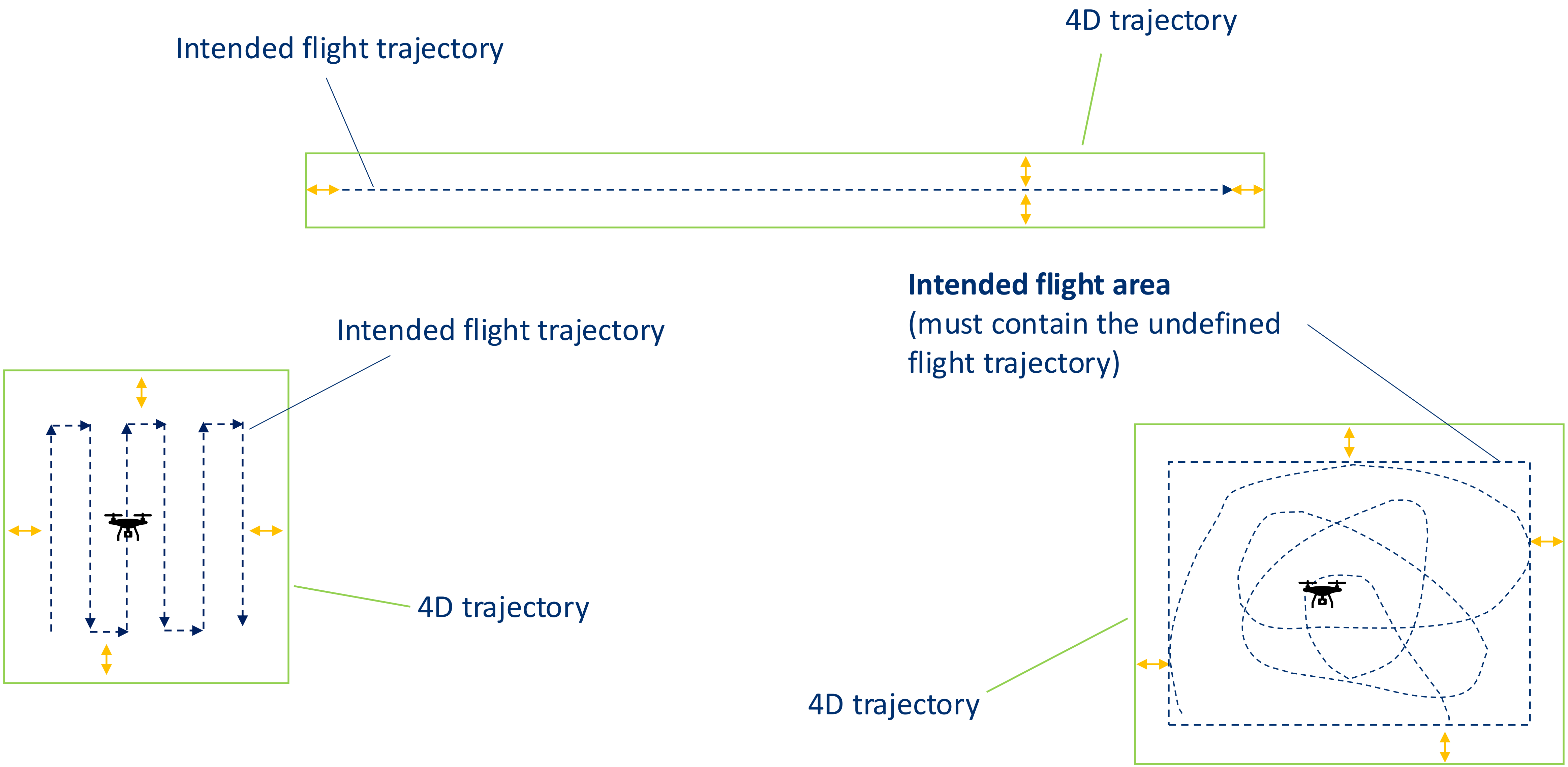
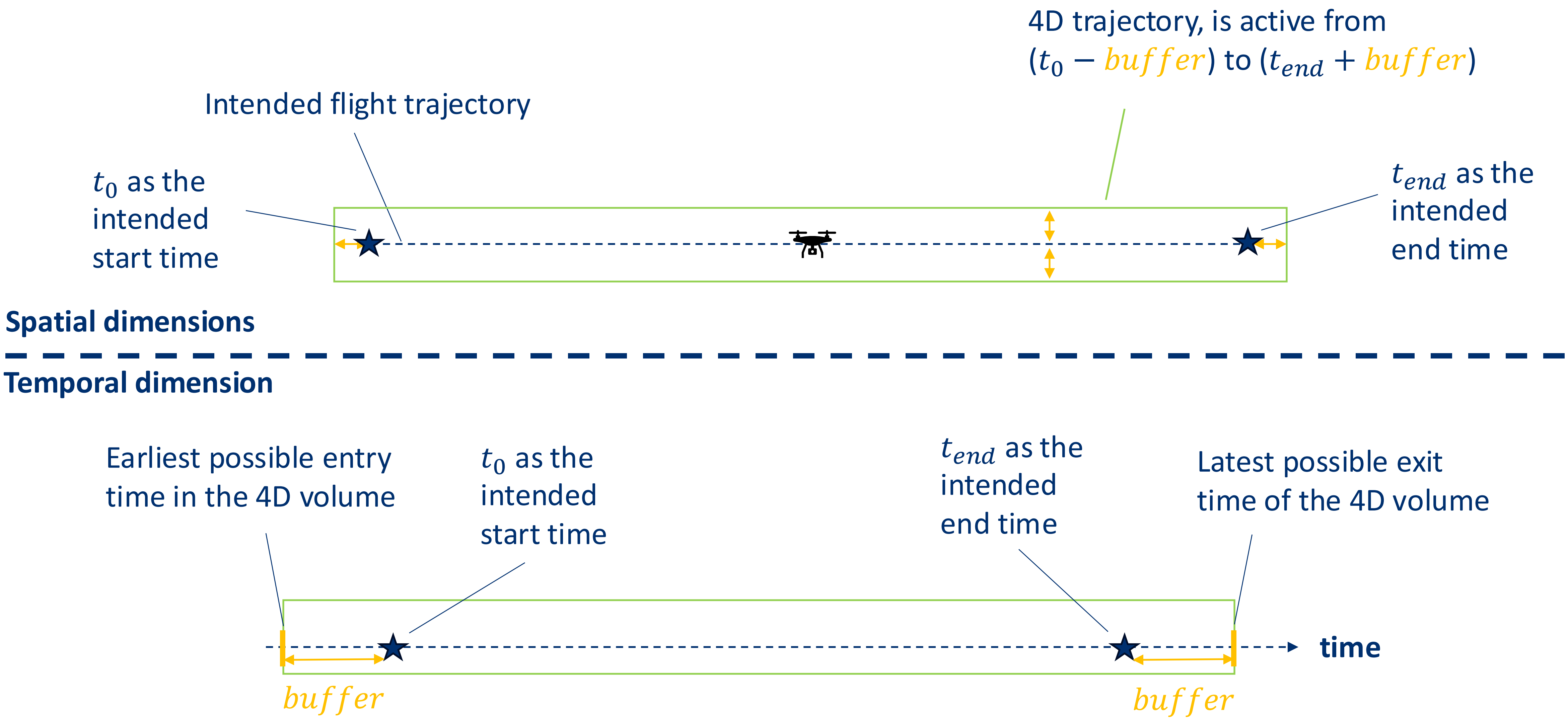


2. Uncertainty also exists in the temporal dimension



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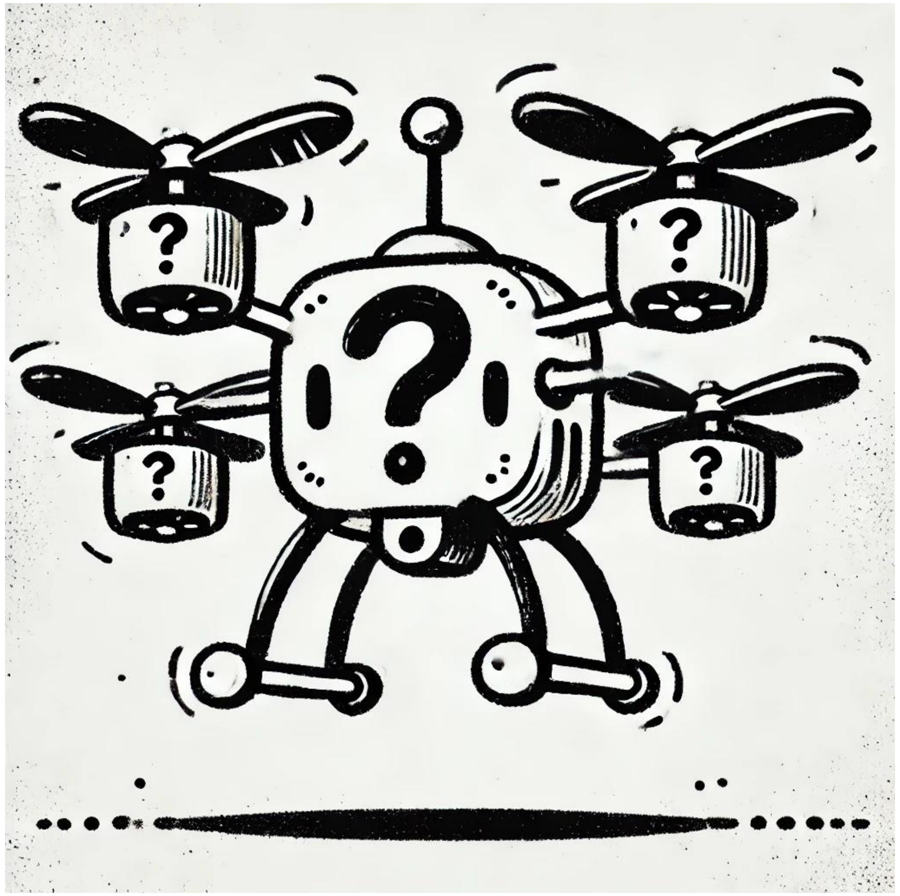
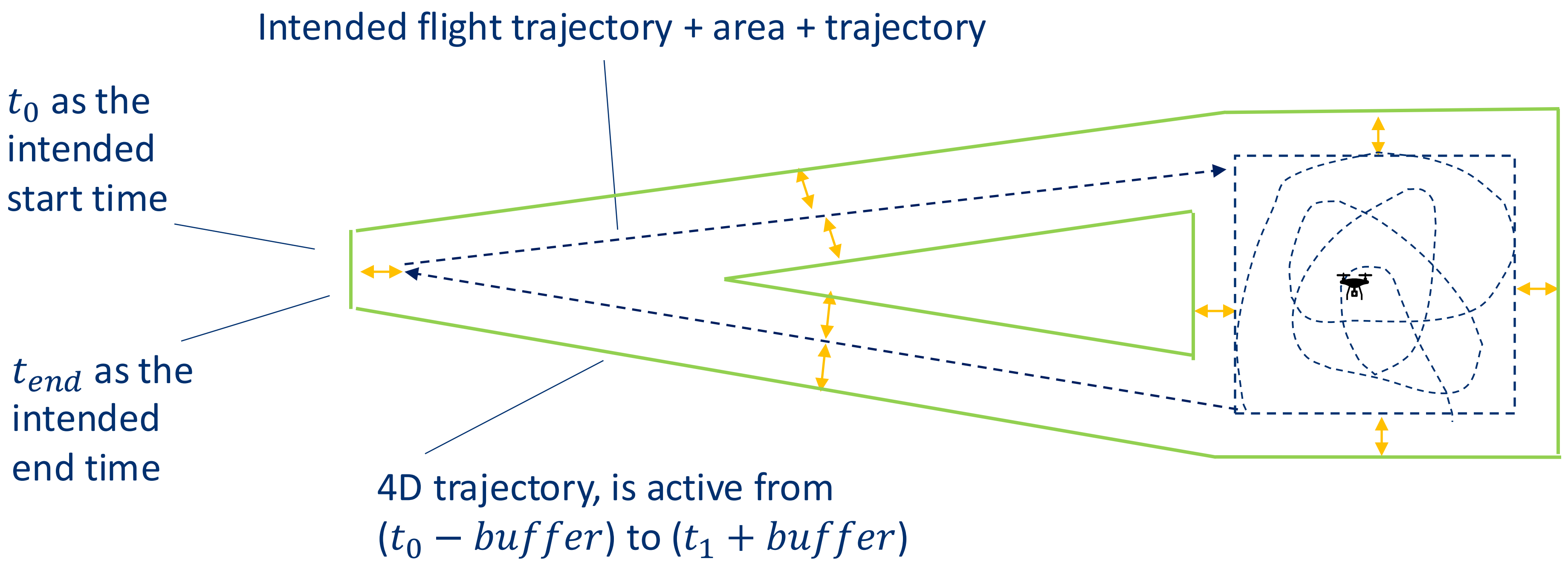
QUESTIONS

