



PARTAKE

Results, achievements and identified challenges

Dr. Miquel A. Piera and Dr. Juan Jose Ramos
UAB, Aslogic

Thematic challenge 2 - Data-driven trajectory prediction
6 of November 2018



Founding Members



PARTAKE “Cooperative departures for a competitive ATM network service”. SJU ER with Grant Agreement No. 699307

Rationale and Objectives



- Title: **cooPerative depArtuRes for a compeTitive ATM network sErvice**
- Duration: 24 Months
- Consortium: **UAB**, Aslogic, Cranfield U. and ENAC
- Start date: 1st March 2016
- Call identifier: H2020-SESAR-2015-1
- Grant Agreement reference: 699307

Outline

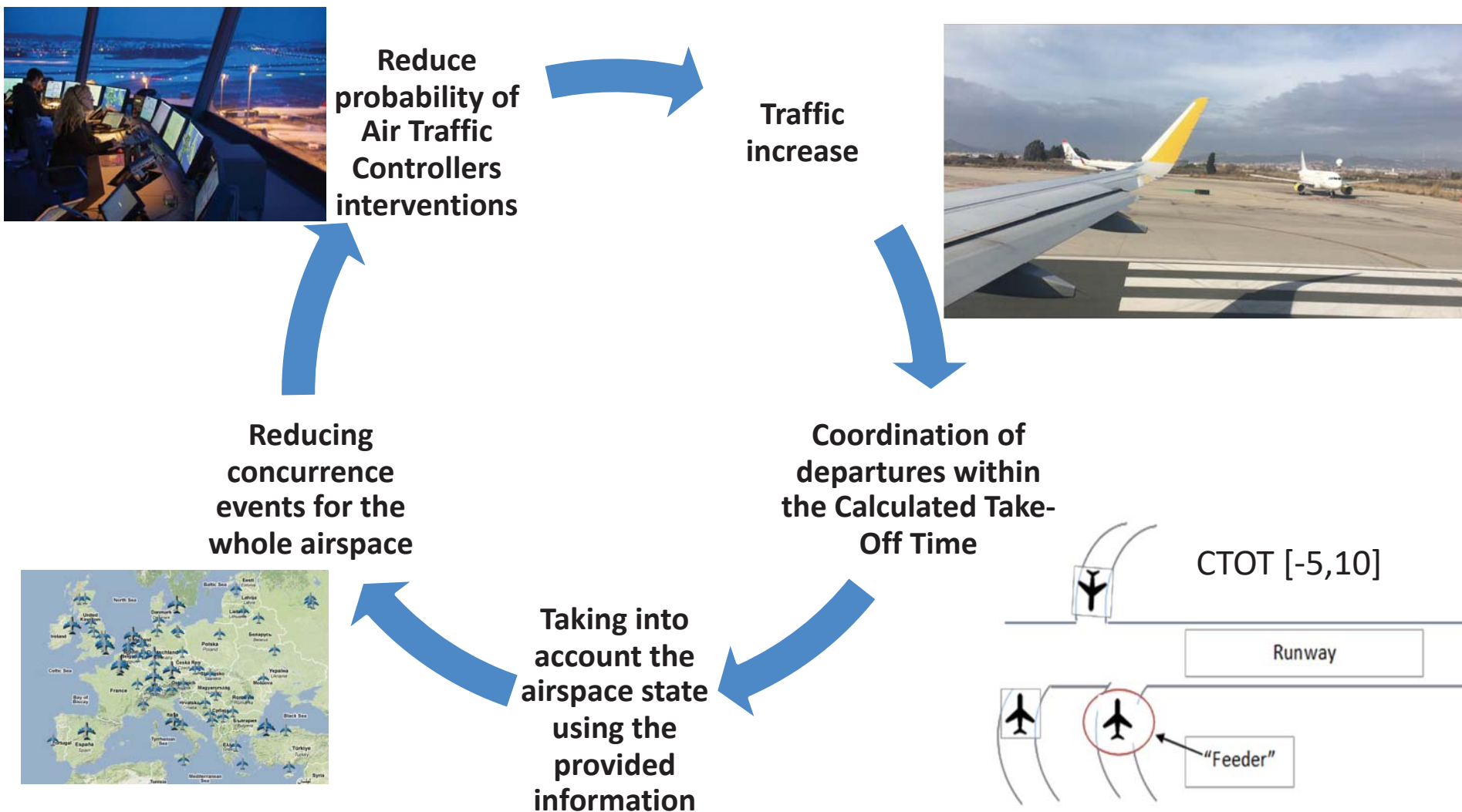
Introduction

PARTAKE Detection & Analysis Tools

PARTAKE Mitigation Tools

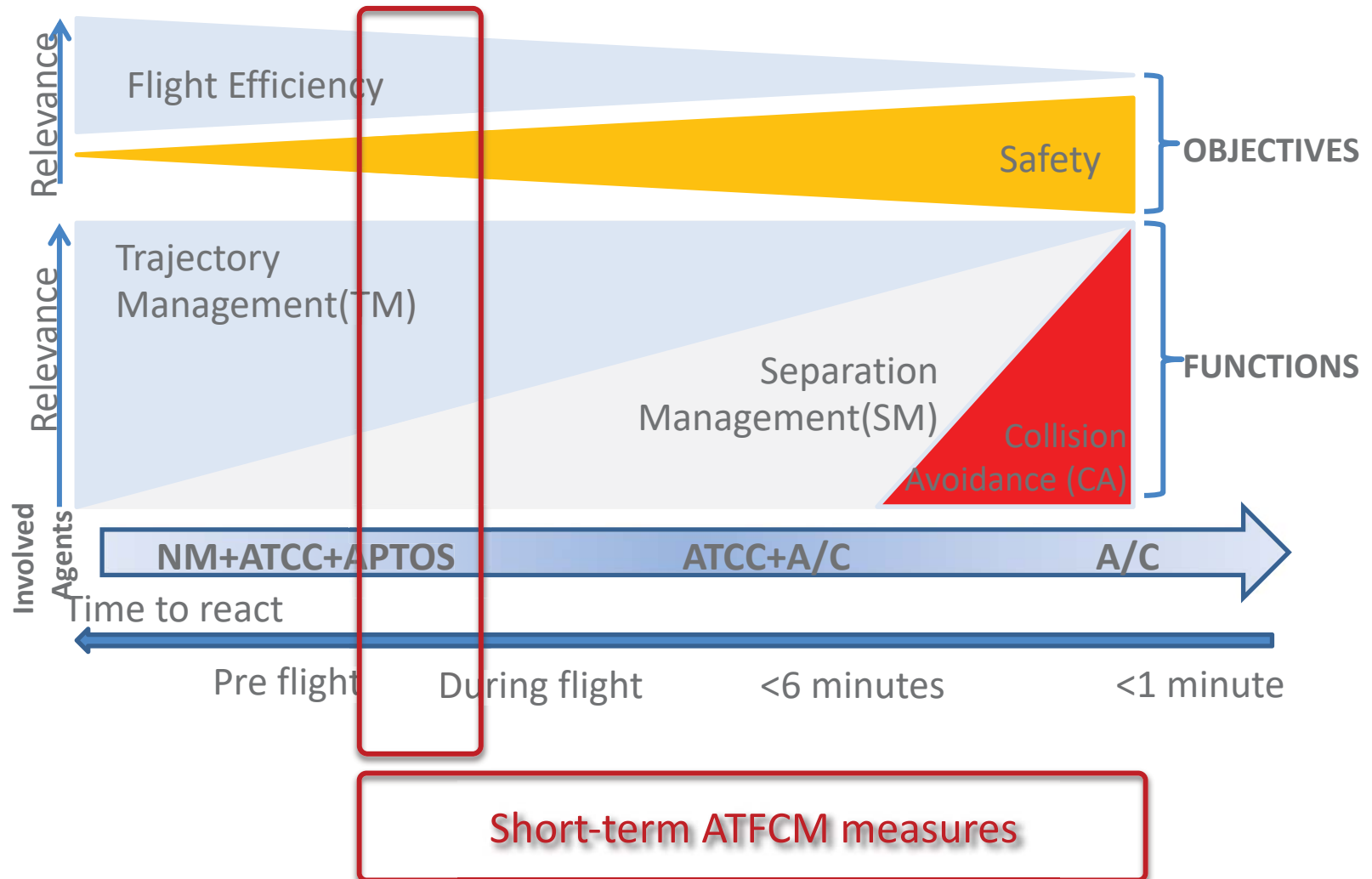
Current developments and future challenges

ATM Context

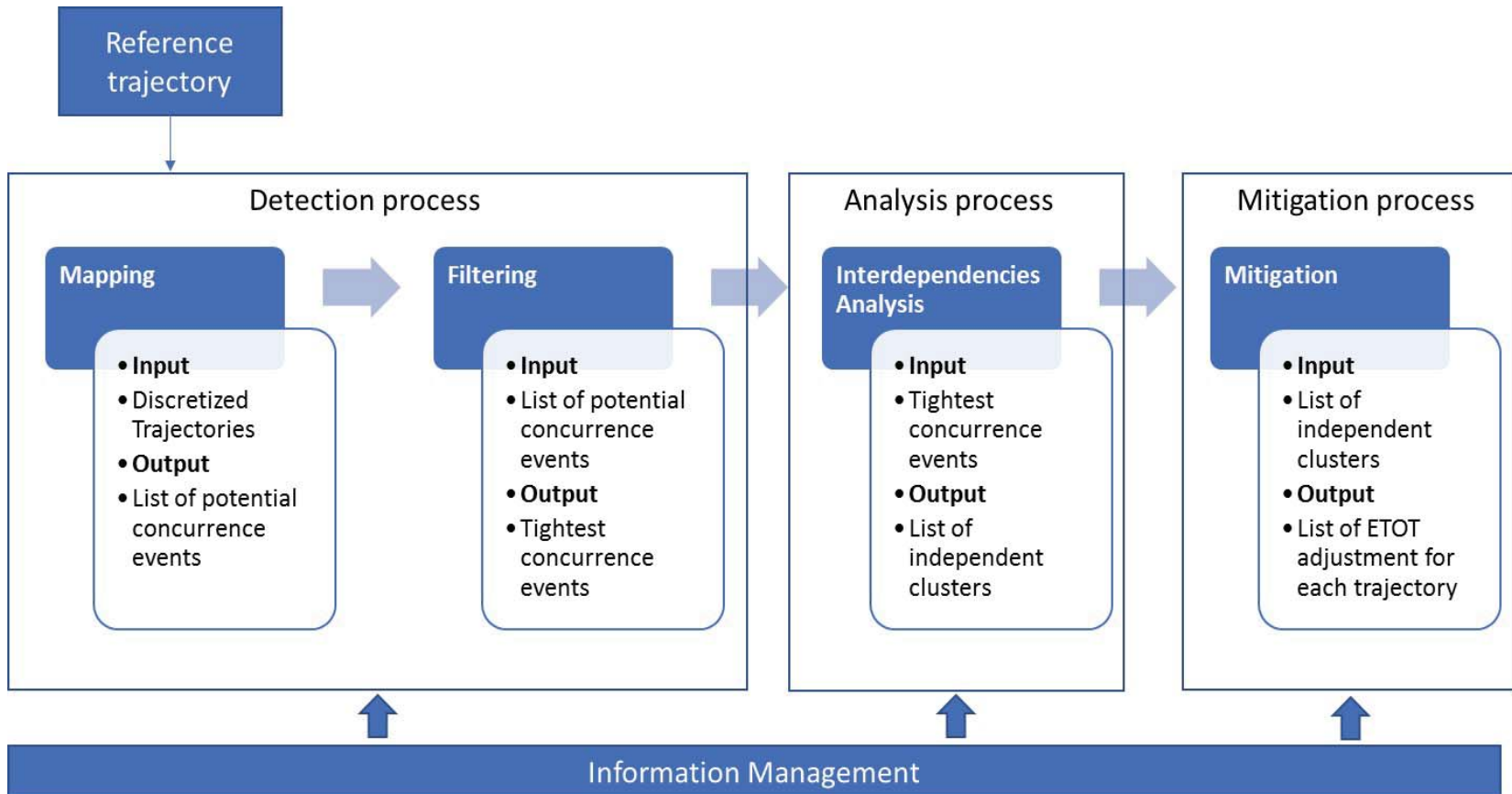


ATM Context

PARTAKE CONTEXT



PARTAKE Methodology



Outline

Introduction

PARTAKE Detection & Analysis Tools

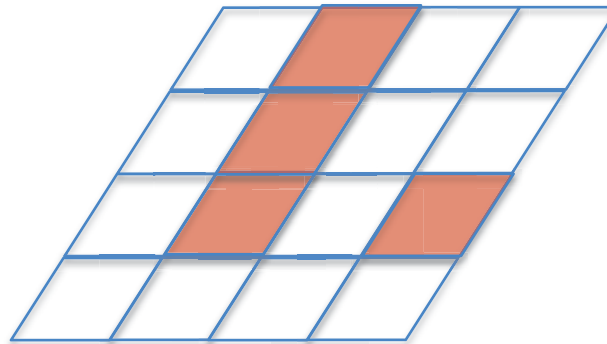
- Digitalization
- Interdependency detection
- Interdependency Analysis