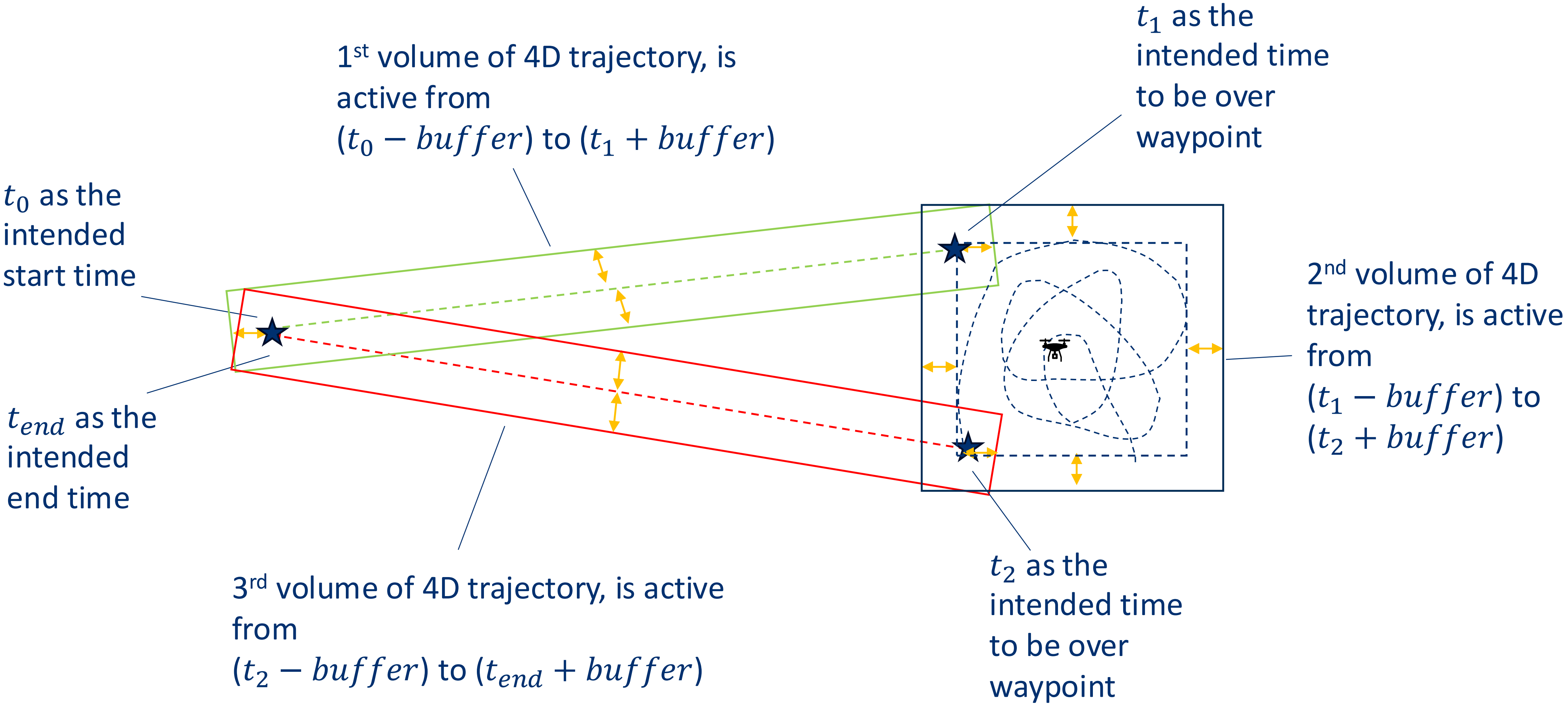
- **QU.1.**How can I estimate the inherent uncertainty of my mission? Who is responsible of defining the PDE, NSE and FTE?. What values are we using?
- **QU.2.** Should we fix maximum/minimum dimensions for the volumes in a 4D trajectory?
- **QU.3.** What about the temporal uncertainty? How should I model that?



3. Simple 4D trajectory with multiple legs



3. Refined 4D trajectory with multiple legs



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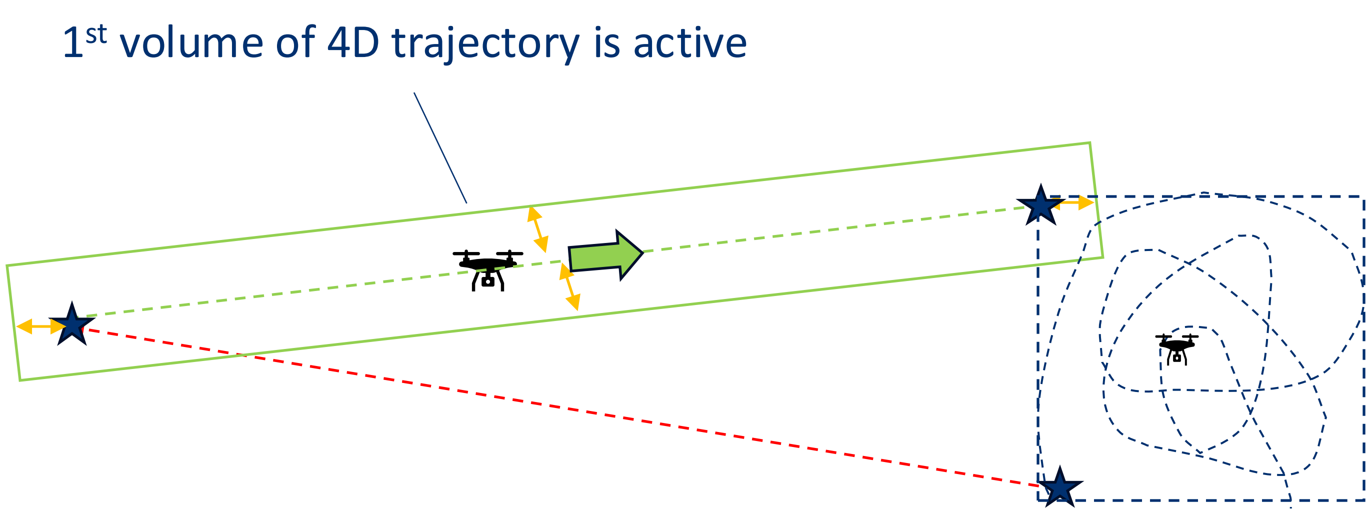

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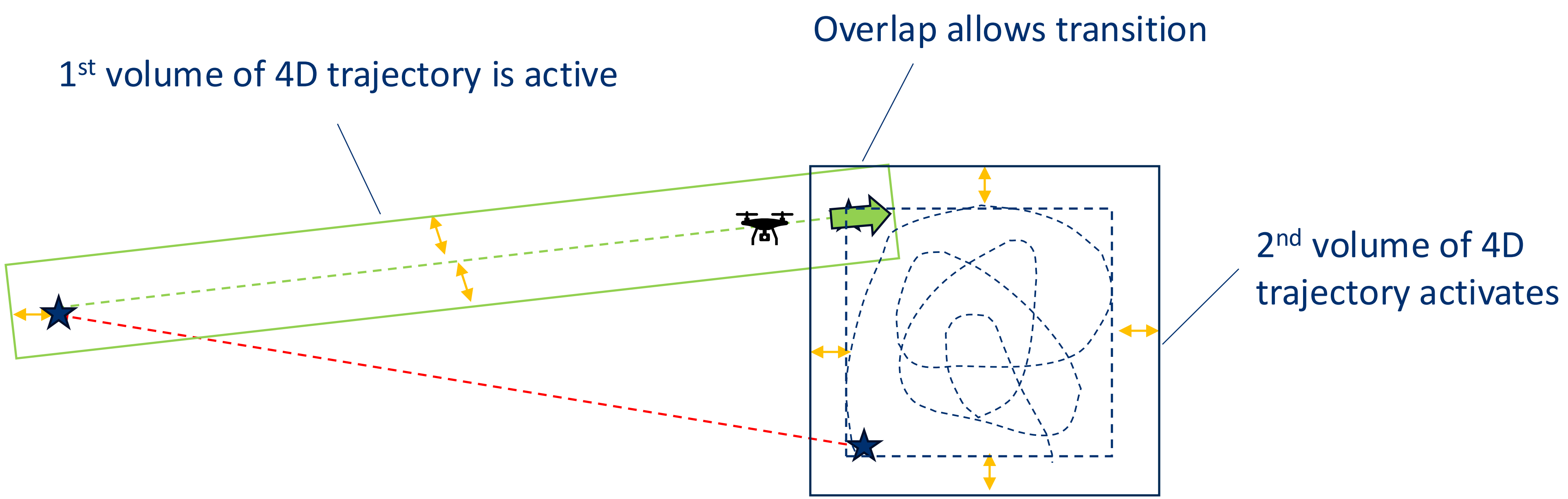

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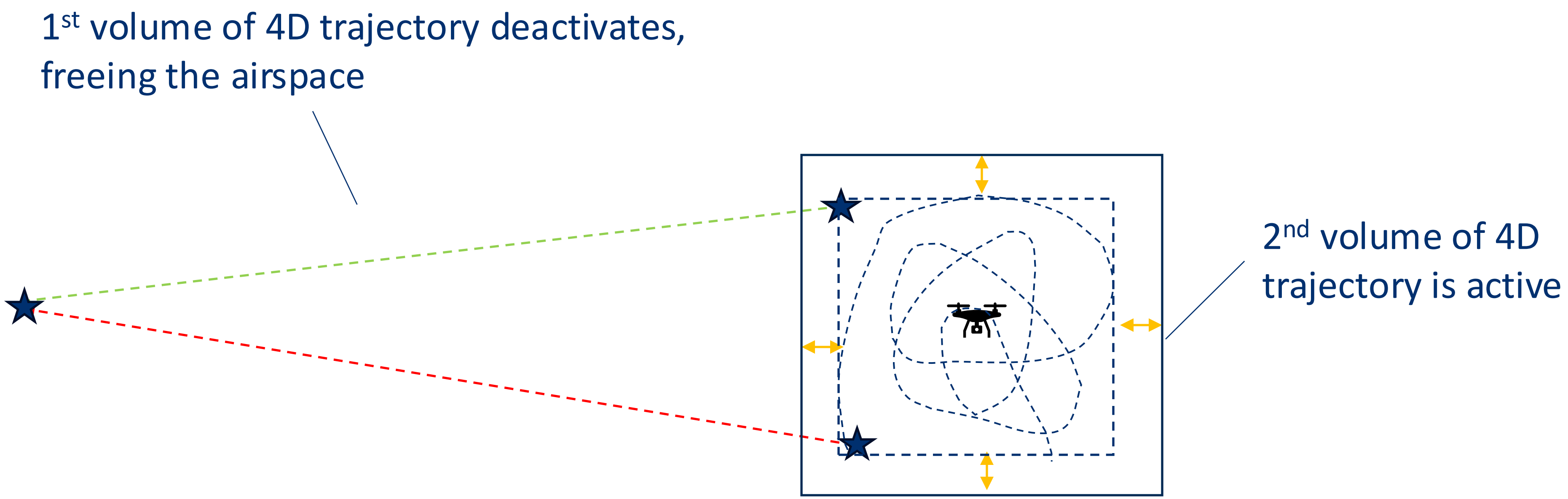
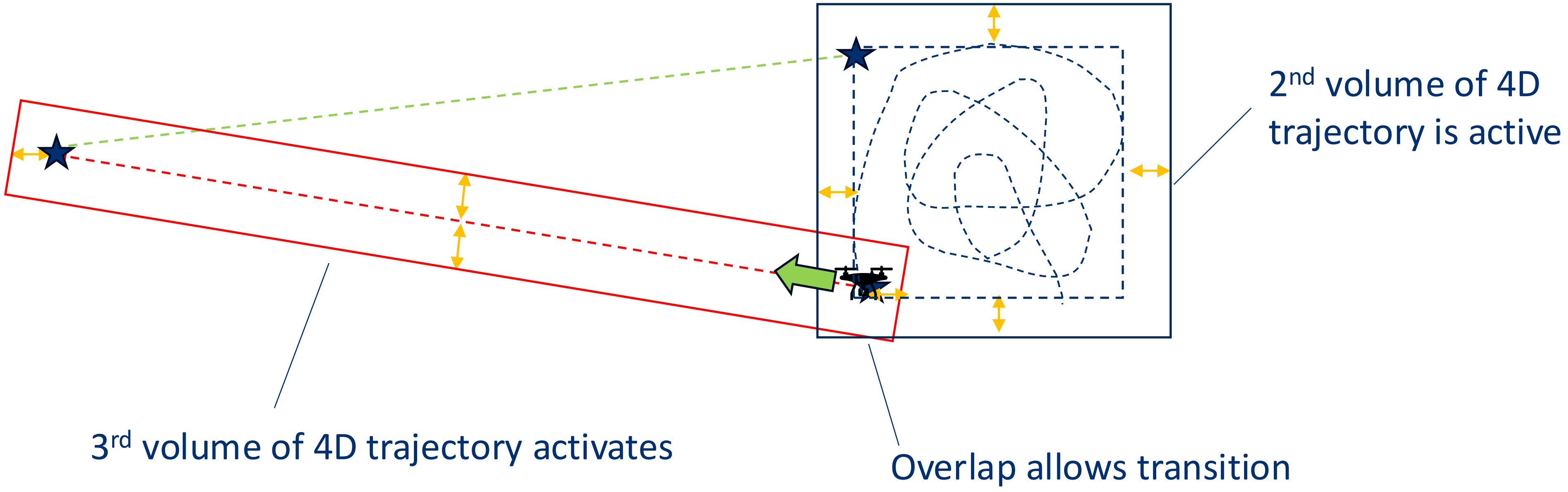
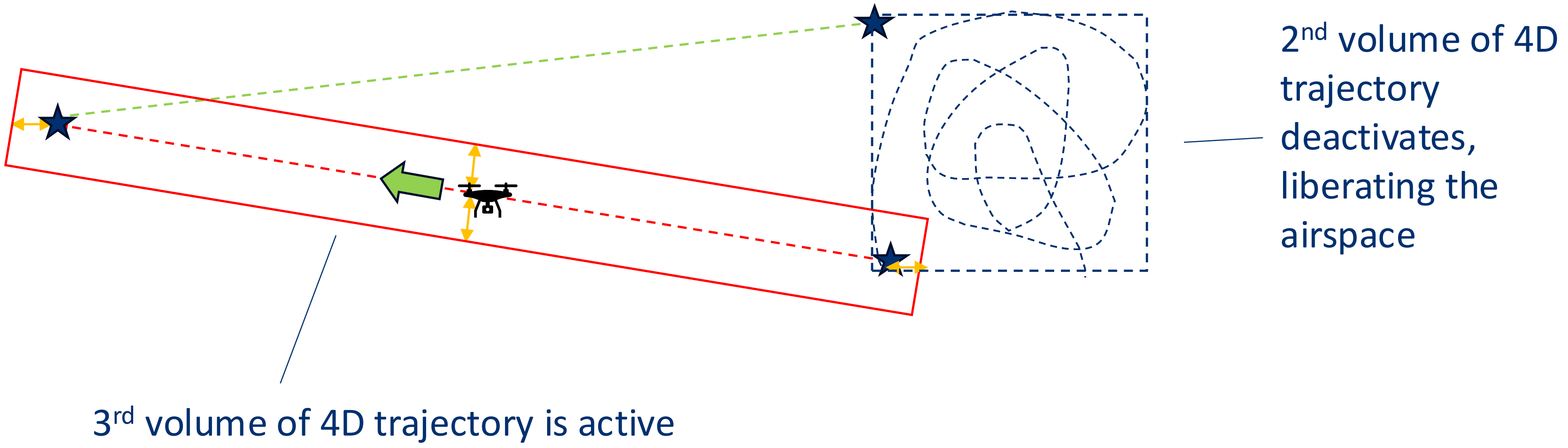


3. Refined 4D trajectory with multiple legs



3. Refined 4D trajectory with multiple legs

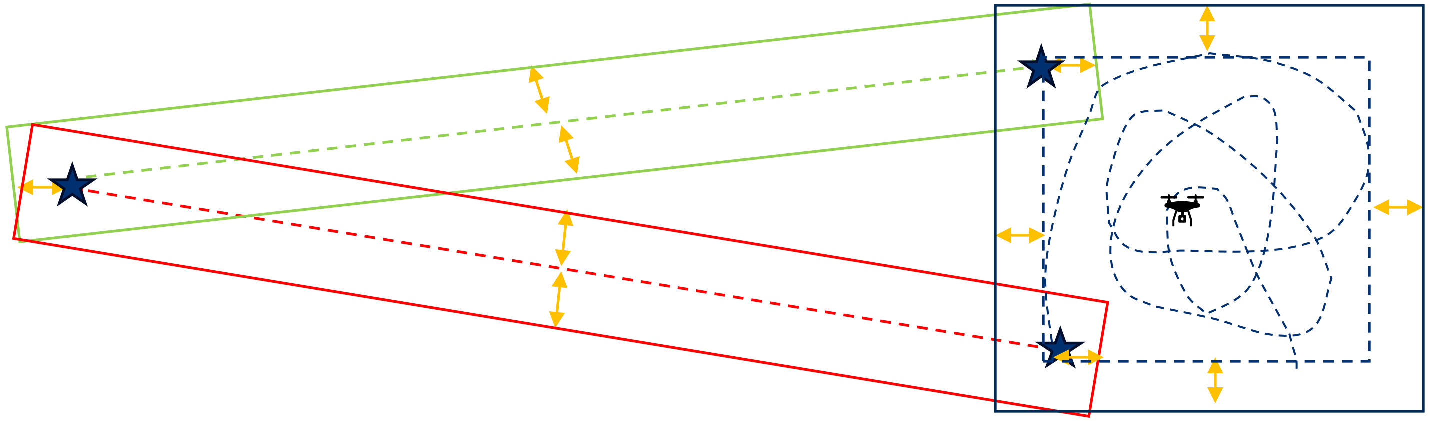


3. Refined 4D trajectory with multiple legs

What is in this 4D trajectory?

- **4 x 4D waypoints = 16 elements**
- **4 x 2D area boundaries + Min & Max area altitude + Entry & Exit times = 12 elements**
- **Horizontal (may split in longitudinal + transversal), vertical, and temporal uncertainties = 3-4 elements**

- **As simple as 31-32 parameters, from which the full 4D volumes can be computed**



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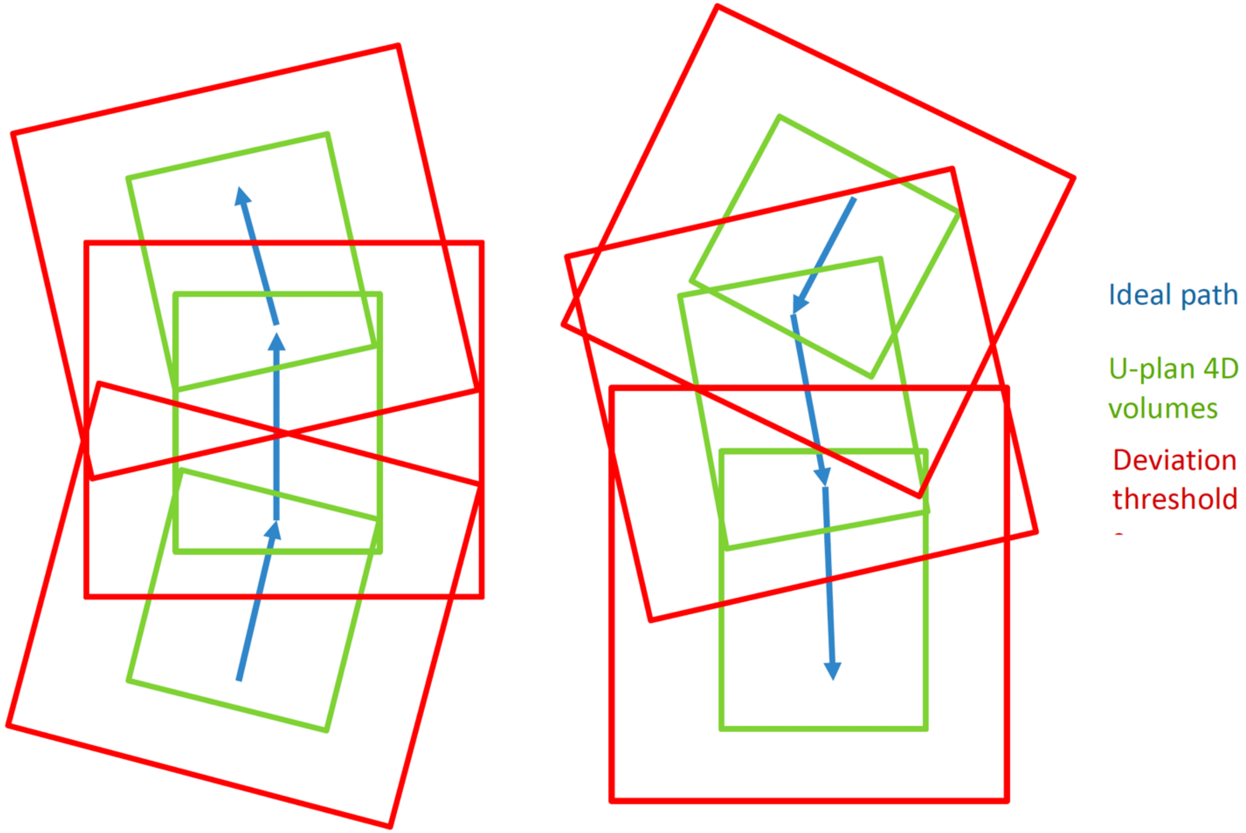
4. What are deviation thresholds?

- Deviation thresholds define the acceptable deviation from a planned intent defined by a UAS operator (the 4D trajectory defined in the UAS flight authorisation request).
- As deviation thresholds refer to 4D volumes, the dimension of the deviation thresholds should also be 4D.
- Deviation thresholds are used for strategic deconfliction and conformance monitoring purposes

- Proposal for the dimension of deviation thresholds:
  - **Deviation threshold in the horizontal plane:** $\boldsymbol{H_{DT}}$ **.** Defines the maximum horizontal deviation from the boundary of the 4D volume(s) defined by the UAS operator before triggering a non-conformance alert (covers 2 dimensions: longitudinal and transversal).
  - **Deviation threshold in the vertical component:** $\boldsymbol{V_{DT}}$ **.** Defines the maximum vertical deviation from the boundary of the 4D volume(s) defined by the UAS operator before triggering a non-conformance alert.
  - **Deviation threshold in the temporal component:** $\boldsymbol{T_{DT}}$ **.** Describes the maximum time a UAS operation can be outside the 4D volume(s) defined by the UAS operator before triggering a non-conformance alert.

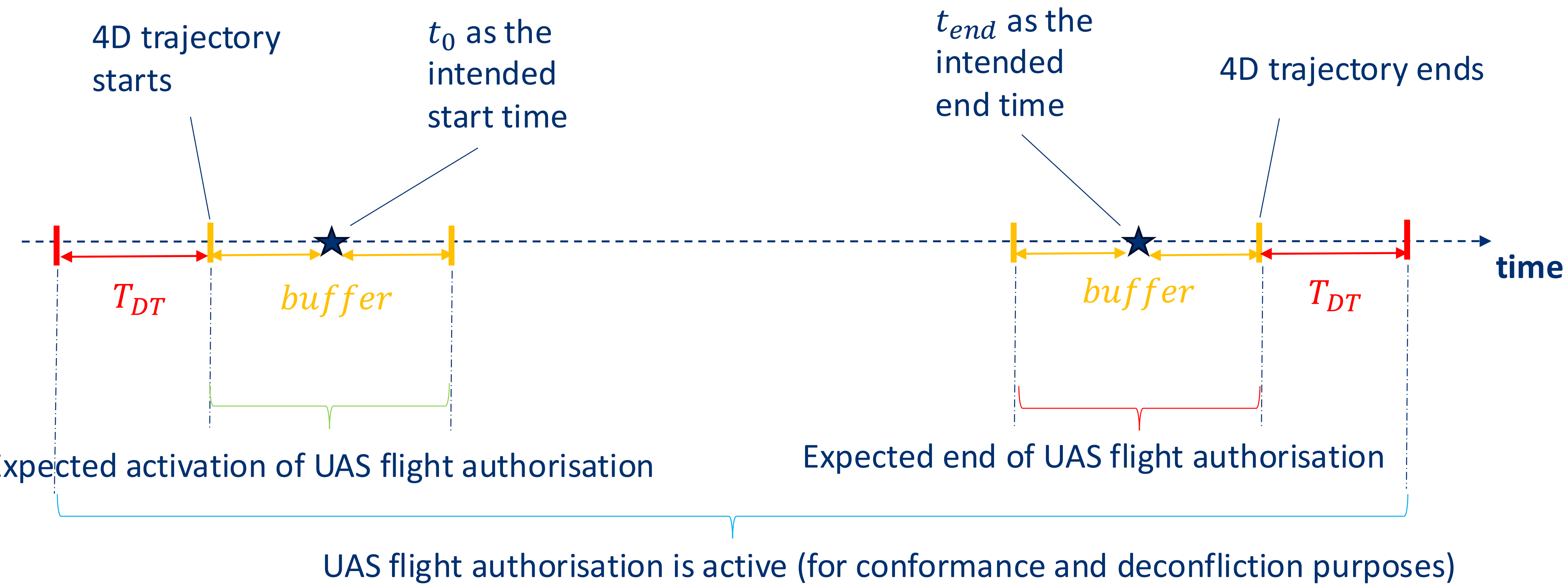
4. What are deviation thresholds?