PARTAKE Mitigation Tools

Current developments and future challenges

Detection Main concepts

Spatio-Temporal interdependencies



Potential Concurrence Events

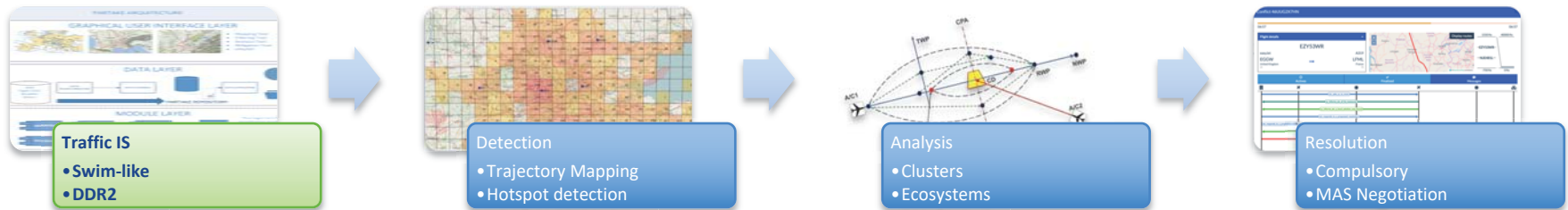


$C_{TOT}(a_i)$

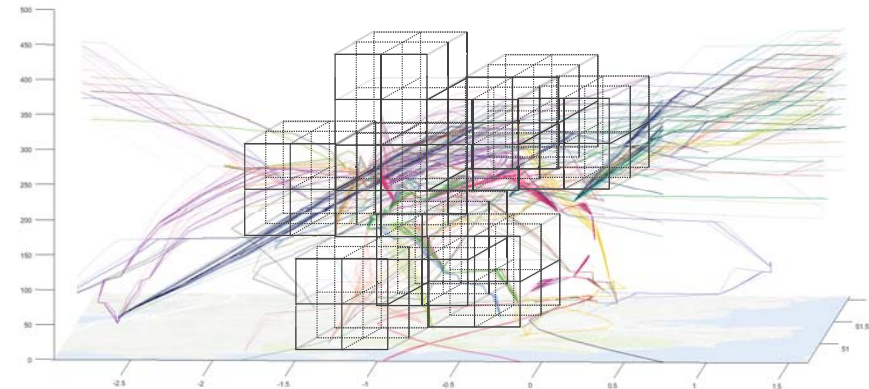
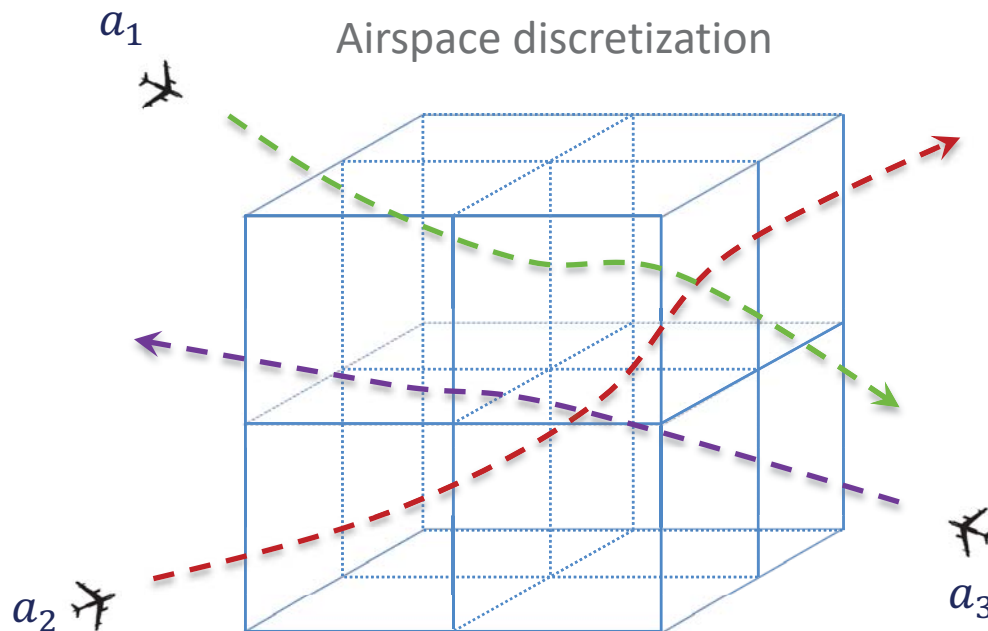
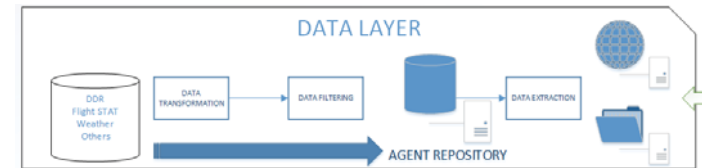


$C_{TOT}(a_j)$

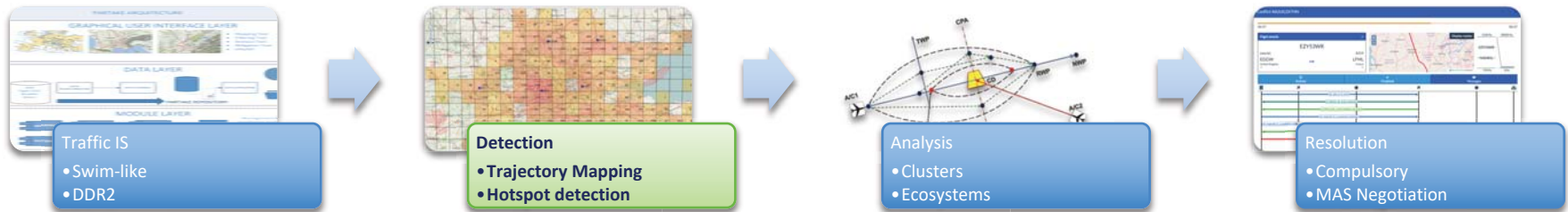
Digitalization: Trajectory mapping



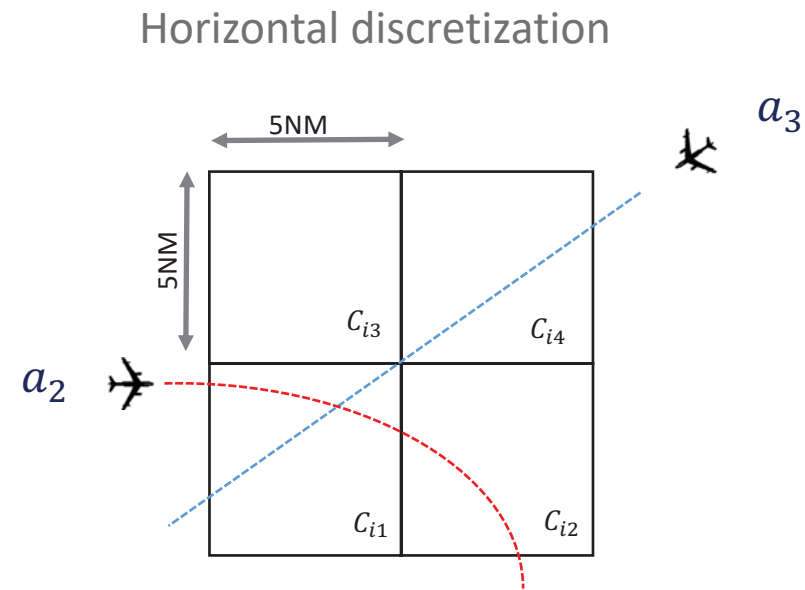
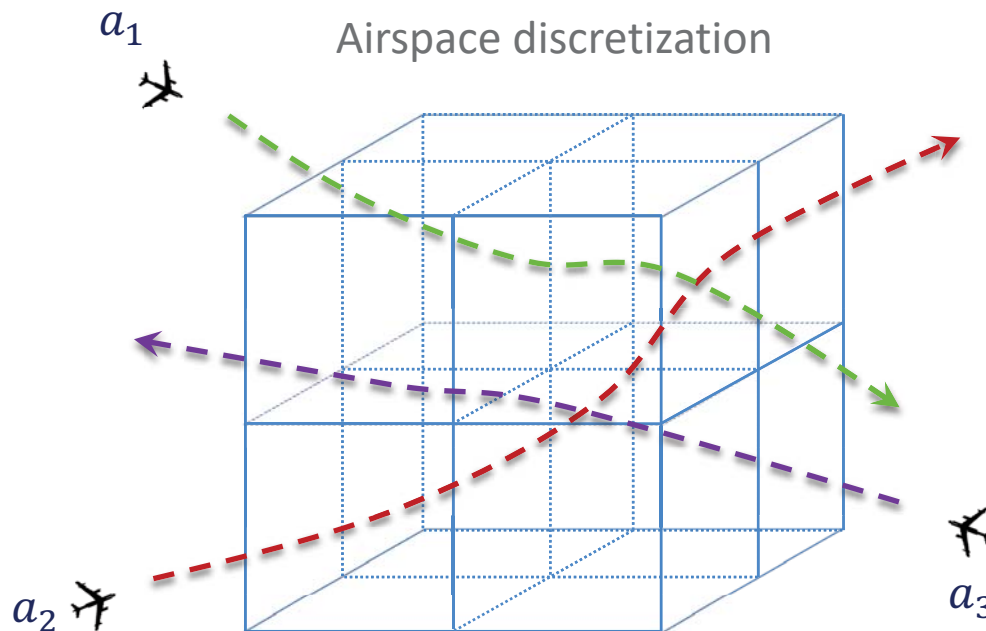
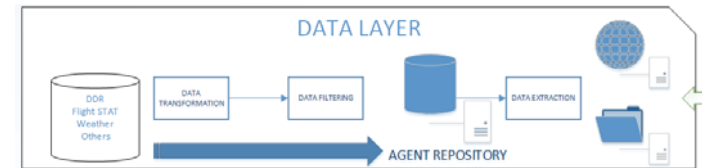
Traffic scenarios are created from RBT's (e.g. DDR2 data)