- The same process as before
- USSPs add deviation thresholds on top of 4D trajectories before checking for conflict
- Deviation thresholds size defined by ARA for each U-space airspace

4. Deviation thresholds are also added in time

Temporal dimension

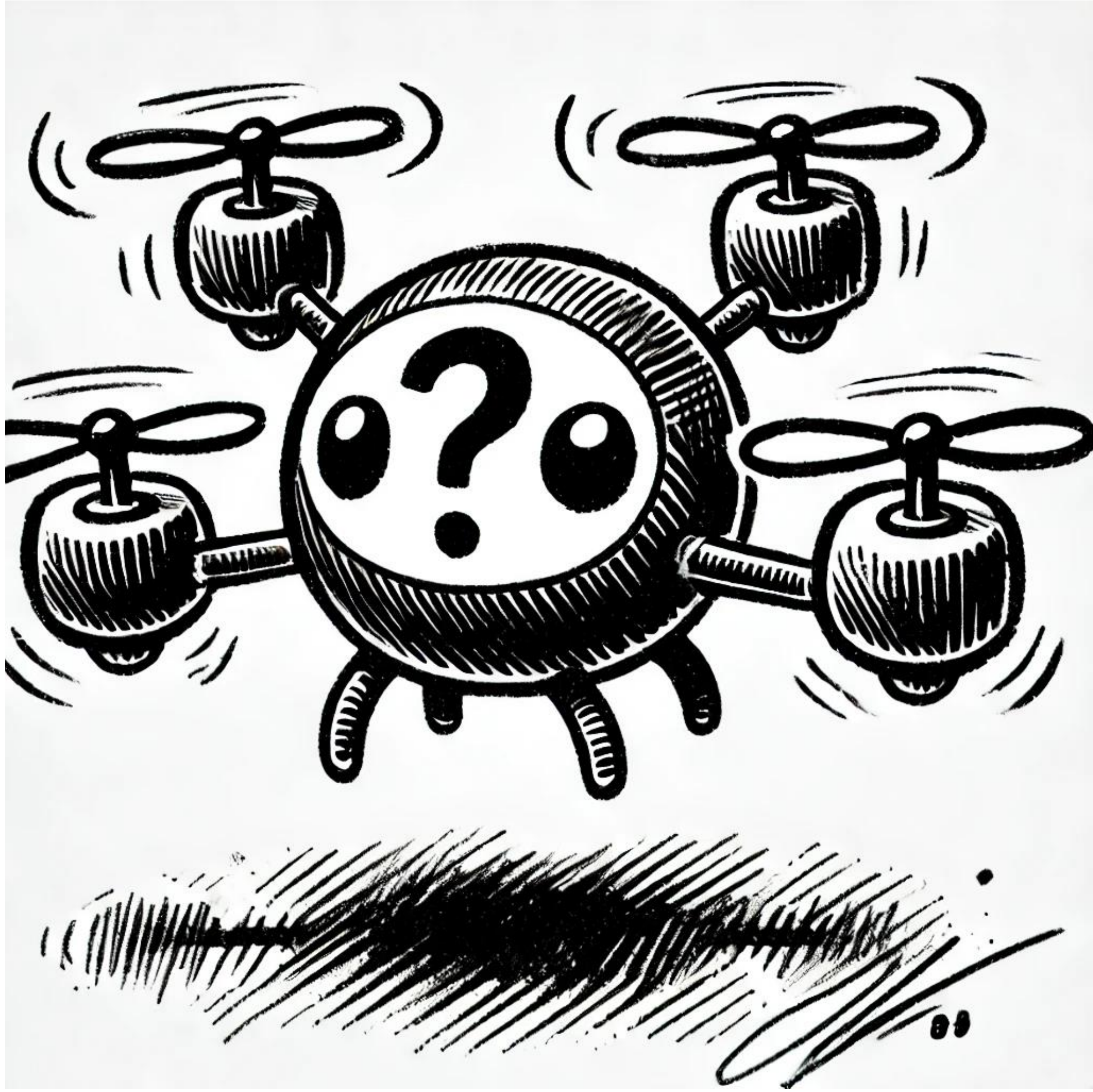


Example with a single 4D volume for simplicity

4. Deviation thresholds

QUESTIONS

- **QU.1.**What size will be the deviation threshold? Who will be determining this?
- **QU.2.** What is the relation between the deviation thresholds and the contingency volume from SORA?



5. Conflict detection – workflow

1. UAS operator defines the intended flight trajectory/area according to the mission targets. As many 4D waypoints/segments as required.

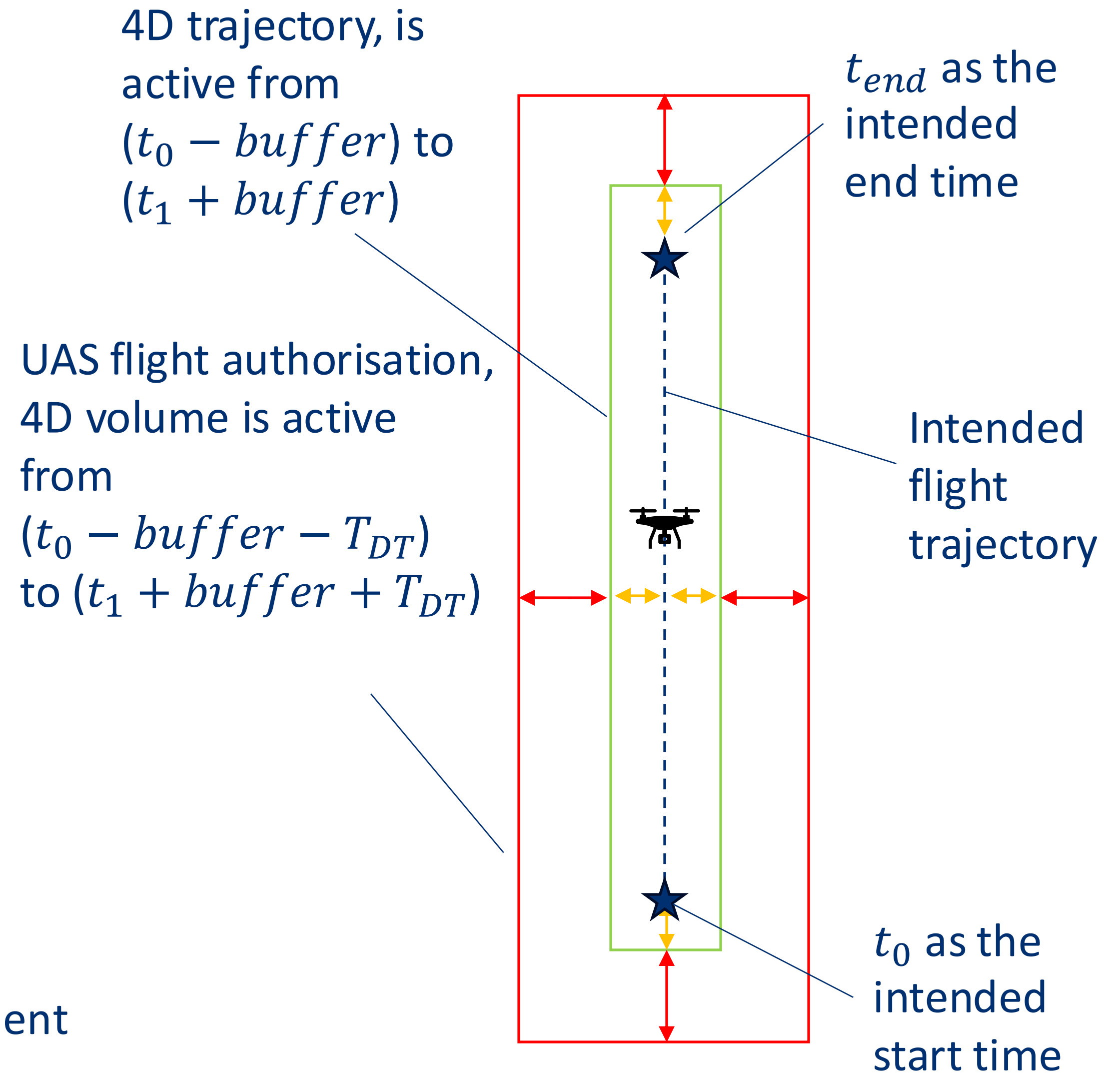
2. UAS operator defines the 4D trajectory (in Specific category, equivalent to the flight geography)

3. USSP adds the deviation thresholds to the 4D trajectory to create the UAS flight authorisation

4. USSP checks if the UAS flight authorisation is <u>free of conflict</u> with already authorised flights*

* Of equal or higher priority

5. If there is no conflict, USSP accepts the flight authorisation request and notifies the UAS operator, indicating the allowed deviation thresholds



↕ = H_{FG} or V_{FG} depending if in horizontal plane or vertical component

↕ = H_{DT} or V_{DT} depending if in horizontal plane or vertical component

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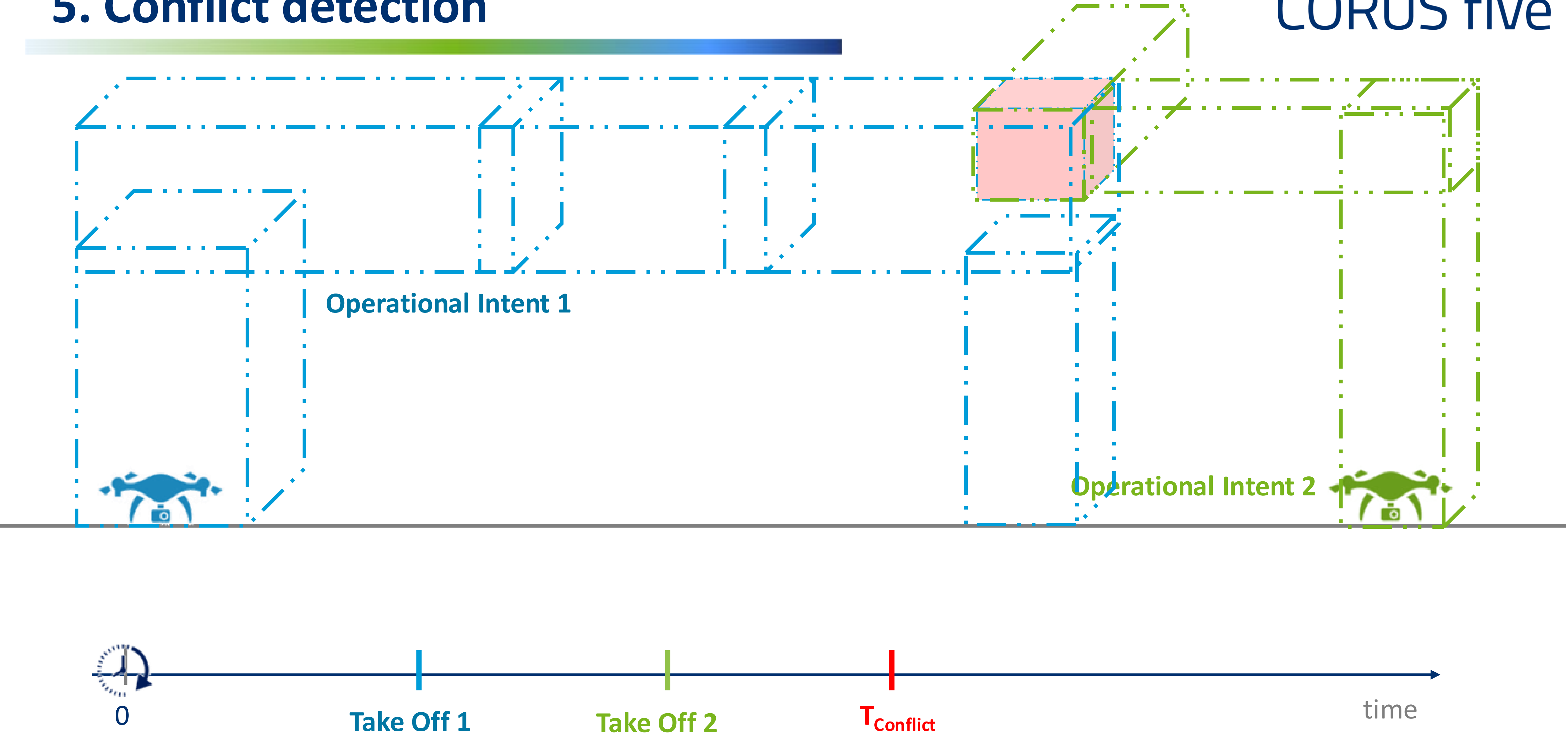
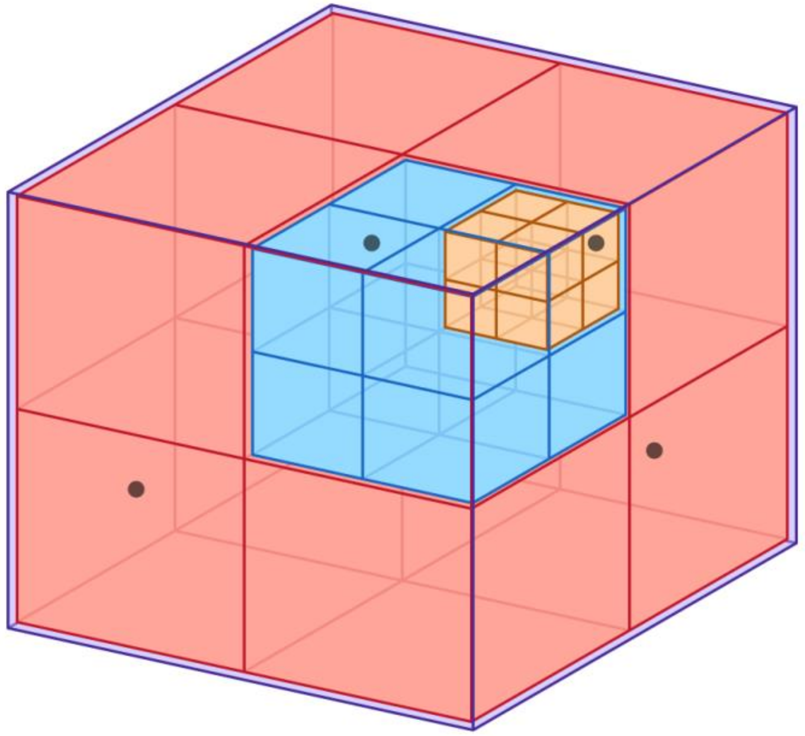
5. Conflict detection