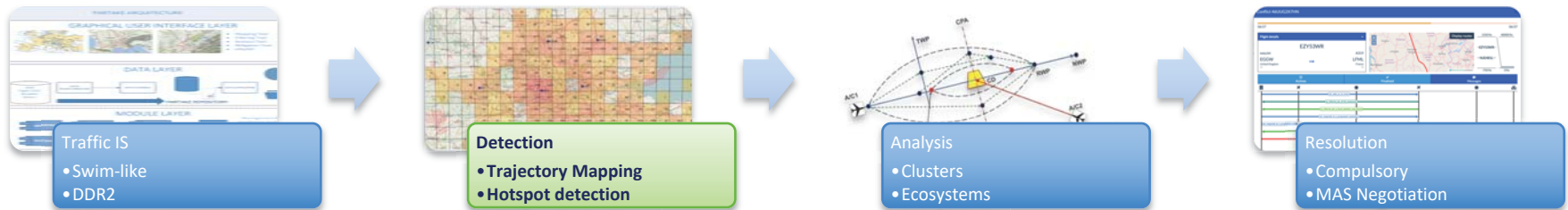
Digitalization: Trajectory mapping



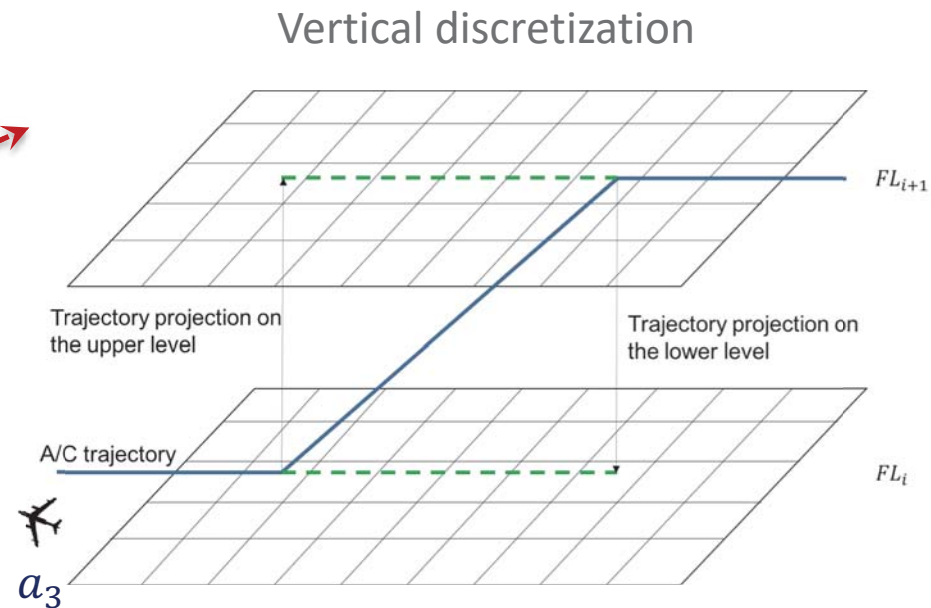
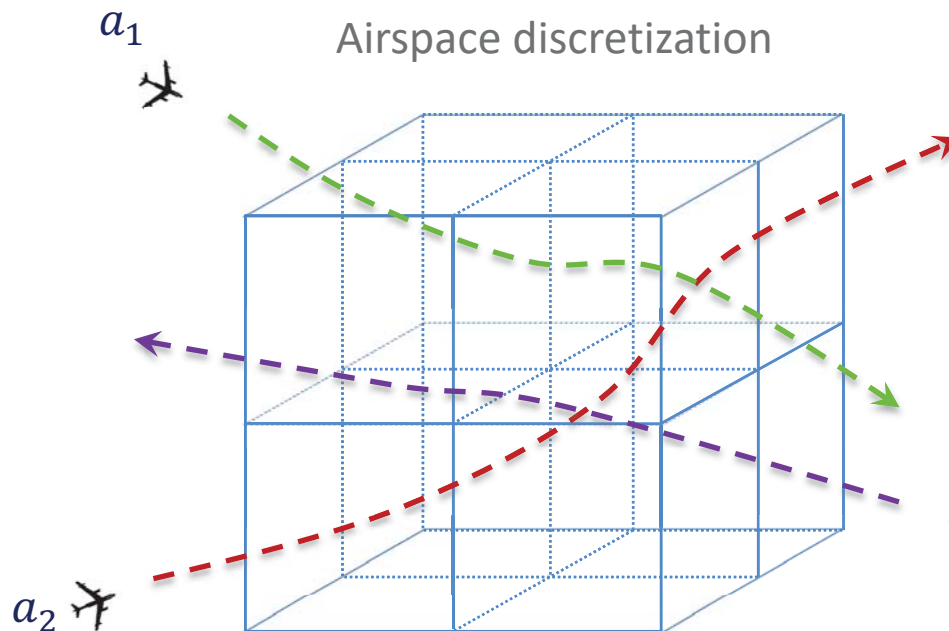
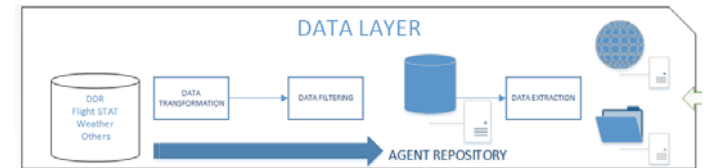
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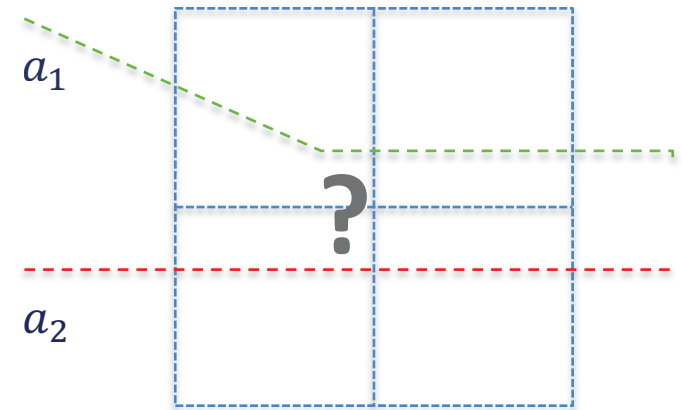
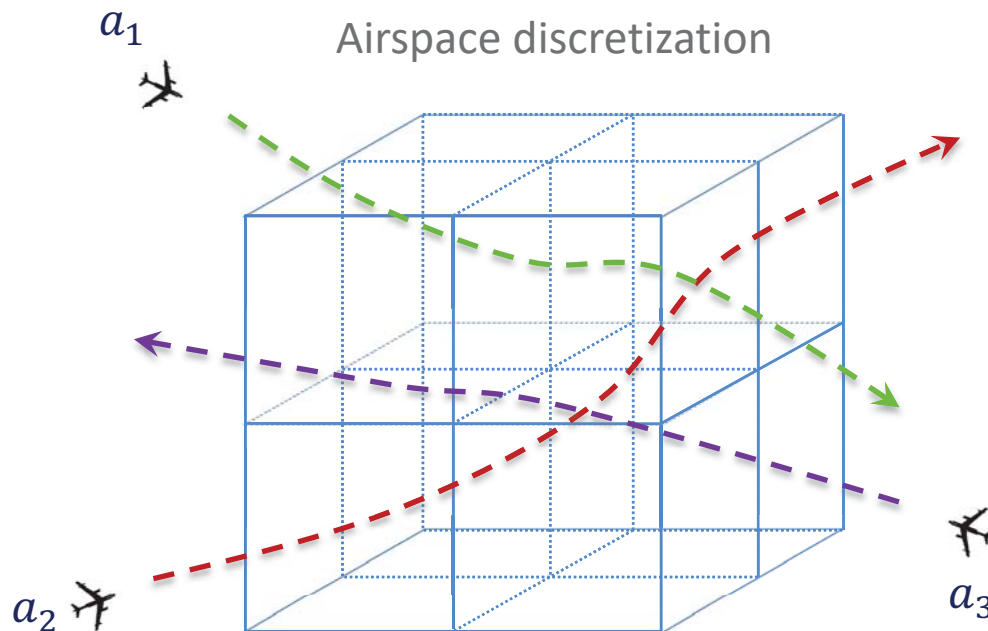
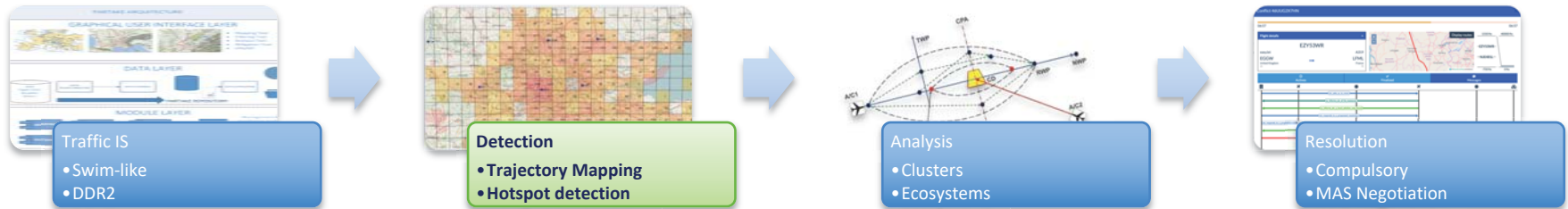
Digitalization: Trajectory mapping



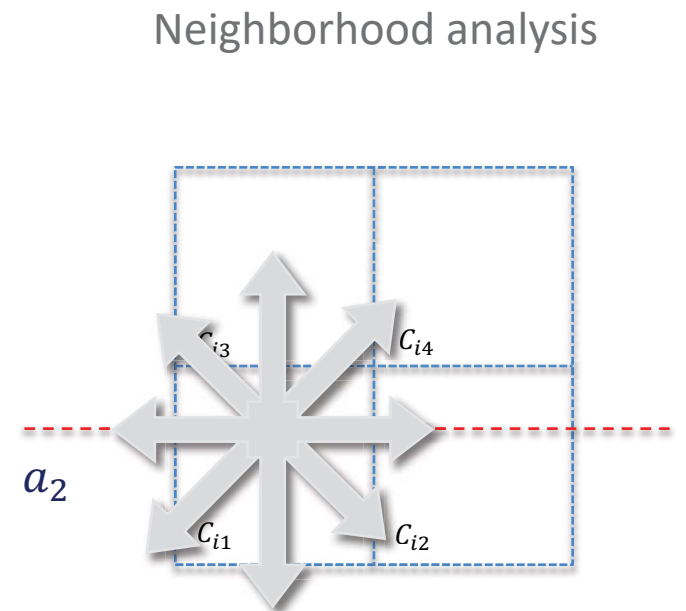
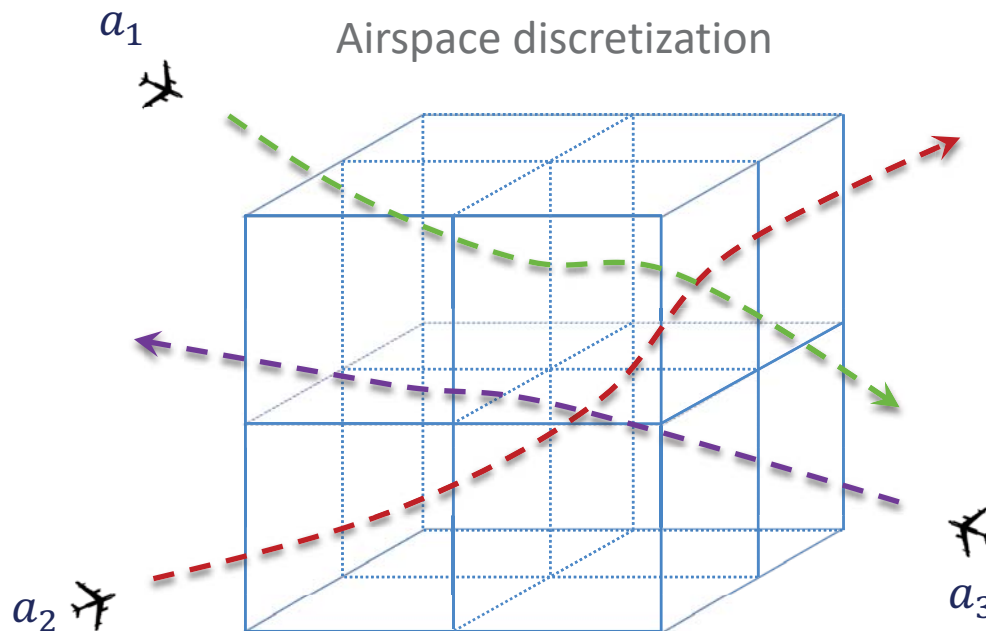
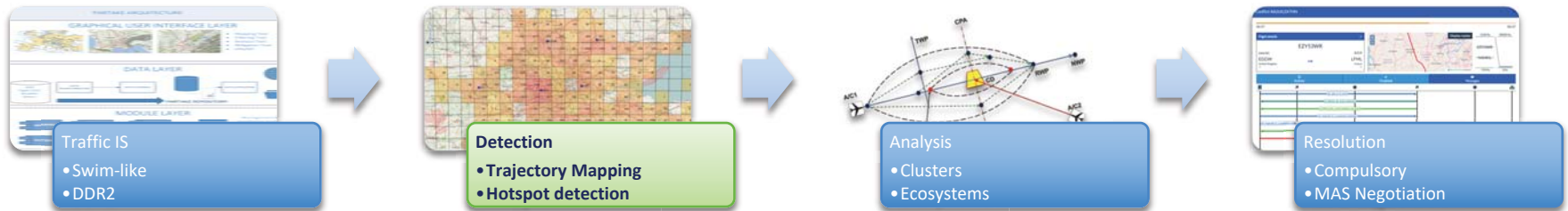
Traffic scenarios are created from RBT's (e.g. DDR2 data)



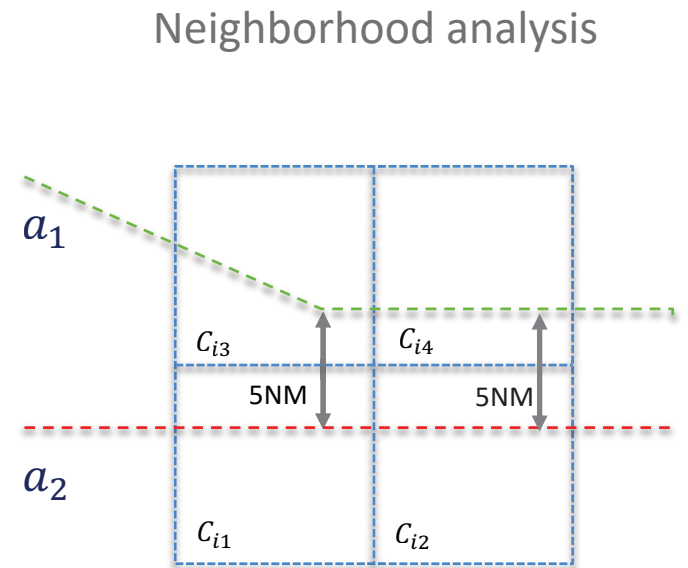
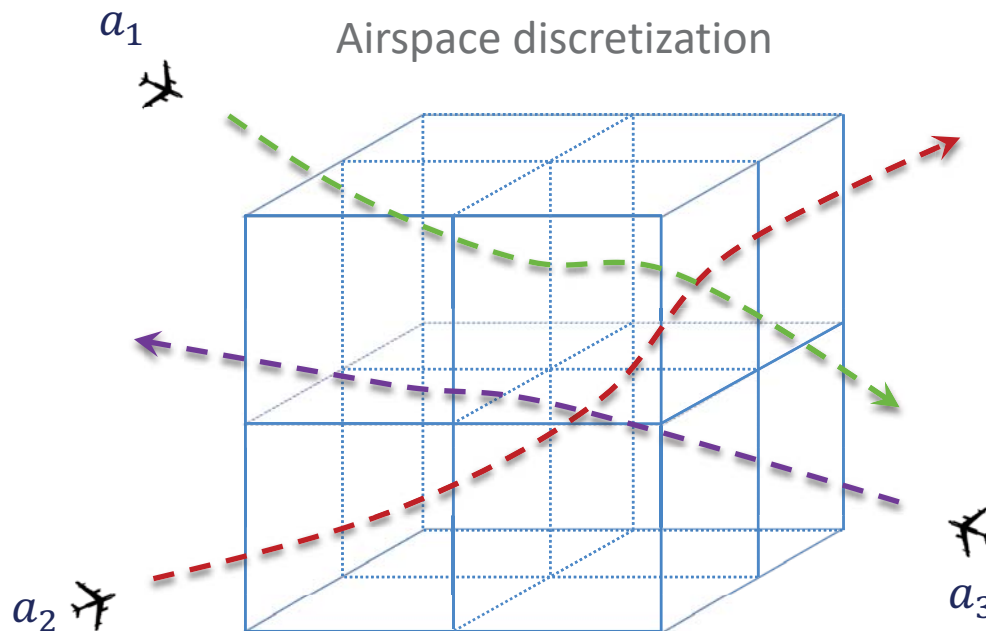
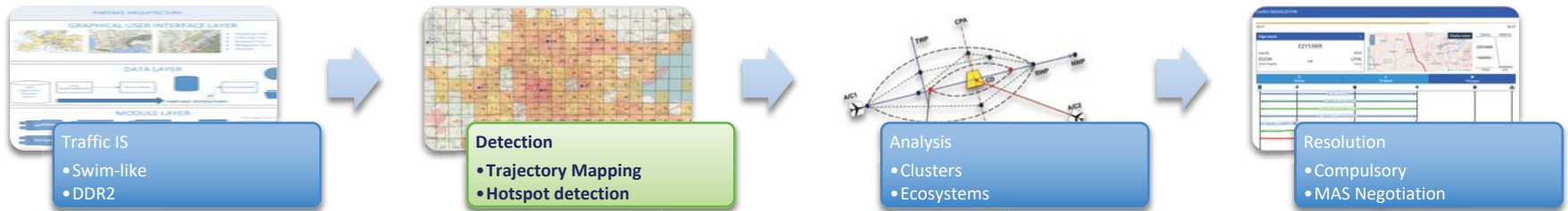
Interdependency detection