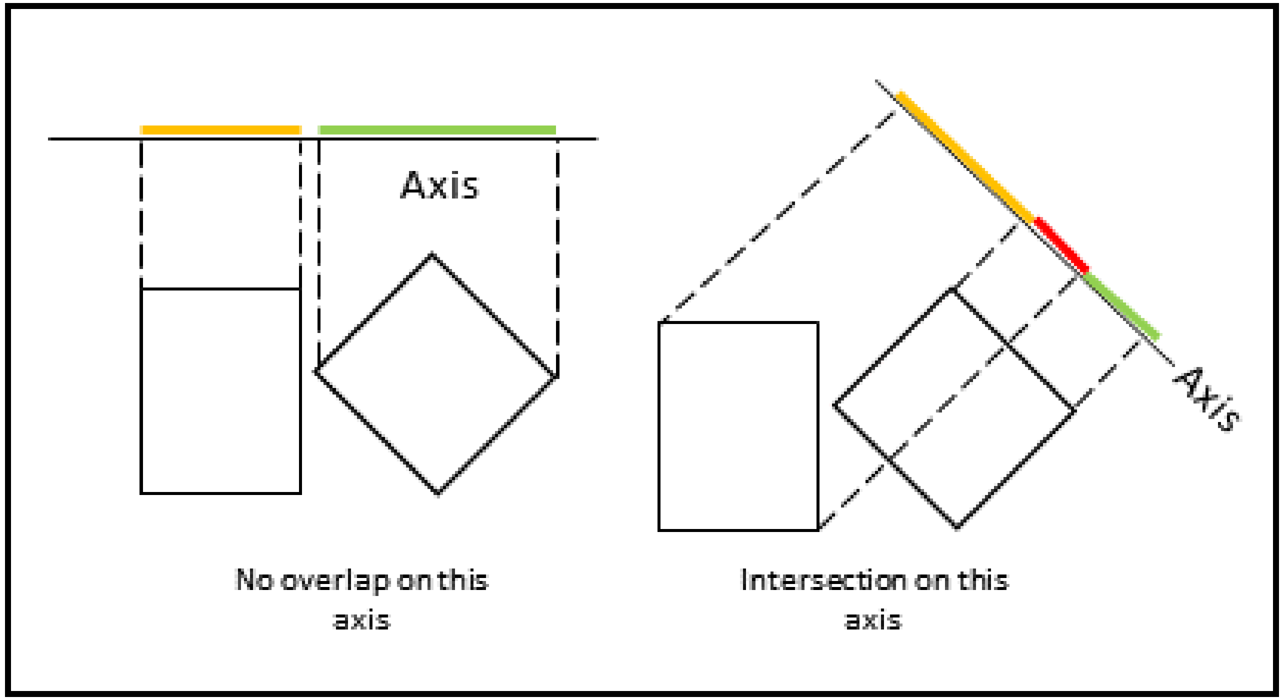


5. Methods for conflict detection

Discrete airspace representation



Analytical approach by Separation Axis Theorem

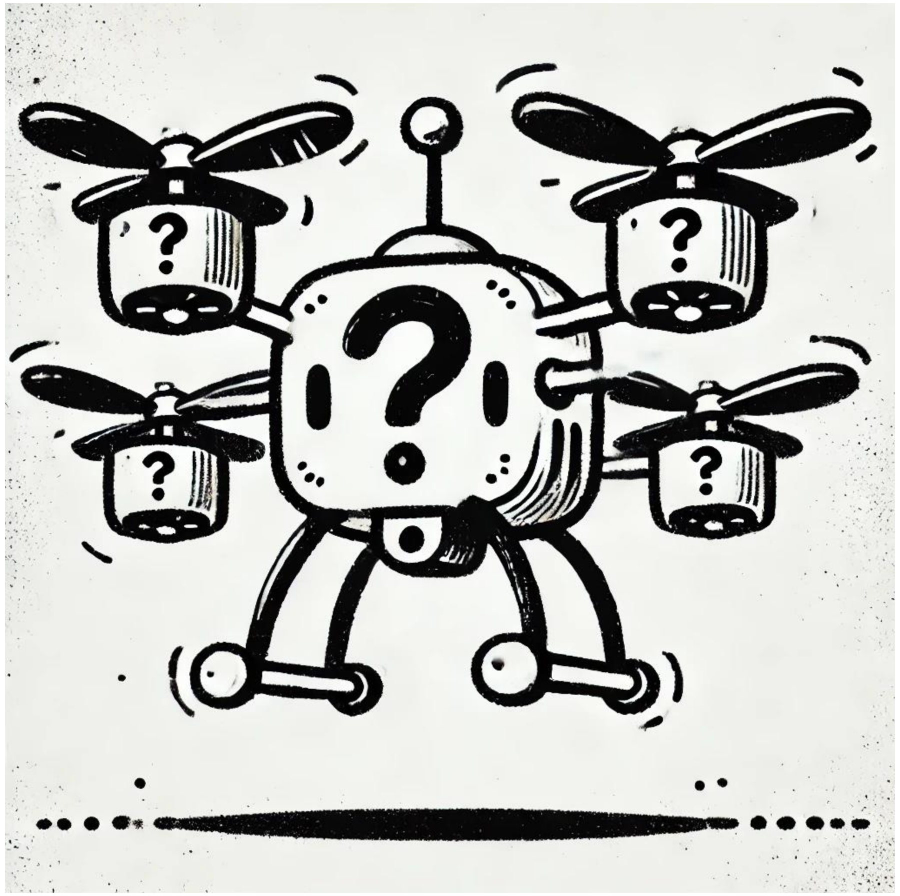


Different methods incur in different complexity and computation cost

5. Conflict detection

QUESTIONS

- **QU.1.** Computational efficiency vs density for numerical and analytical approaches
- **QU.2.** Impact of false positives in numerical approaches
- **QU.3.** Constraints for different approaches



6. Conflict solving

- Remains optional in the STH. USSPs can just reject the U-plan request

- Conflict detection computational cost scales linearly with traffic density (in FCFS), but
- Conflict solving computational cost scales exponentially with traffic density
  - More flights makes conflicts more difficult to solve

- Conflict solving algorithms are much more complex than simple detection
  - Brute force solving iteratively proposes incremental changes and checks again for conflict until no conflict is detected
  - Smart solving can directly find a solution but needs much more complex algorithms

6. Solving conflicts in the STH using delays

- EU 2021/664. Article 10(2)(b): USSP check … that the UAS flight authorisation request is free of intersection in space and time with any other notified UAS flight authorisations …
- EU 2021/664. Article 10(6): “proper arrangements to resolve conflicting UAS flight authorisation requests received from UAS operators by different U-space service providers”
- It is expected that within STH, delay will be applied to 4D volumes
- A seemingly simple alternative, such as modifying the trajectory, would alter the mission volumes and could potentially affect its assigned SAIL

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6. Solving conflicts in the STH using delays

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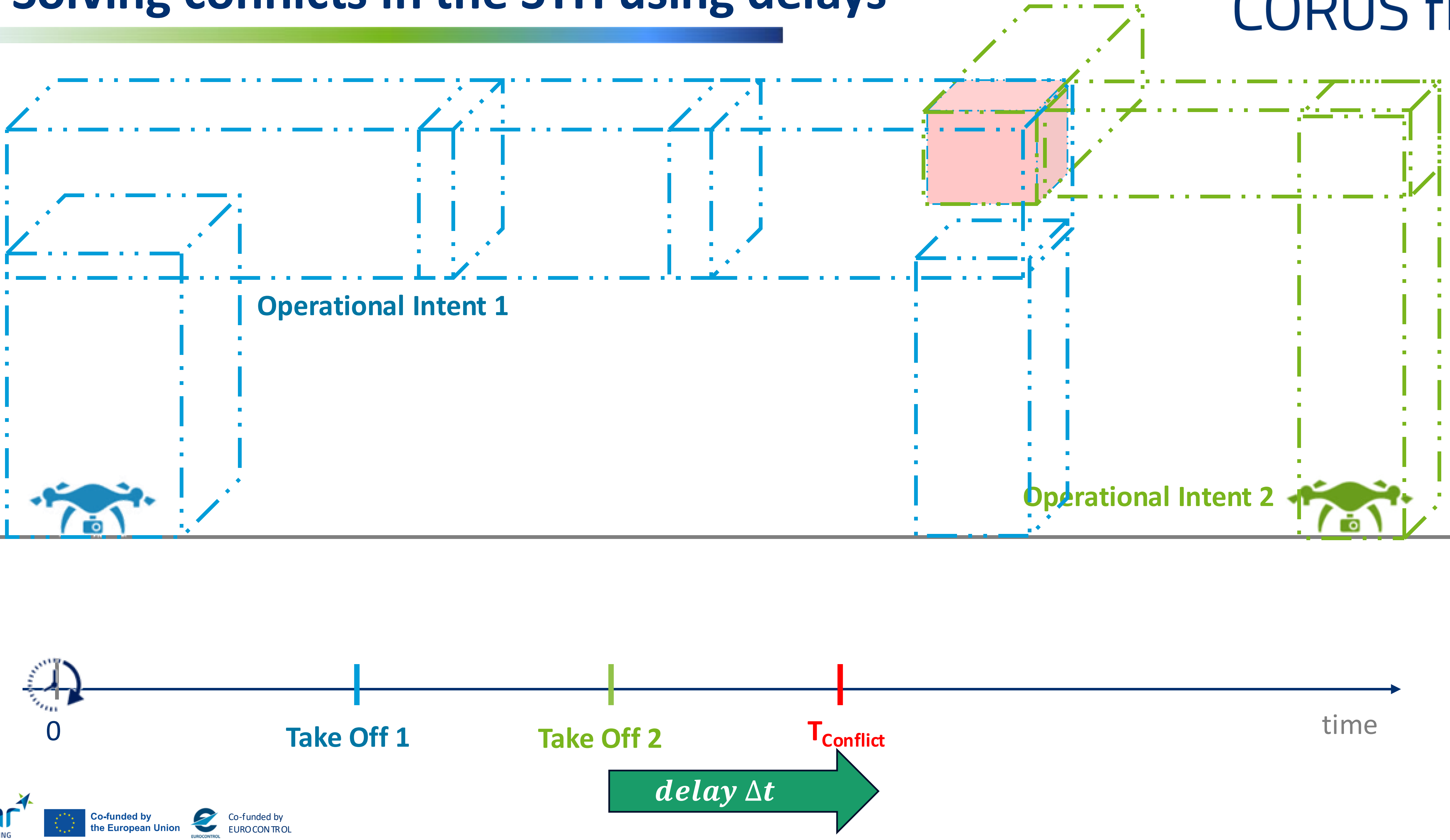

6. Solving conflicts in the STH using delays

QUESTIONS

- **QU.1.** Can expected average delay be used as a proxy for U-space airspace efficiency? What about the expected acceptance ratio?
- **QU.2.** Can the density/capacity limit for U-space airspace described in AMC be linked to the expected delay for such density?
- **QU.3.** Is delay an acceptable solving mechanism for the STH?

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MTH – Possible ideas about TS

The MTH is characterised by more complex scenarios and much higher demand than in the STH. In the MTH, Traffic Synchronisation must evolve to tackle these challenges, ensuring safety and efficiency.

1. Single vs Batch
2. Dynamic Uncertainty
3. RTTA
4. Allow overlap (strategic)
5. TS in aerodrome operations

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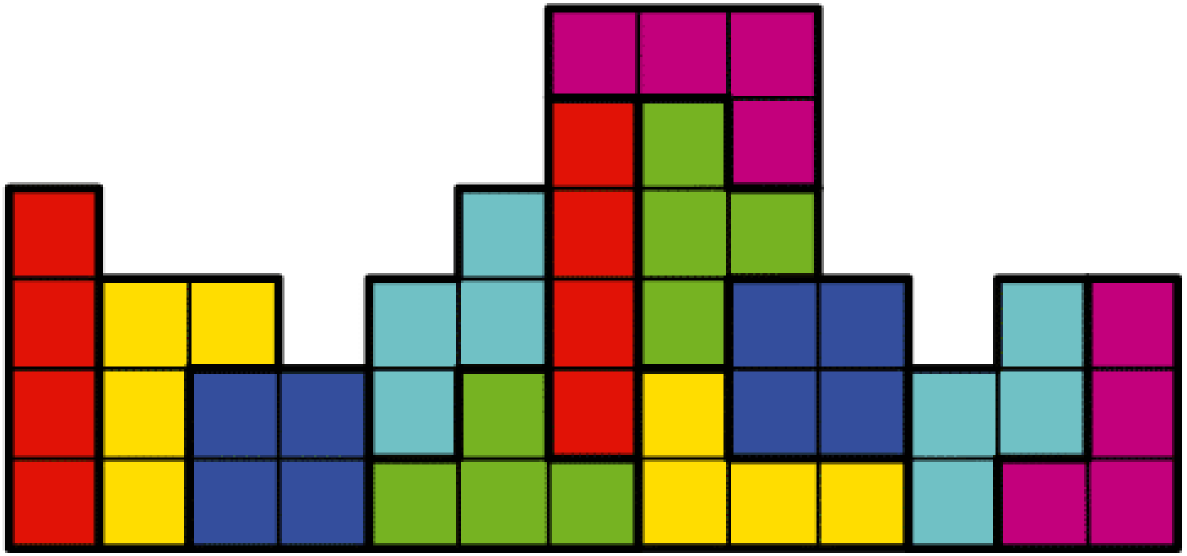
1. Single vs Batch synchronisation

WHO WILL GET THE HIGHEST SCORE?