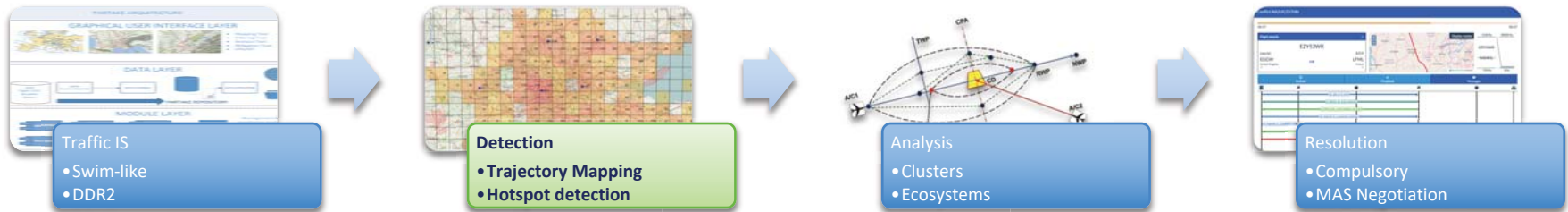
Interdependency detection



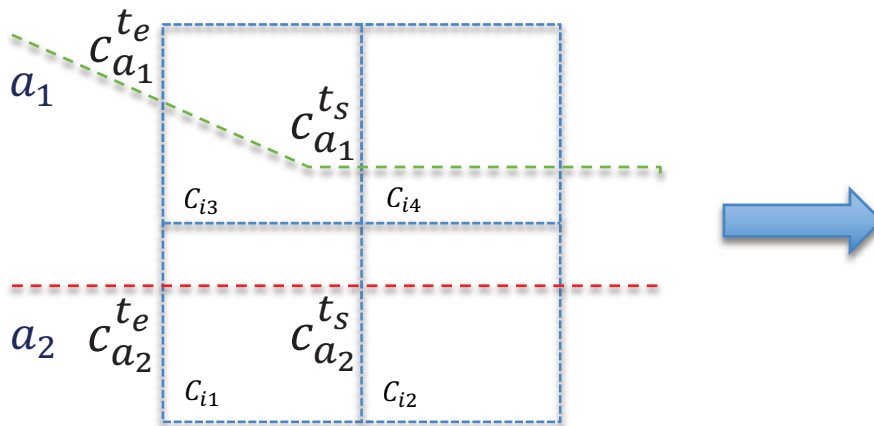
Interdependency detection



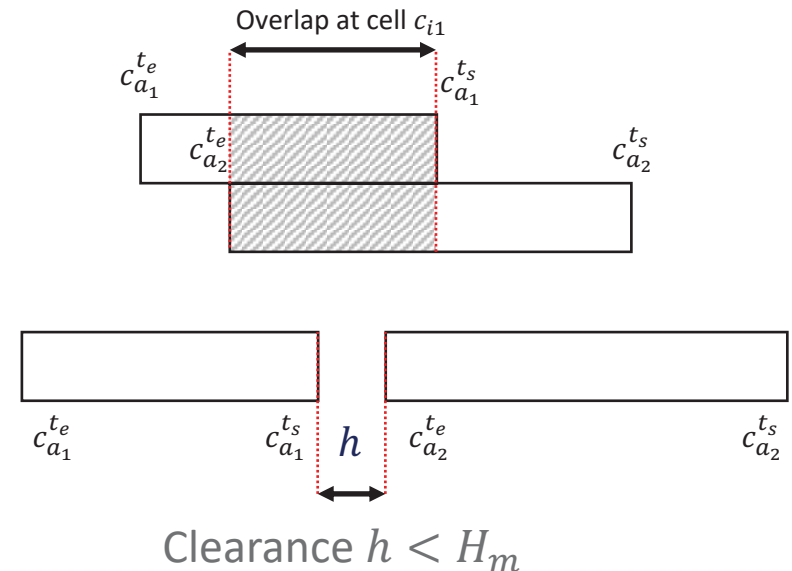
Interdependency detection



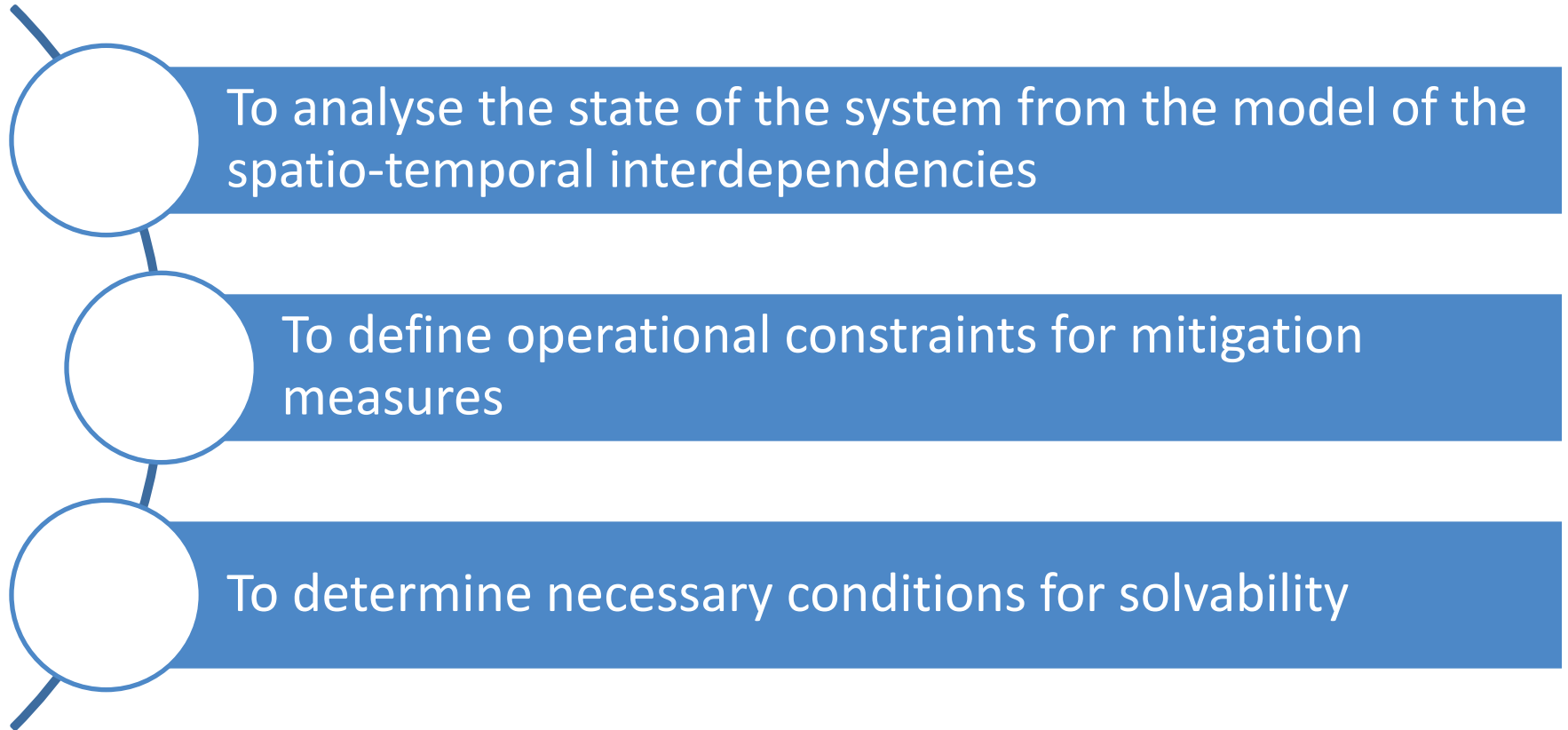
Digitalization: time discretization



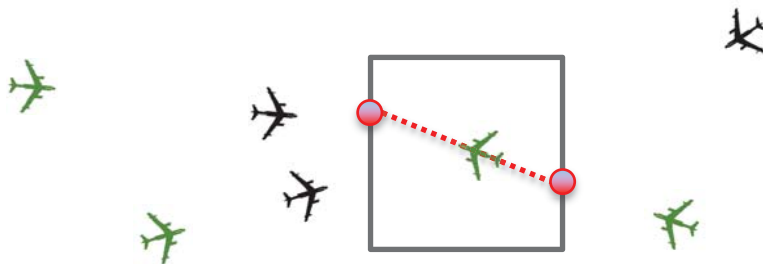
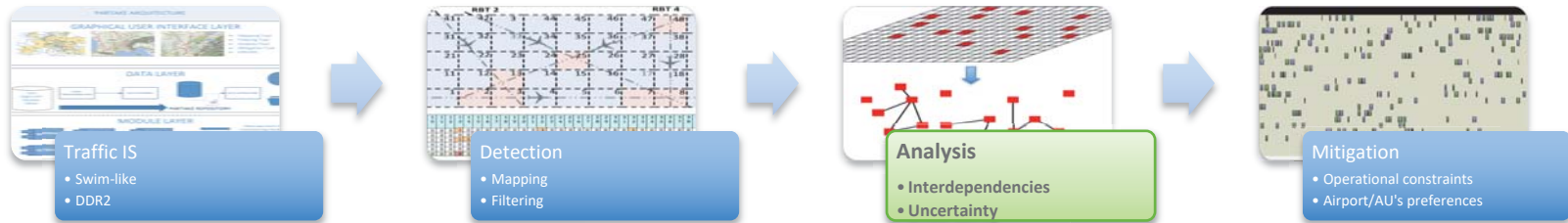
Potential Concurrence Event
Loss of separation minima



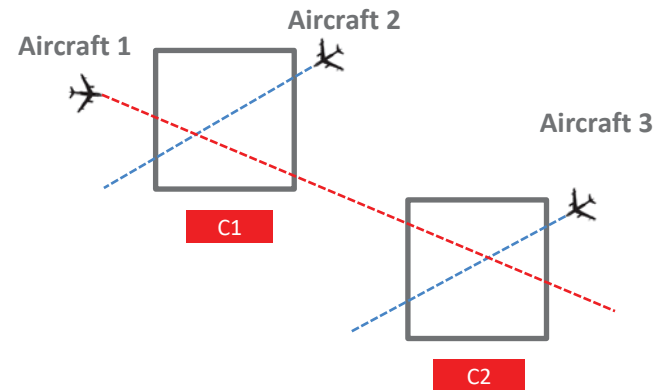
Interdependency Analysis. Challenges



Analysis: trajectory interdependencies



Concurrent interdependencies



Coupling interdependencies

Analysis: concurrent interdependencies

Parameters

$$C_A = \{ \langle c, a \rangle \mid \forall c \in C, \forall a \in A \}$$

$c_a^{te} \equiv \text{entry time}$

$c_a^{ts} \equiv \text{exit time}$

Decision Variables

$$\delta_a \in [\delta_{min}, \delta_{max}], \forall a \in A$$

$$\forall c_a \in C_a$$

$$P_{ca} = [s_{ca}, e_{ca}), \quad \forall c_a \in C_a$$

$$sz(P_{ca}) = e_{ca} - s_{ca} (= c_a^{ts} - c_a^{te})$$

$$P_{ca} \in [c_a^{te} + \delta_{min}, c_a^{ts} + \delta_{max}]$$

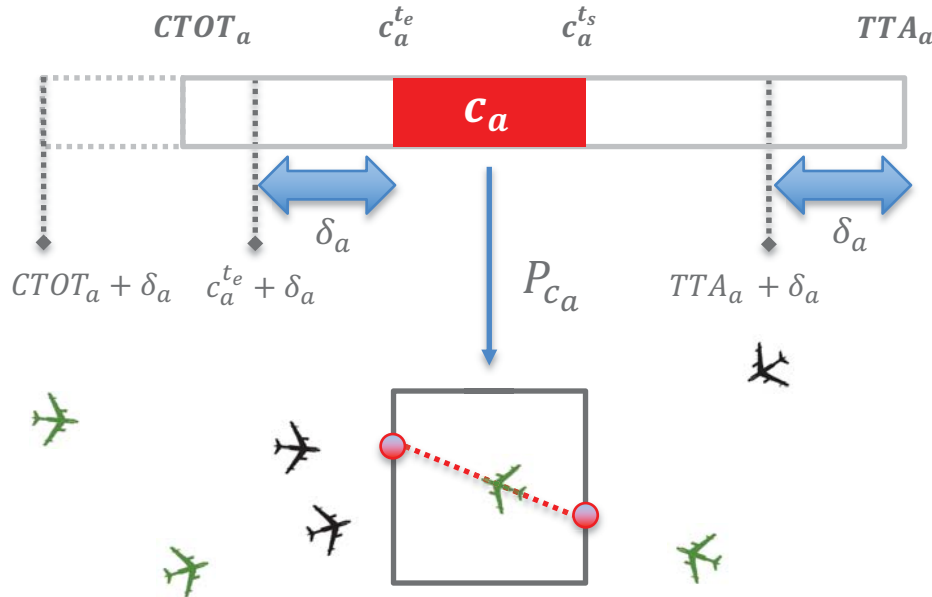
$$\forall c \in C$$

$$F_c = \{P_{ca} \mid c_a \in C_A\}$$

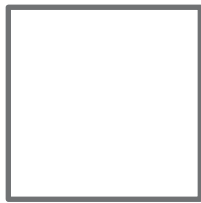
$$\forall P_{c_i}, P_{c_j} \in F_c$$

$$NO(F_c) \Leftrightarrow \pi(P_{c_i}) < \pi(P_{c_j})$$

$$\Rightarrow e(P_{c_i}) \leq s(P_{c_j})$$



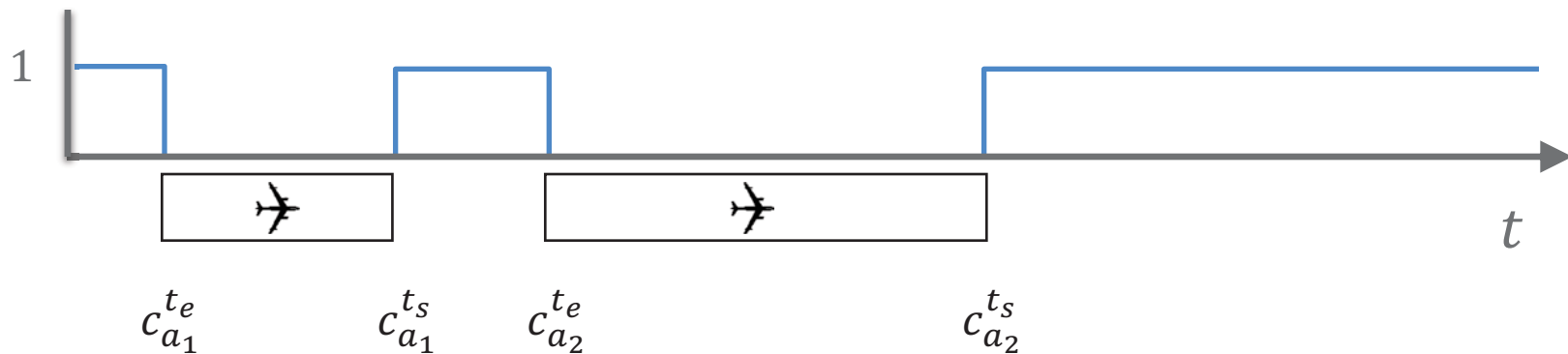
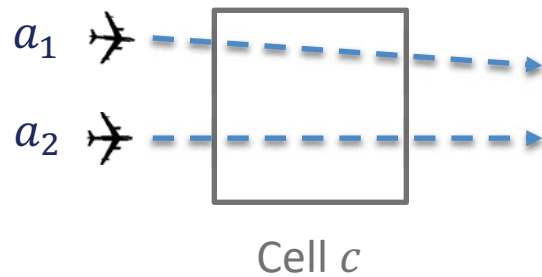
Analysis: concurrent interdependencies



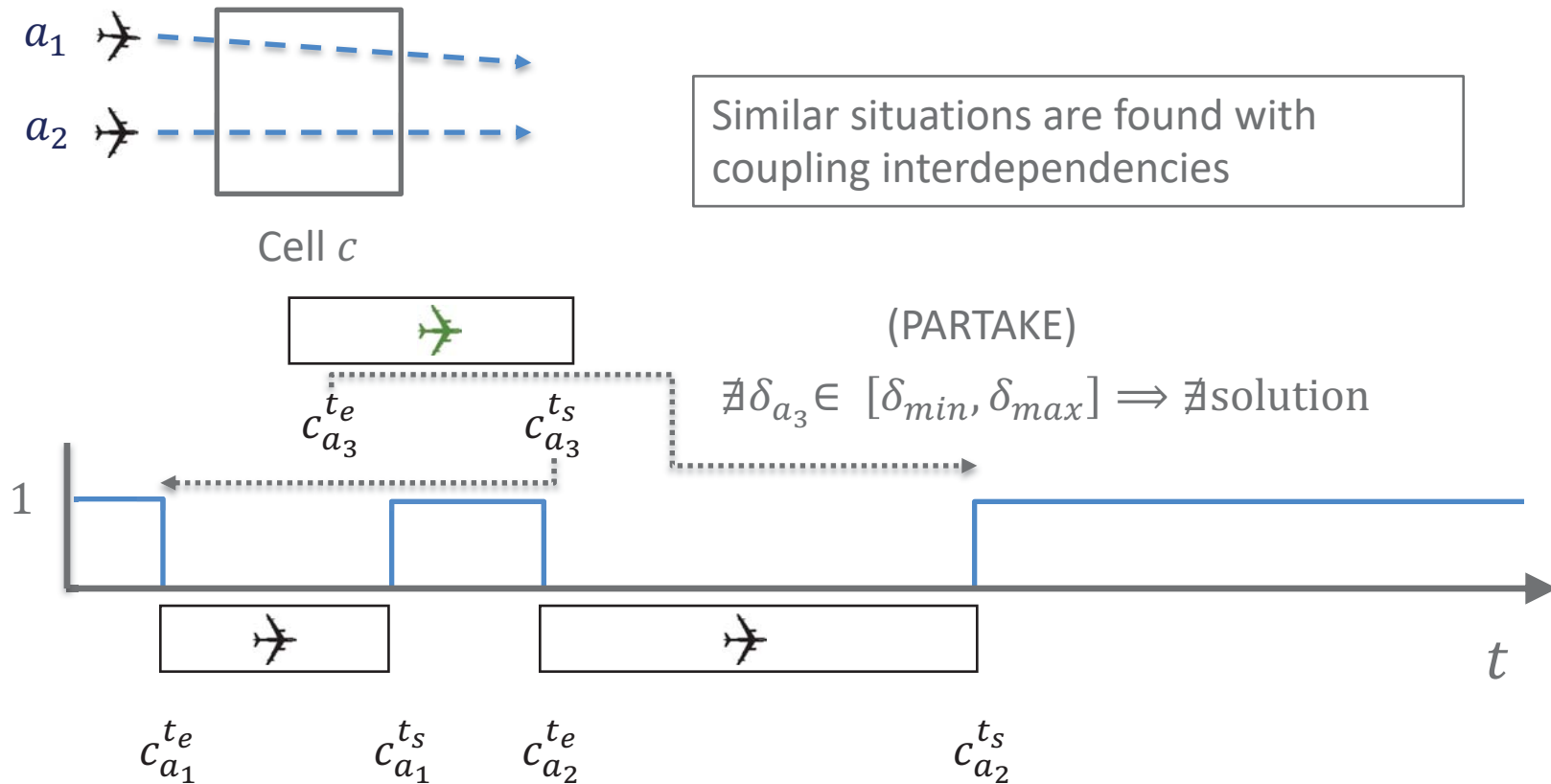
Cell c



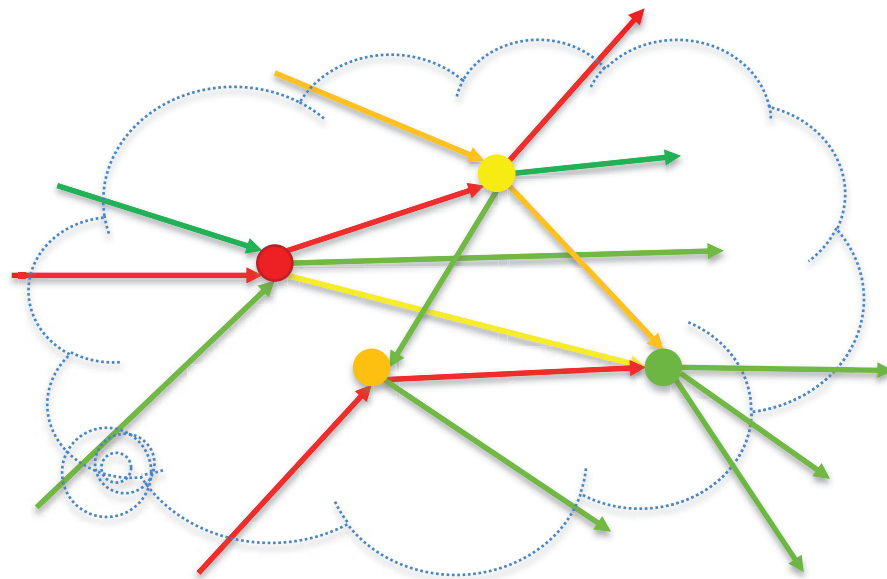
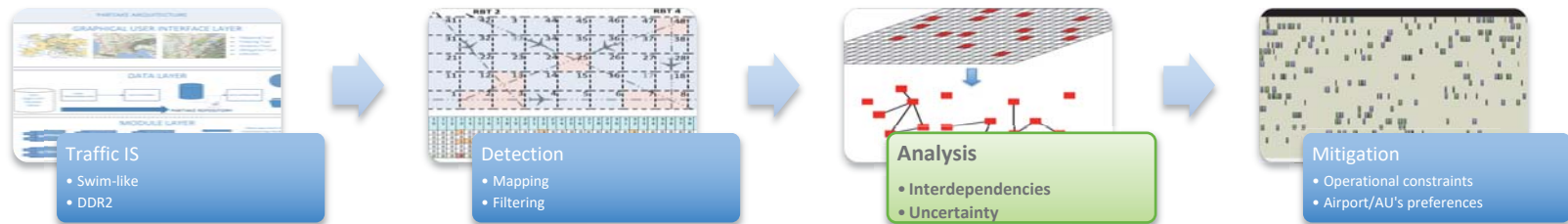
Analysis: concurrent interdependencies



Analysis: concurrent interdependencies



Mitigation solvability



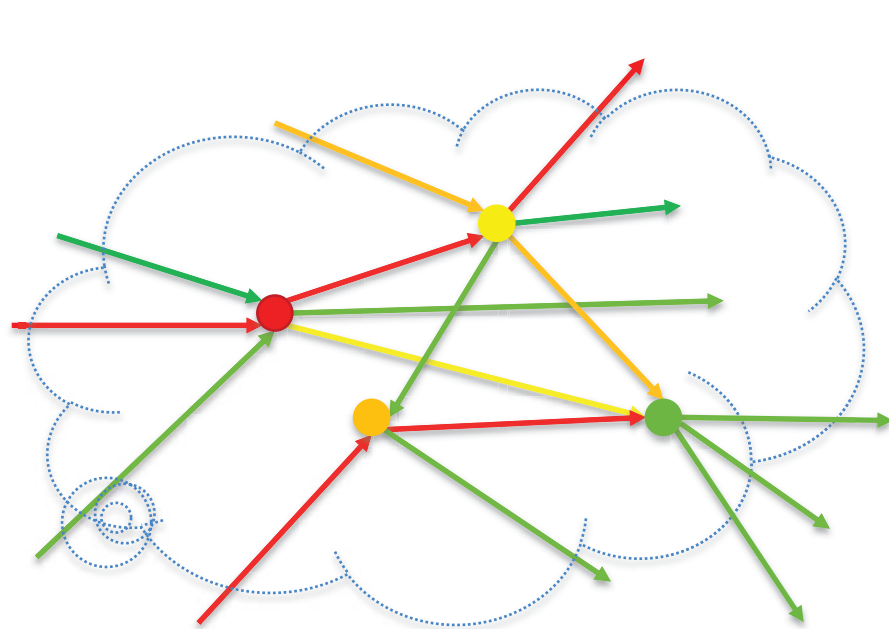
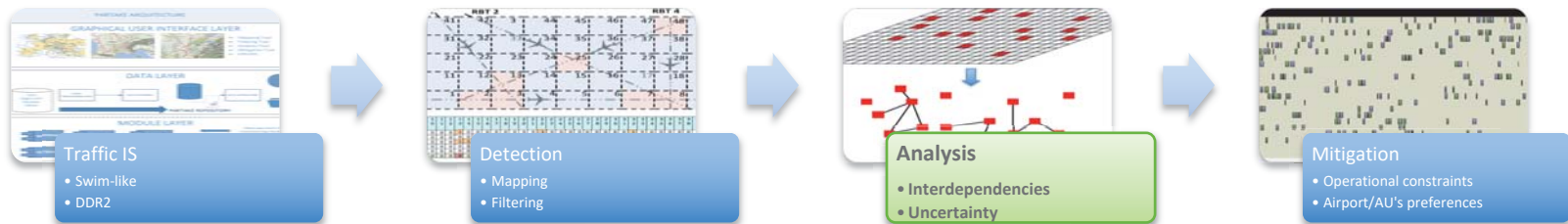
Analysis of Spatio-Temporal interdependencies

Situational awareness of:

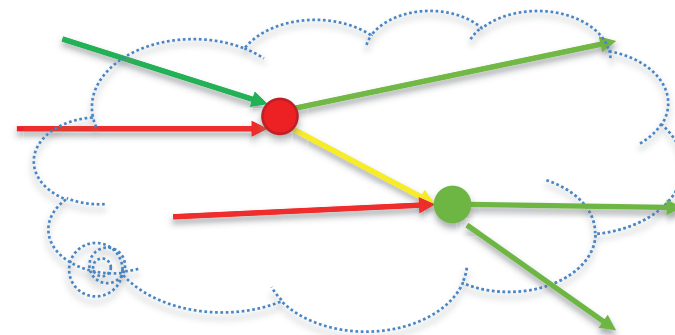
- Local Concurrence Events
- Coupling interdependencies (potential downstream effects of mitigation measures)

1. **Reducing problem size**: ensures a reduction of the problem size maintaining all interdependencies, which enable even parallelization during mitigation phase.
2. **Deadlock detection**: the analysis tool can anticipate and remove possible deadlock configurations.