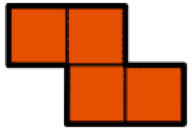
U-space volume with accepted U-plans



Single (FCFS)

All the information that you have is just the next piece

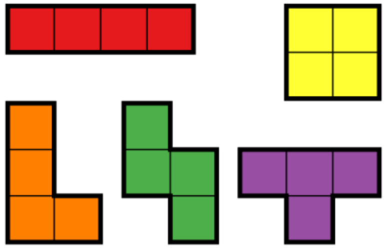
You need to accommodate the next piece/U-plan



BATCH

You accommodate a set of U-plans together.

Focus on a wider picture



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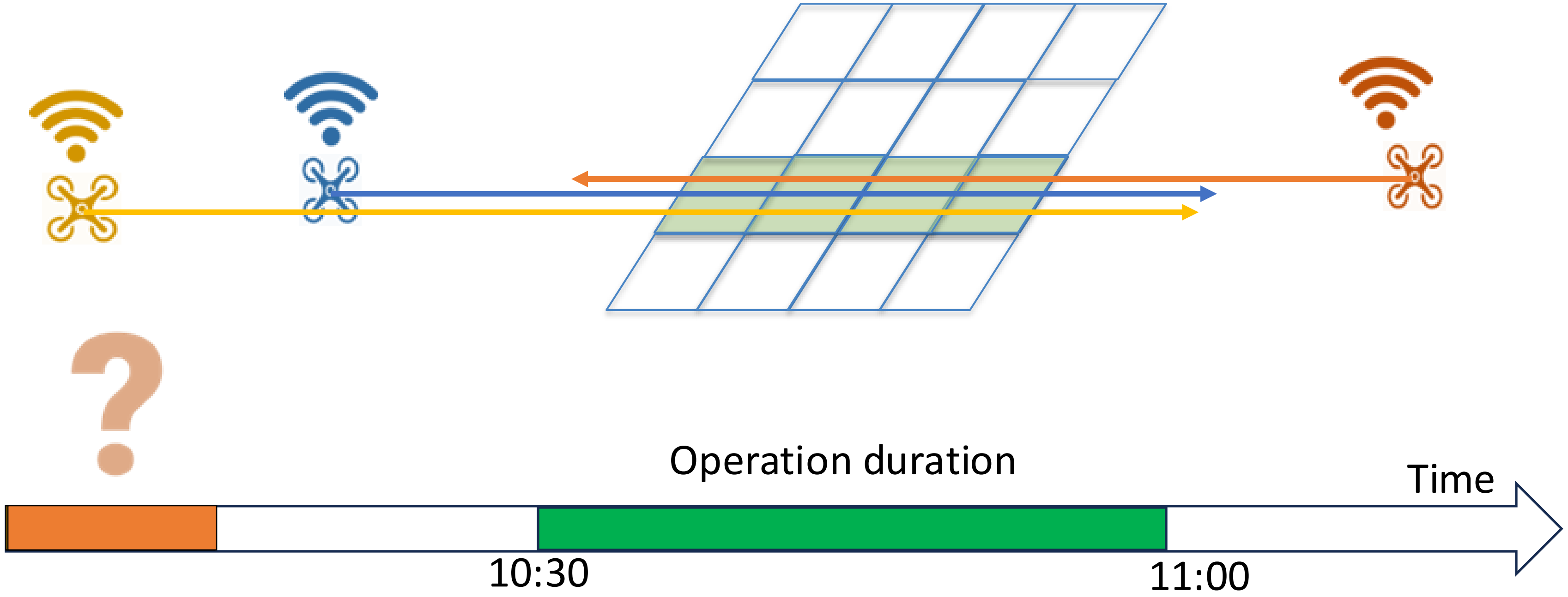
1. Single vs Batch synchronisation

- The prioritisation scheme in STH is first-come first-served: the U-plan that has been submitted earliest has priority.
- This implies that the available capacity may not always be fully exploited.
- High priority missions can override previously approved missions

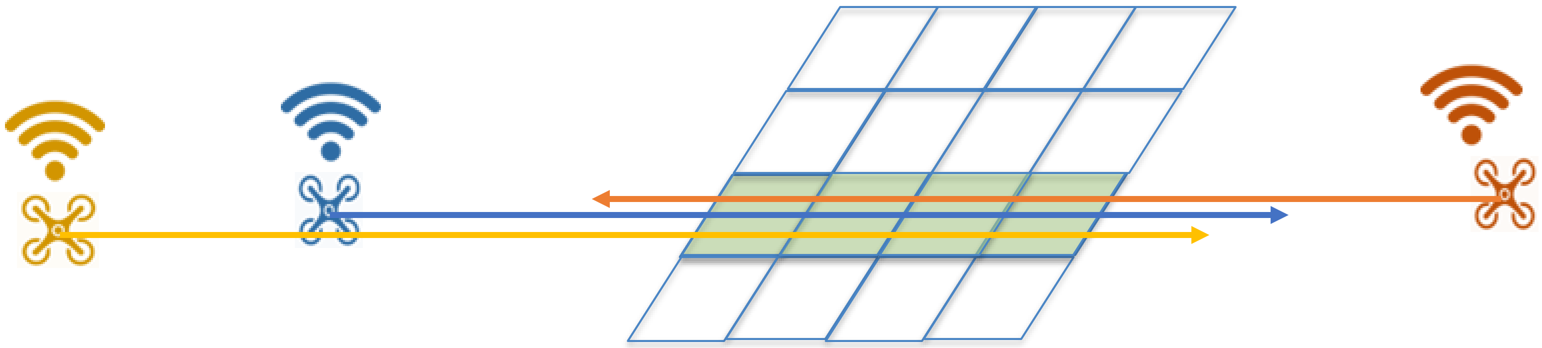
Single

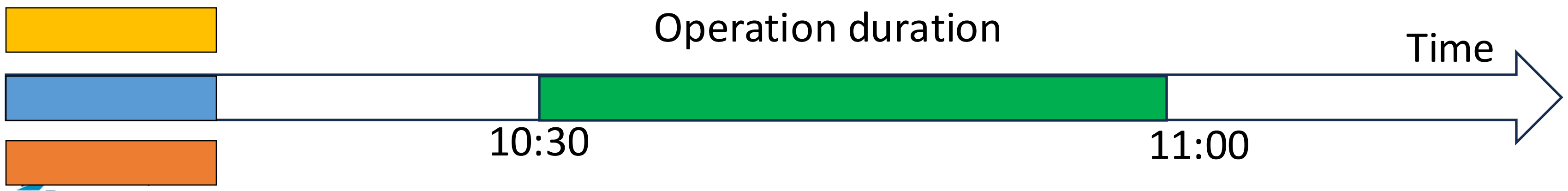


1. Single vs Batch synchronisation

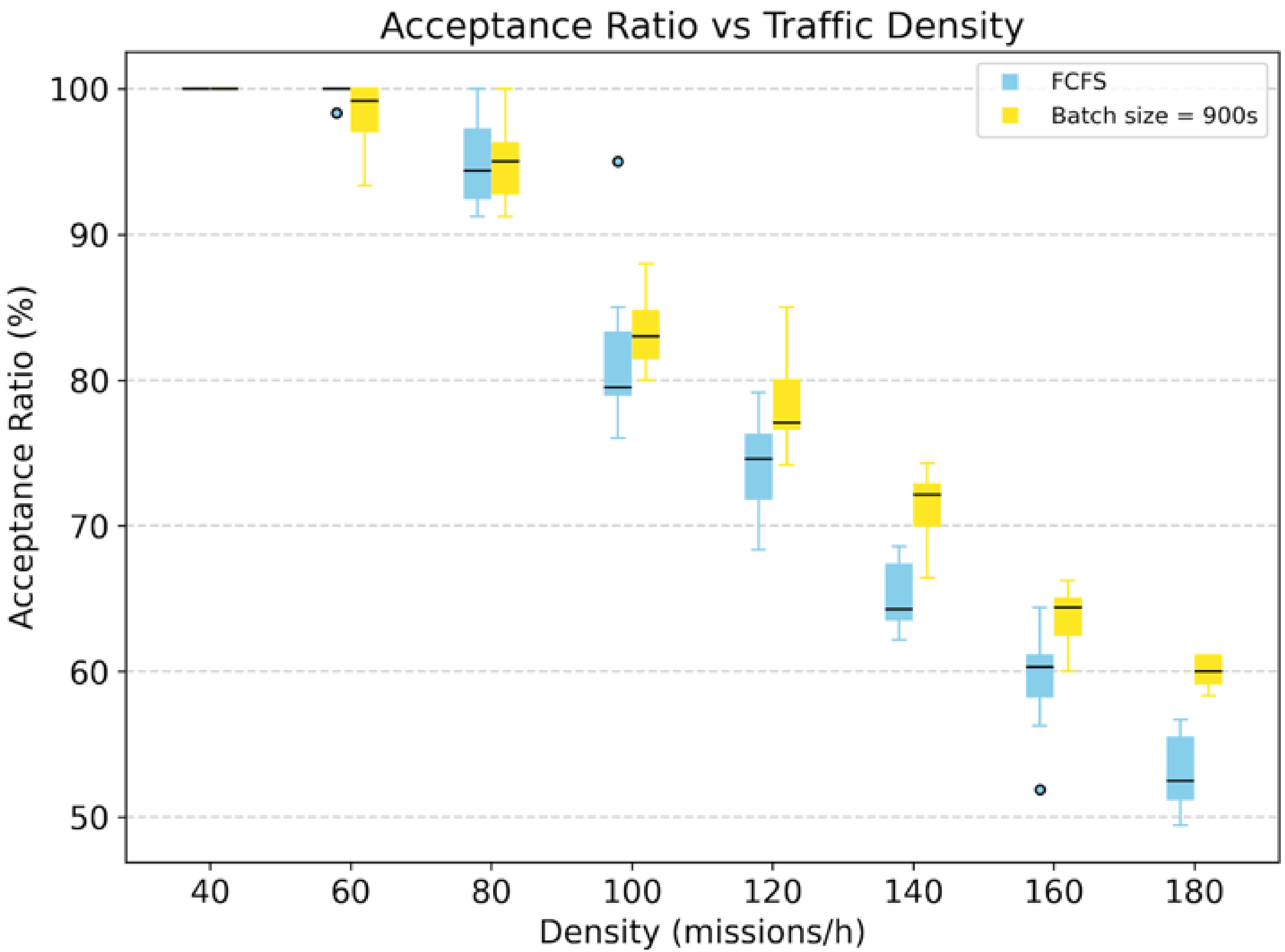
- Rather than relying solely on an FCFS policy, batch processing provides a coordinated approach to solve trajectory conflicts through collective adjustment of mission start times, leading to more balanced and efficient solutions

Batch





1. Single vs Batch synchronisation



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1. Single vs Batch synchronisation

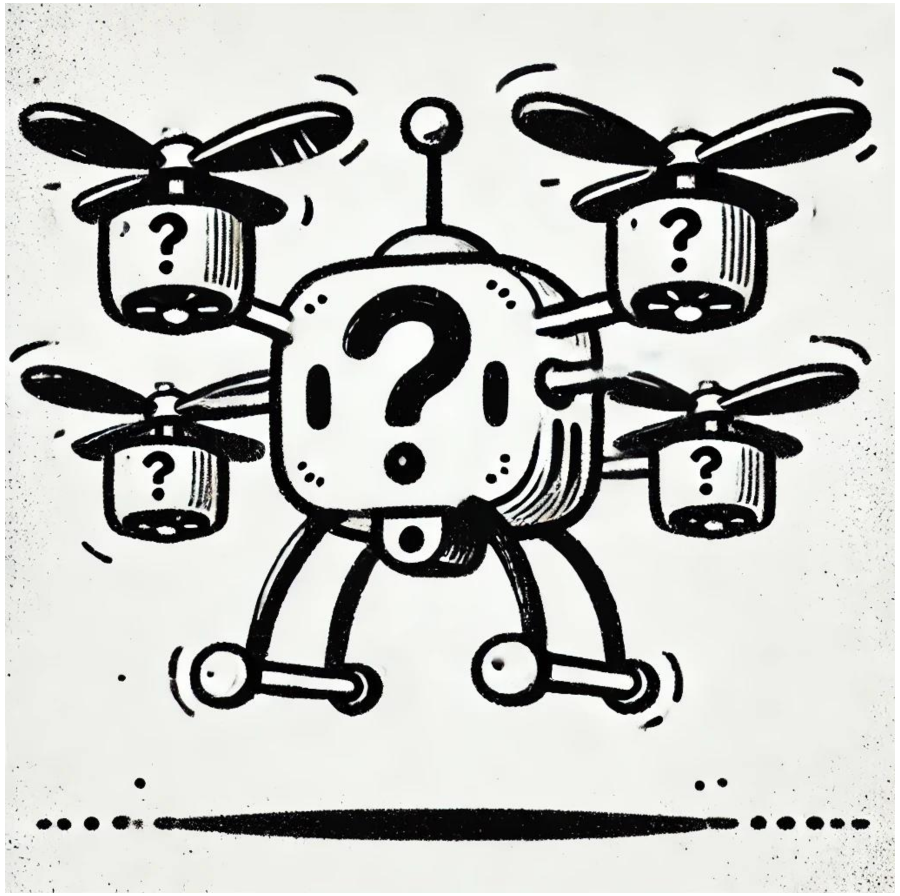
QUESTIONS

- **QFCFS.1.**Is FCFS sustainable scheduling policy for dense drone traffic in urban environments?
- **QFCFS.2**.Should FCFS be enforced as a default U-space system, or only under specific conditions?
- **QP.1.** How do we ensure safety and fairness when high-priority missions pre-empt scheduled or routine flights?
- **QP.2.** Is there a viable hybrid model between FCFS and priority-based access that balances fairness with operational needs?

1. Single vs Batch synchronisation

QUESTIONS

- **QB.1.**How is this going to work in a multi-USSP environment?
- **QB.2**. How can USSPs guarantee transparency in the batching process so that operators understand why their missions were delayed or adjusted?
- **QB.3.** What technical or scalability challenges do you foresee if thousands of flight plans are processed in batches?
- **QB.4**. The shorter the time window in which the final assigned take-off time is provided (prior to departure), the more U-plans can be accommodated—but at the cost of requiring greater flexibility. Is this acceptable?



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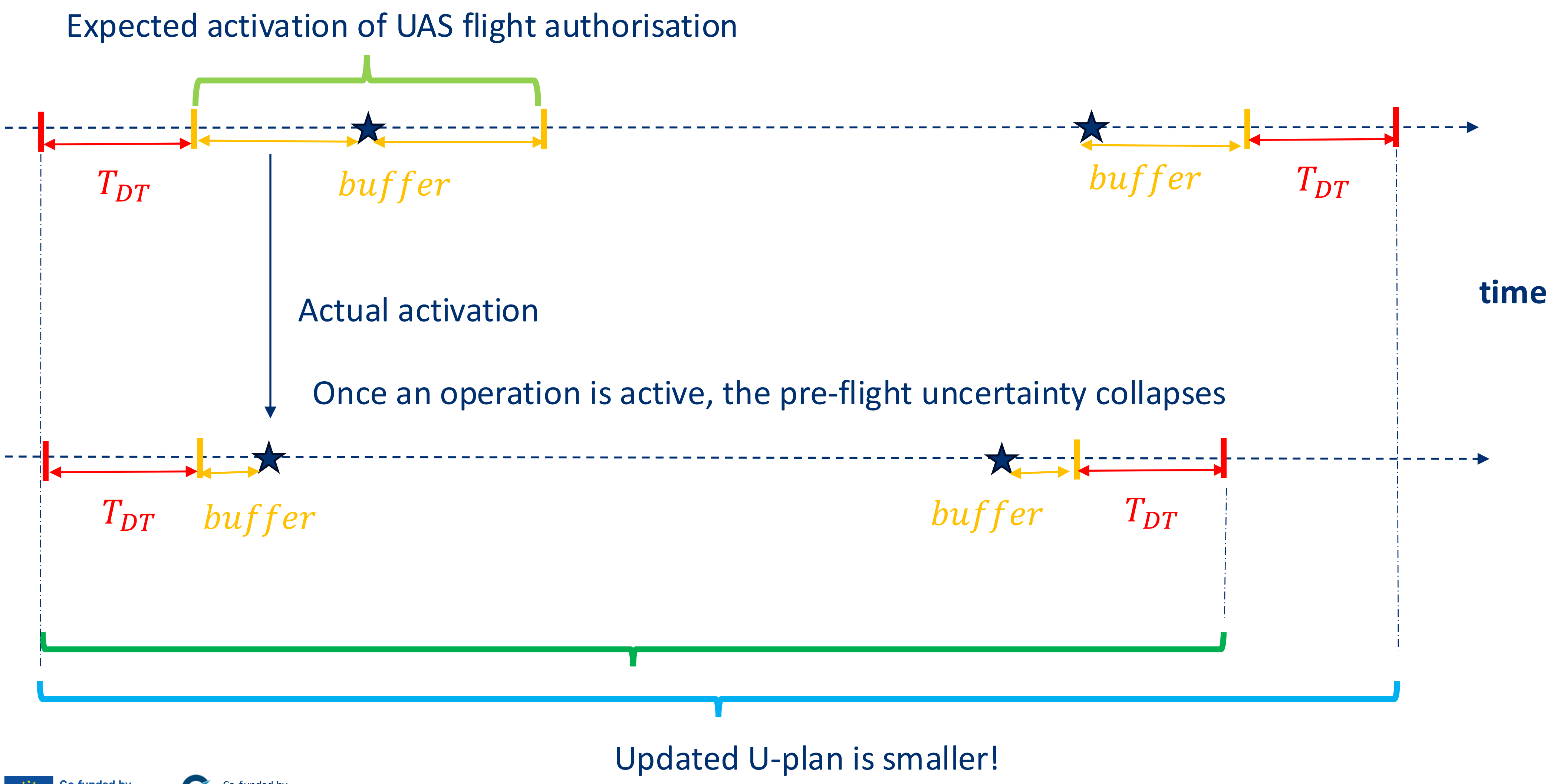
2. Dynamic uncertainty management

When a U-plan request is made, the temporal buffer includes pre-flight and in-flight uncertainties



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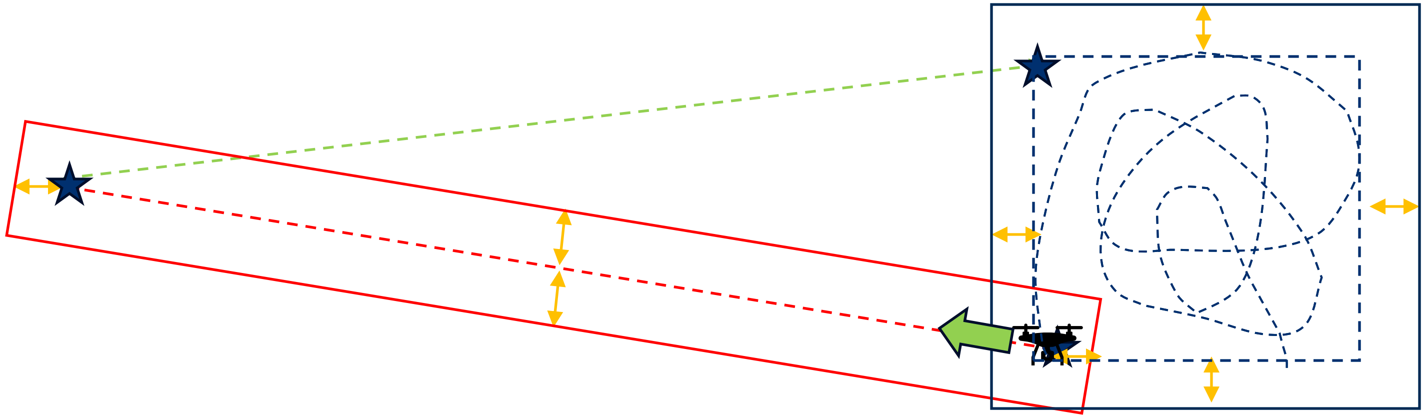
2. Dynamic uncertainty management

CORUS five

TACTICAL temporal dimension

Upon transition between 4D volumes, the vacated volume can be deactivated early

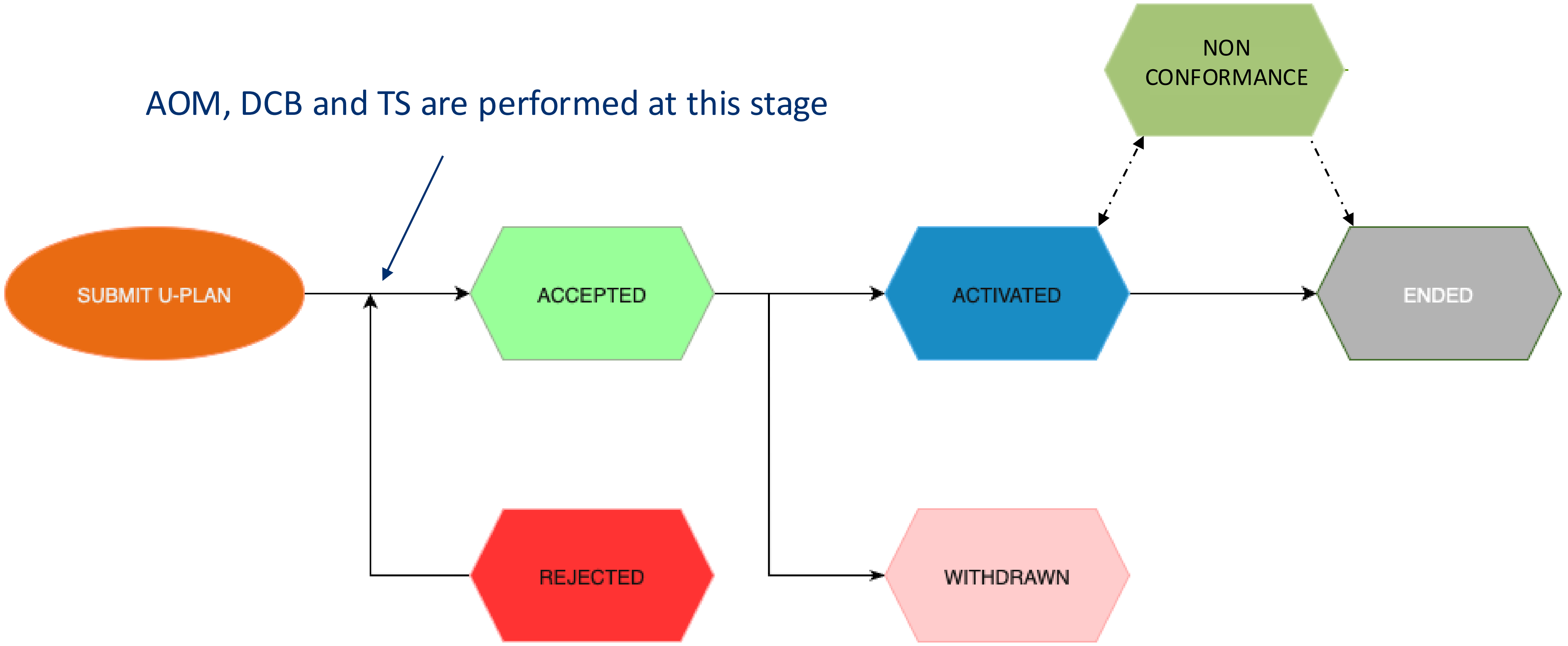


QUESTIONS

- **QU.1.** How can UAS operators and USSP coordinate on dynamic uncertainty management?
- **QU.2.** How large is pre-flight uncertainty compared to in-flight uncertainty?
- **QU.3.** Is in-flight uncertainty the same for all individual 4D volumes?
- **QU.4.** What is the actual gain in capacity or efficiency?