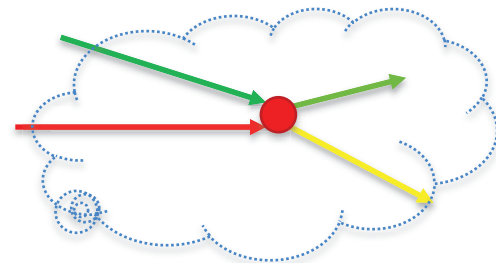
Mitigation solvability



Cluster 1

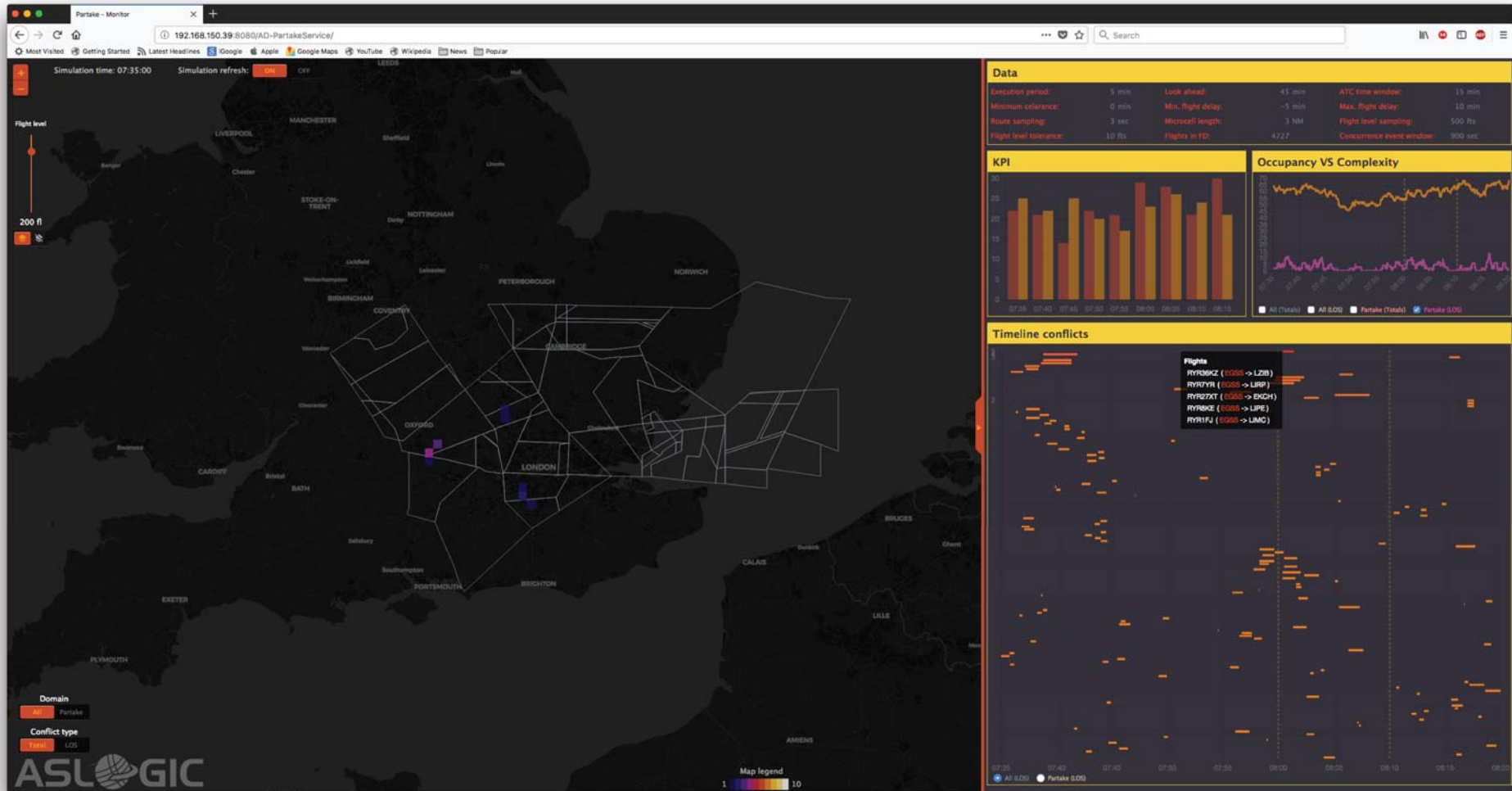


Cluster 2

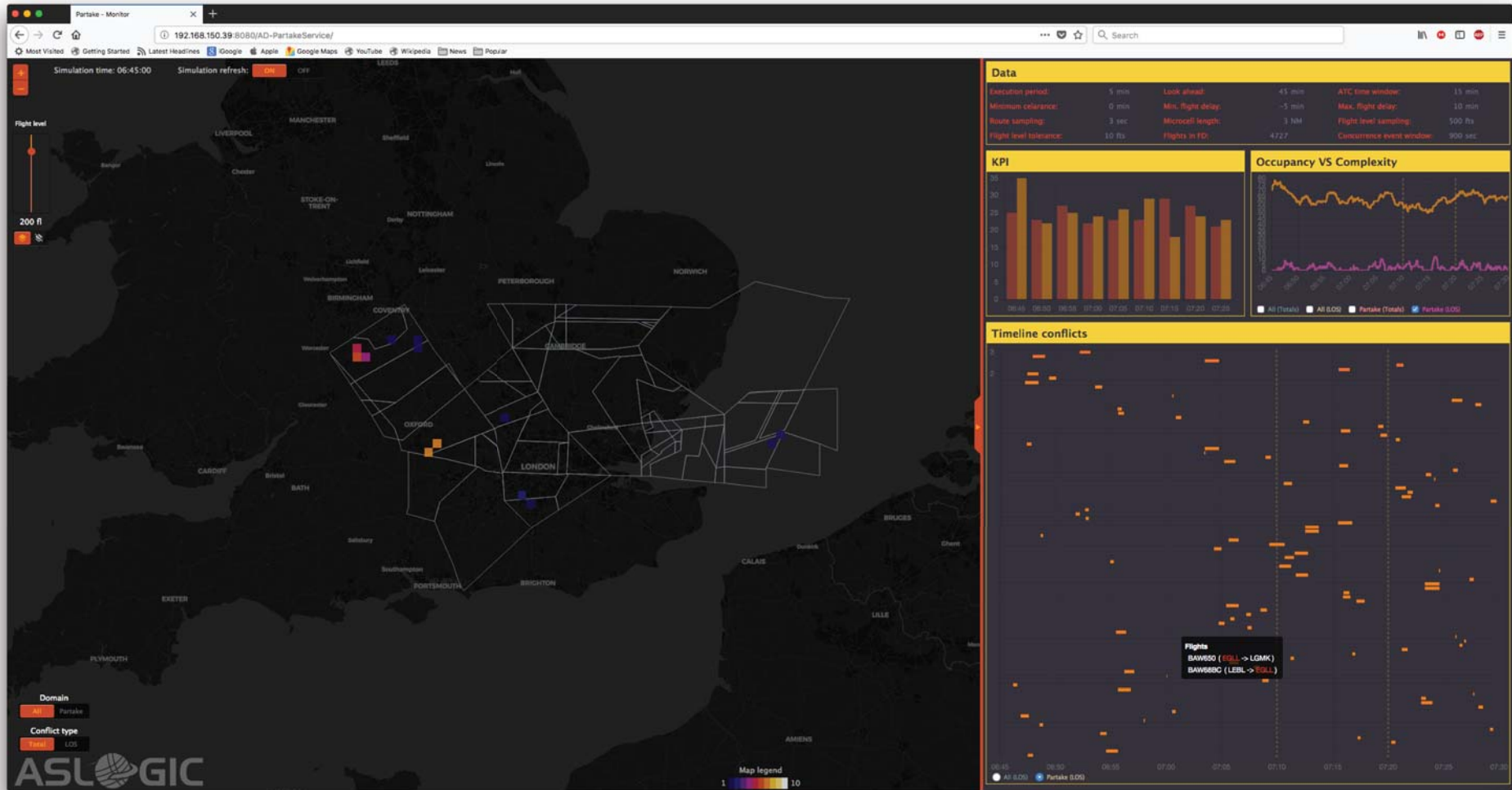


Cluster 3

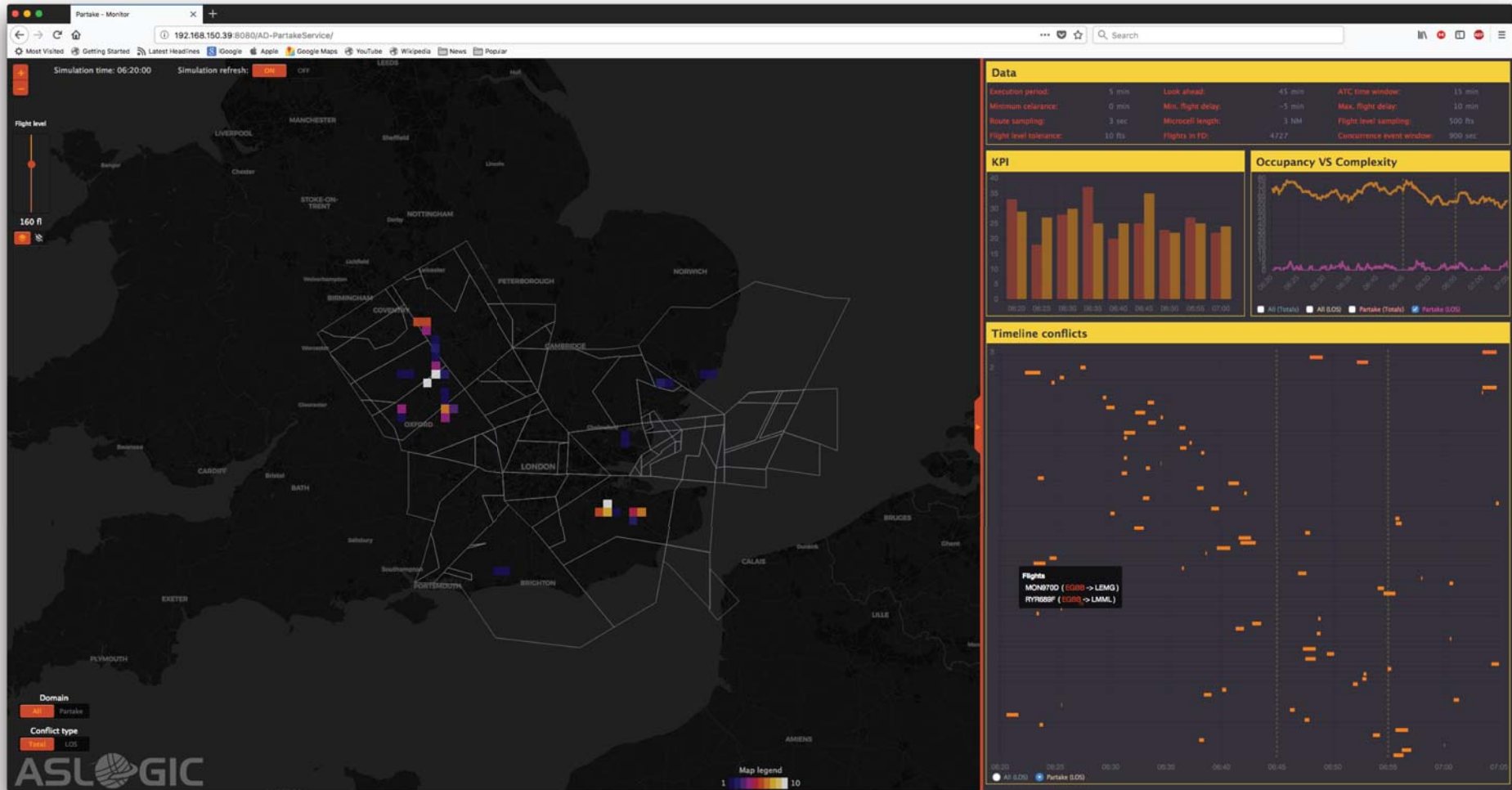
Interdependency Analysis. Challenges



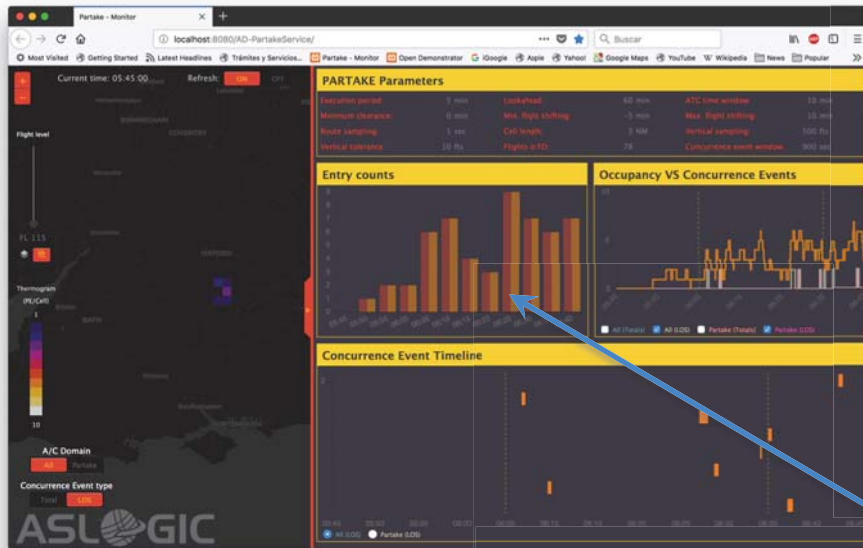
Interdependency Analysis. Challenges



Interdependency Analysis. Challenges



Interdependency Analysis. Challenges



Parameter window shows the different parameters that have been specified for the simulation.

Occupancy vs. concurrence event: forecast of the occupancy evolution is plotted along with the predicted concurrence events.