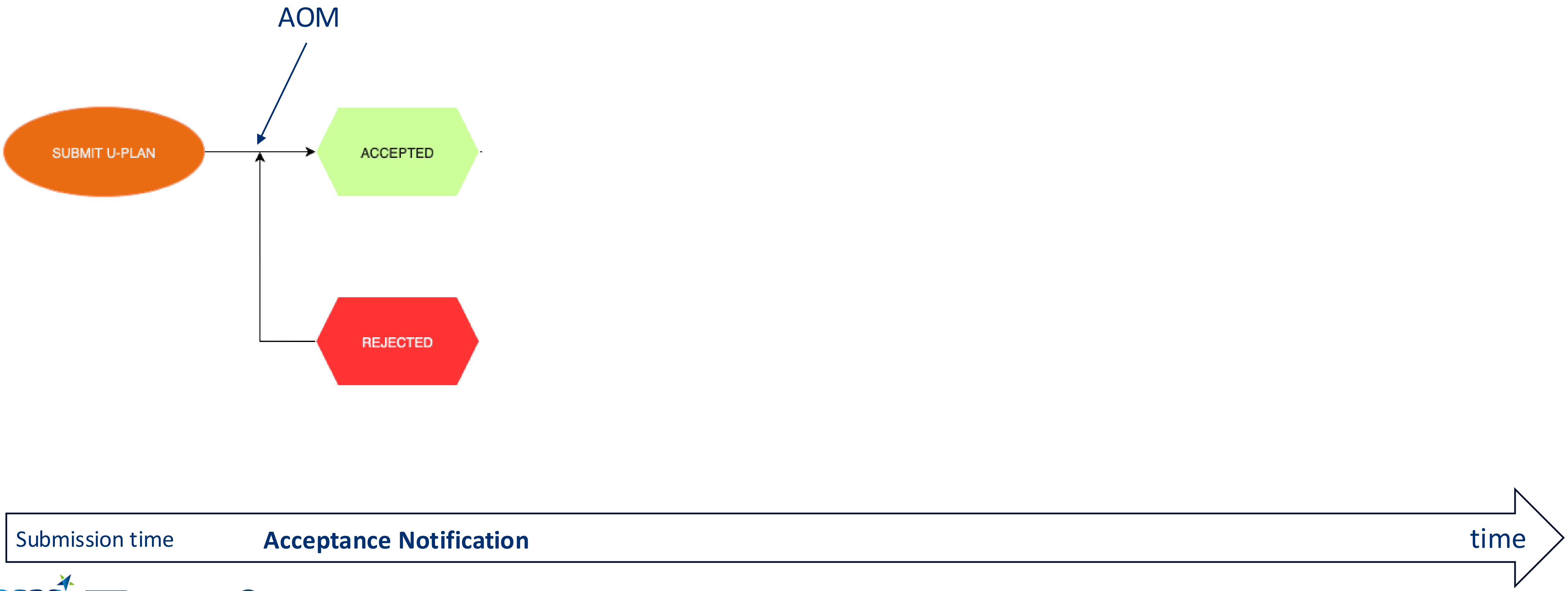
3. RTTA

- U-PLAN STATES SHORT TERM



3. RTTA

- U-PLAN STATES MEDIUM TERM



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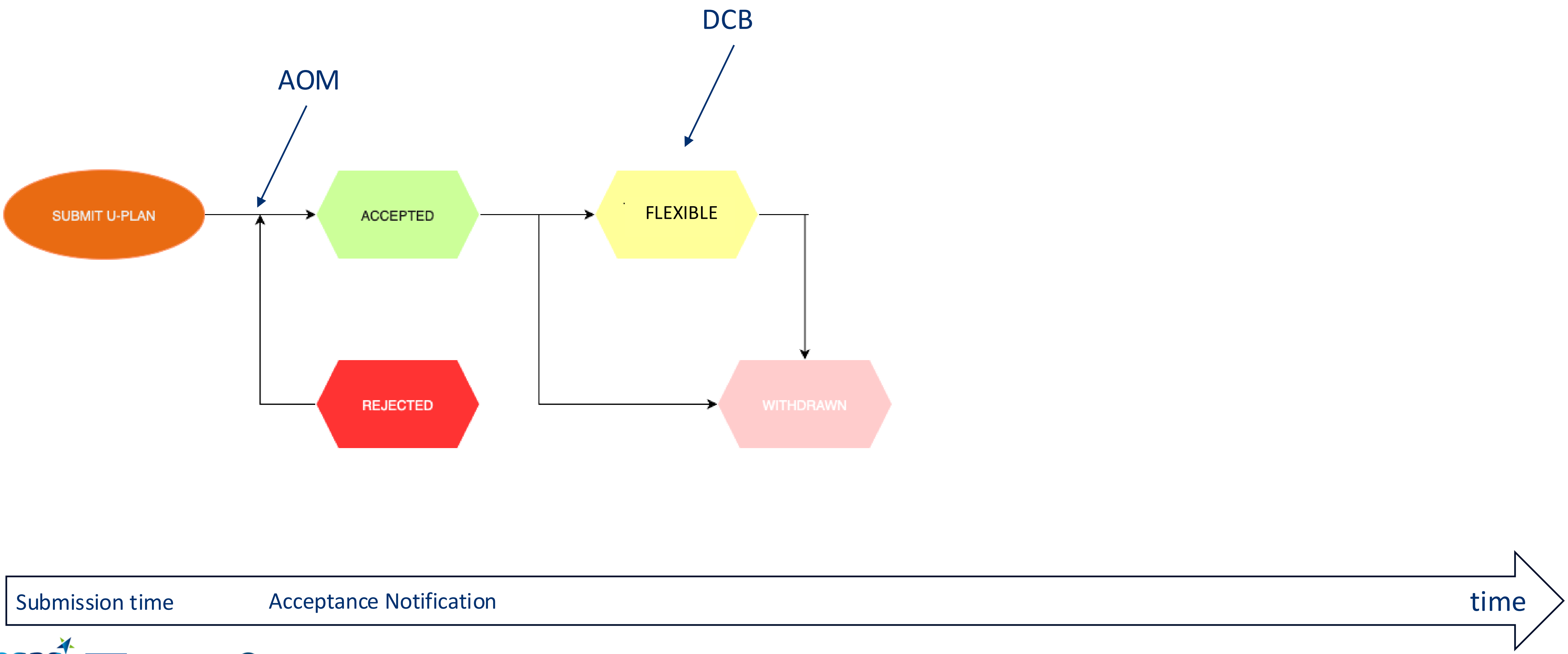
3. RTTA

- U-PLAN STATES MEDIUM TERM



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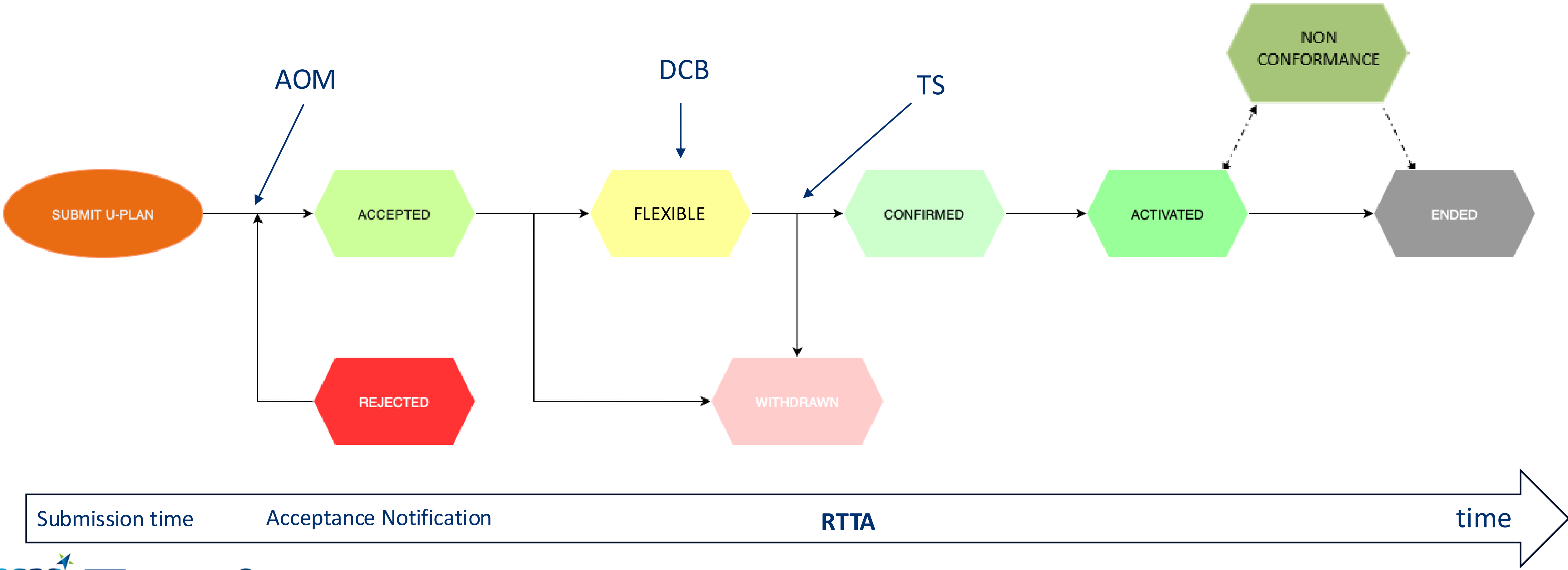
3. RTTA

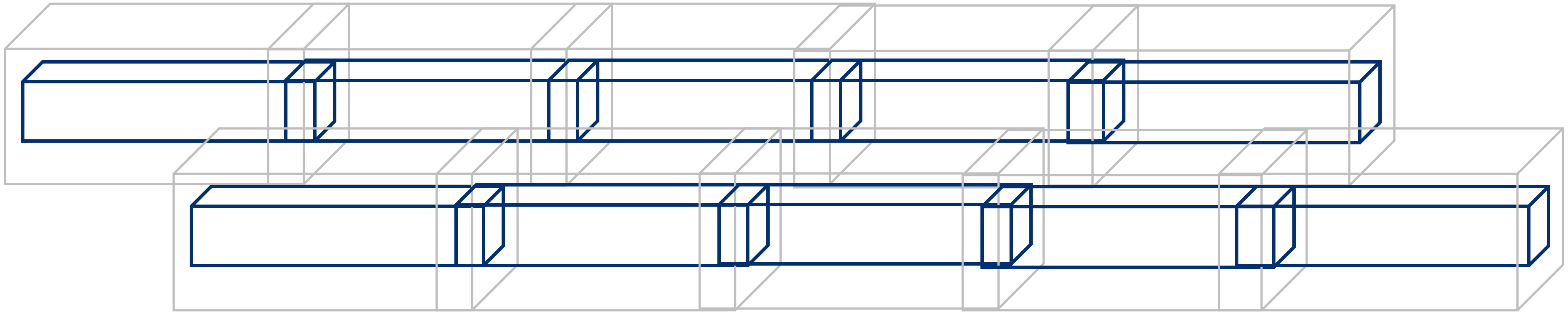
- U-PLAN STATES MEDIUM TERM
  - Delaying the TS until RTTA is reached provides the system with greater flexibility to absorb new demand at the same time as it get most of the uncertainty reduction.



4. Allow overlap of U-plans

CORUS five

Medium-term



In the MTH, strategic mitigations can be relaxed, with stronger tactical means to mitigate a larger residual risk

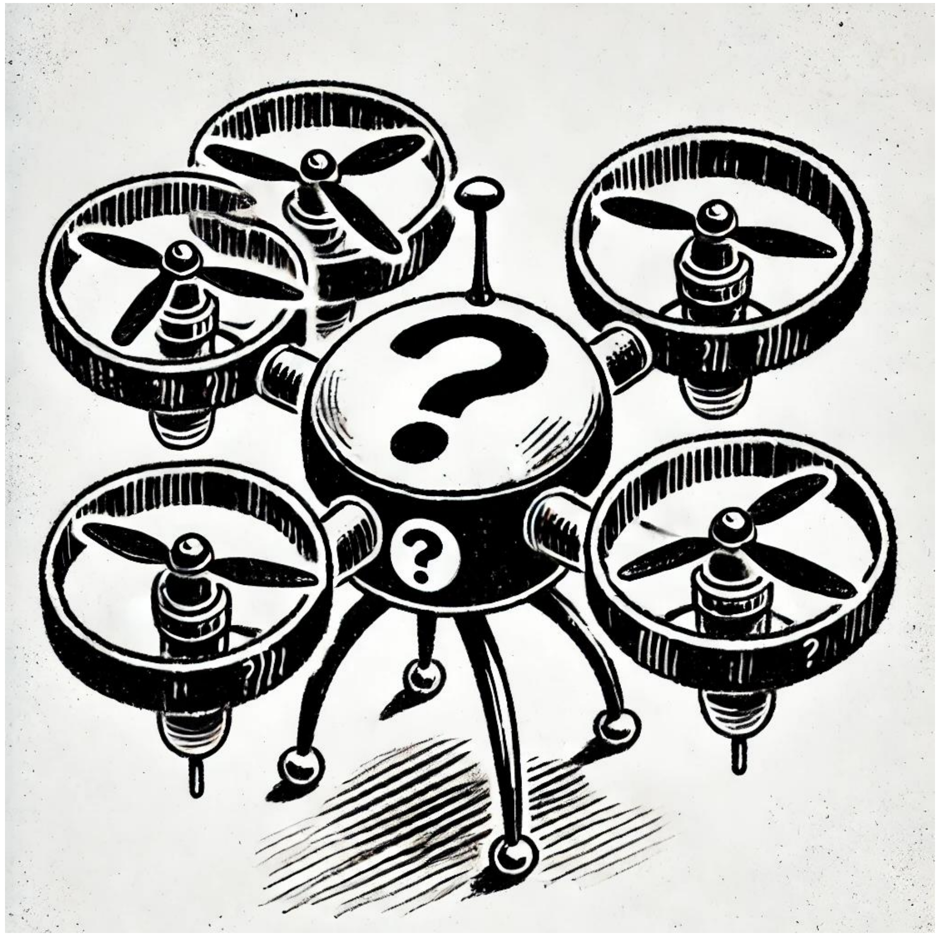
Overlap of deviation thresholds may be allowed in the medium term (in line with F3548)

Eventually, even the overlap of 4D trajectories may be accepted when the residual risk of conflict remains below a given threshold

4. Allow overlap of U-plans

QUESTIONS

- **QU.1.** How to determine the residual risk of tactical conflict among strategically deconflicted plans?
- **QU.2.** What is the expected gain in capacity and efficiency?



5. TS in aerodrome operations

Aerodromes with high unmanned traffic density within U-space airspace may need dedicated TS functions to arrange inbound/outbound traffic.

QUESTIONS

QU.1. Do we need a dedicated services to arrange local inbound/outbound traffic (i.e. by a local service provider, akin to TWR? Or can USSPs collaboratively perform these functions?

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MEDIUM TERM HORIZON

By Tackling these specific points, we answering the next set of questions raised in the first CORUS- 5Workshop

ID	Question
RQ2.6	How to ensure scalability of the operational concept with increasing numbers and complexity of UAS operations
RQ2.23	Which U-space services require the use of flight plans and which additional requirements may emerge from them?
RQ4.7	How are the IAS performance characteristics referenced and used in the decision making?
RQ4.13	To what extent does RTTA improve the fairness of operational intent authorization over the first-come, first-served (as described in F3548-21)?
RQ4.15	Under what conditions in U-space can DCB, with tactical deconfliction, be used to complement strategic deconfliction in accommodating operational uncertainty efficiently, while ensuring safety?
RQ4.18	What does conflict management look like within U-space airspace? How are the three layers of management provisioned and which technology falls under which category? How does this relate to a potential set/subset of new flight rules for U-space airspace?
RQ4.19	What would be the methods to combine DCB, strategic deconfliction and tactical deconfliction, while ensuring safety to appropriate levels?

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VTT

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THANK YOU
FOR YOUR ATTENTION