Entry counts: both the estimated (as defined in the so6 file) and the most up-to-date (according to current time)

Concurrency event timeline: shows the time instant when concurrence event takes place as well as its duration

Spatial information: presented as a *thermogram* on the map where color relates to the number of potential concurrence events identified in a cell.

Outline

Introduction

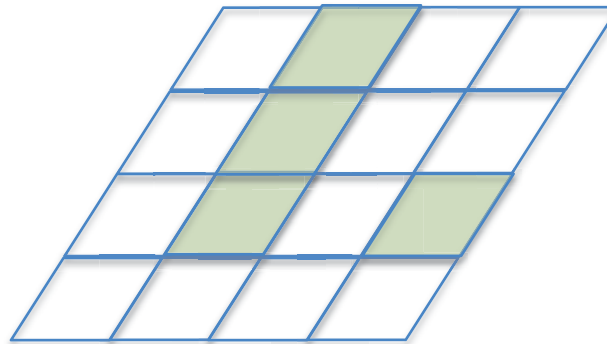
PARTAKE Detection & Analysis Tools

PARTAKE Mitigation Tools

- Concept
- Mitigation Services

Conclusions

PARTAKE Mitigation Tool



- Concurrence event detection
- Departure Coordination

δ shifting within $[-5, 10]$ minutes

Bounded speed adjustments



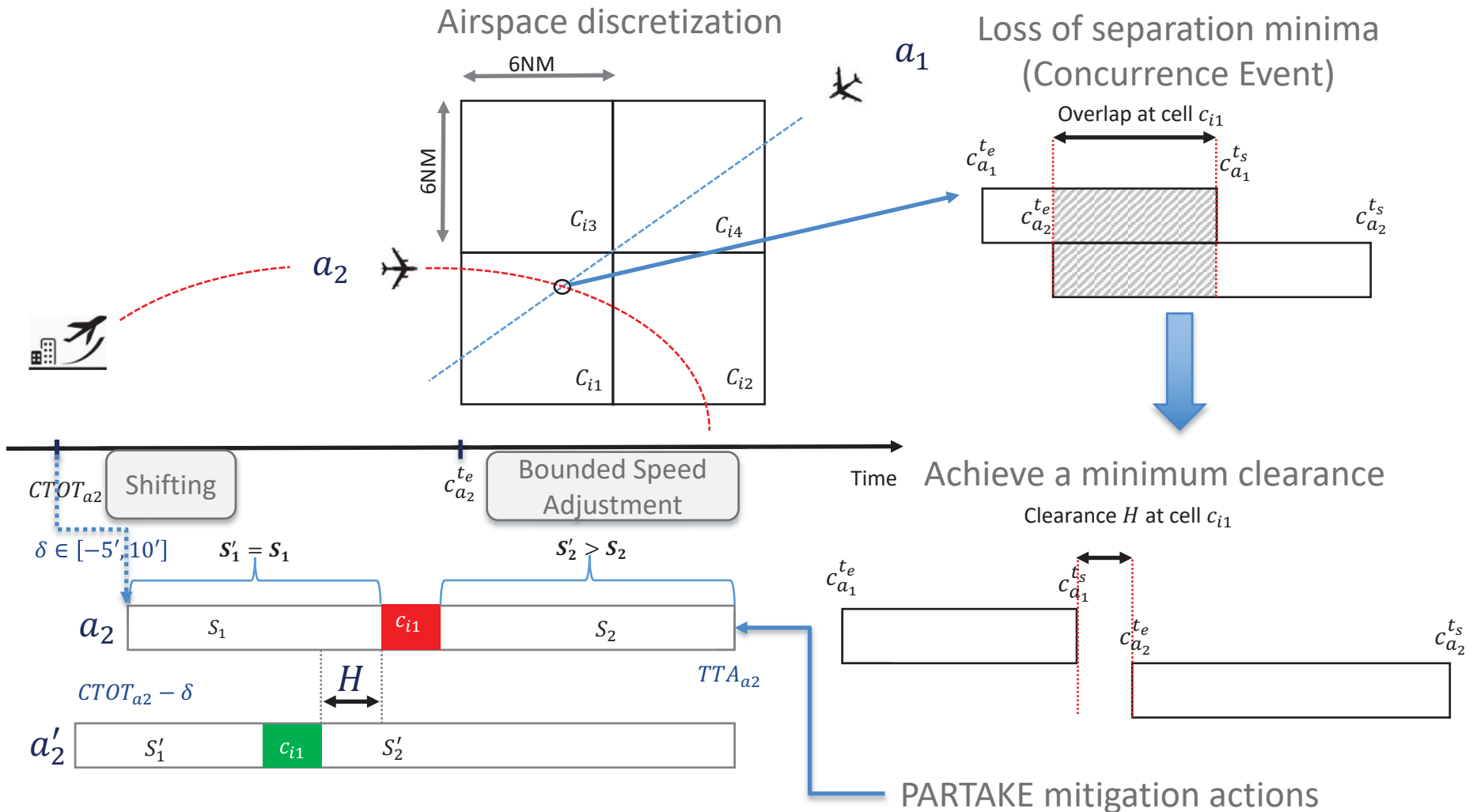
$$C_{TOT}(a_i) + \delta(a_i)$$

$$TOT(a_i) > TOT(a_j)$$

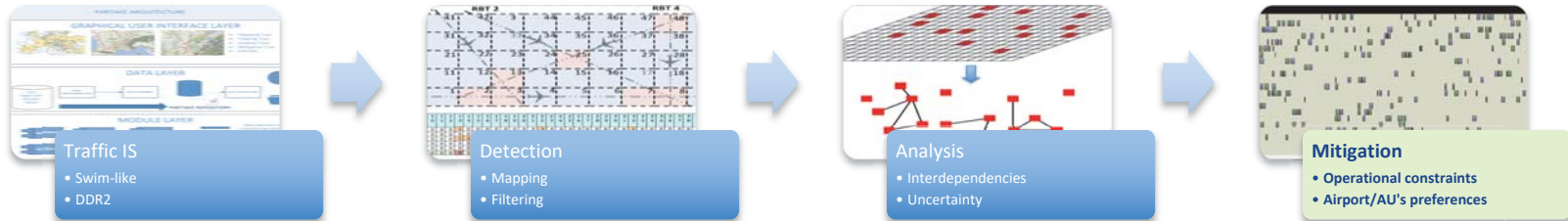


$$C_{TOT}(a_j) - \delta(a_j)$$

PARTAKE Mitigation Tool



Mitigation based on Constraint Programming



Parameters

$$RBT_a = \{\hat{g}_i^a \mid \forall a \in A, i = 1..p(a)\}$$

$\hat{g}_i^a \equiv$ segment of a trajectory

$p(a) \equiv$ # of required segments

Objective function

$$L(G_a) = \begin{cases} 1, & e(G_a) \notin [TTA_a - 1, TTA_a + 1] \\ 0, & \text{otherwise} \end{cases}$$

$$\min_{a \in A} w_1 \sum_{a=1}^n |\delta_a| + w_2 \sum_{a=1}^n L(G_a)$$

Constraints

$$span(G_a, \{g_i^a\}), \forall a \in A, \forall g_i^a \in T_a$$

$$\begin{cases} s(G_a) = \min_{i \in [1, p(a)]} (\{s(g_i^a)\}) \\ e(G_a) = \max_{i \in [1, p(a)]} (\{e(g_i^a)\}) \end{cases}$$

$$NO(G_a) \Leftrightarrow \pi(g_i^a) < \pi(g_j^a)$$

$$e(g_i^a) \leq s(g_j^a), \forall i, j: i < j$$

$$e(g_i^a) = s(g_j^a), \forall i, j: j = i + 1$$

$$s(G_a) = CTOT_a + \delta_a$$

$$\forall c_a \in c_A$$

$$\begin{cases} s(g_i^a) = s(P_{c_a}) \\ e(g_i^a) = e(P_{c_a}) \end{cases} \Leftrightarrow \begin{cases} s(\hat{g}_i^a) = c_a^{te} \\ e(\hat{g}_i^a) = c_a^{ts} \end{cases}$$

Introduction

PARTAKE Detection & Analysis Tools

PARTAKE Mitigation Tools

Current developments and future challenges

- Main results
- Direct & Free routing
- PARTAKE & Future U Space
- Future challenges

Approved
Flight Plans



Flight Plan
Approval
Process



Flight Operations Centers (FOCs)

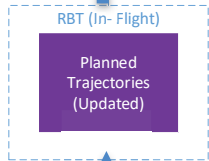


Main Results: London TMA



+

Trajectories



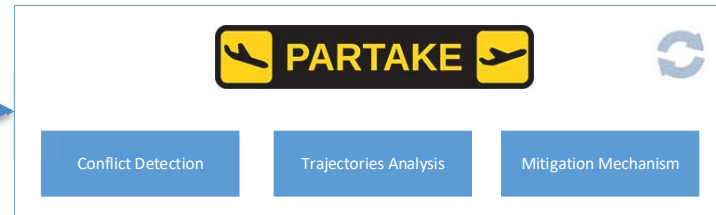
Predicted
Trajectory



Airspace flights



Previous departed flights



ETOTs

18:20	26L
18:20	18:20
18:20	18:20
18:20	18:20
18:20	18:20
18:20	18:20
18:20	18:20
18:20	18:20
18:20	18:20
18:20	18:20
18:20	18:20

Pre-Departure Sequence

Modified ETOTs Flights

Crew in selected flight
(taxi/ready-to-depart)

Comm Link

Tower ATCos



Take-Off

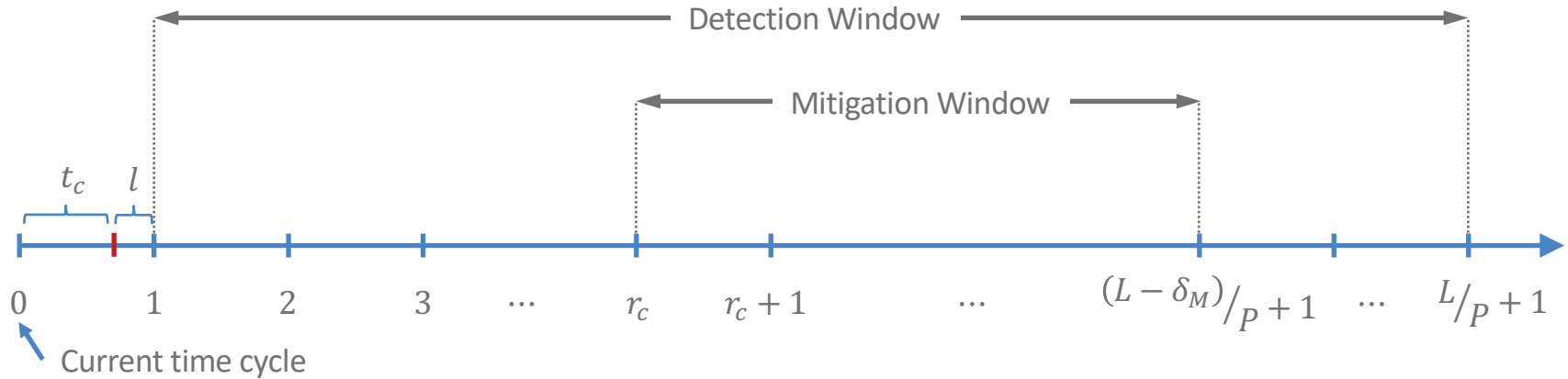


Taxi/Push-Back



Control Tower

Main Results: London TMA



Parameters	P	Execution period
	L	Look ahead time
	δ_m	Minimum shifting delay
	δ_M	Maximum shifting delay
	r_c	Begin cycle of mitigation window
	t_c	Partake computational time of one cycle
	t_{ATC}	Required ATC reaction time
	l	Latency

Parameter Conditions:

$$P = \gcd(L, \delta_m, \delta_M, t_{ATC}) \text{ whenever possible}$$

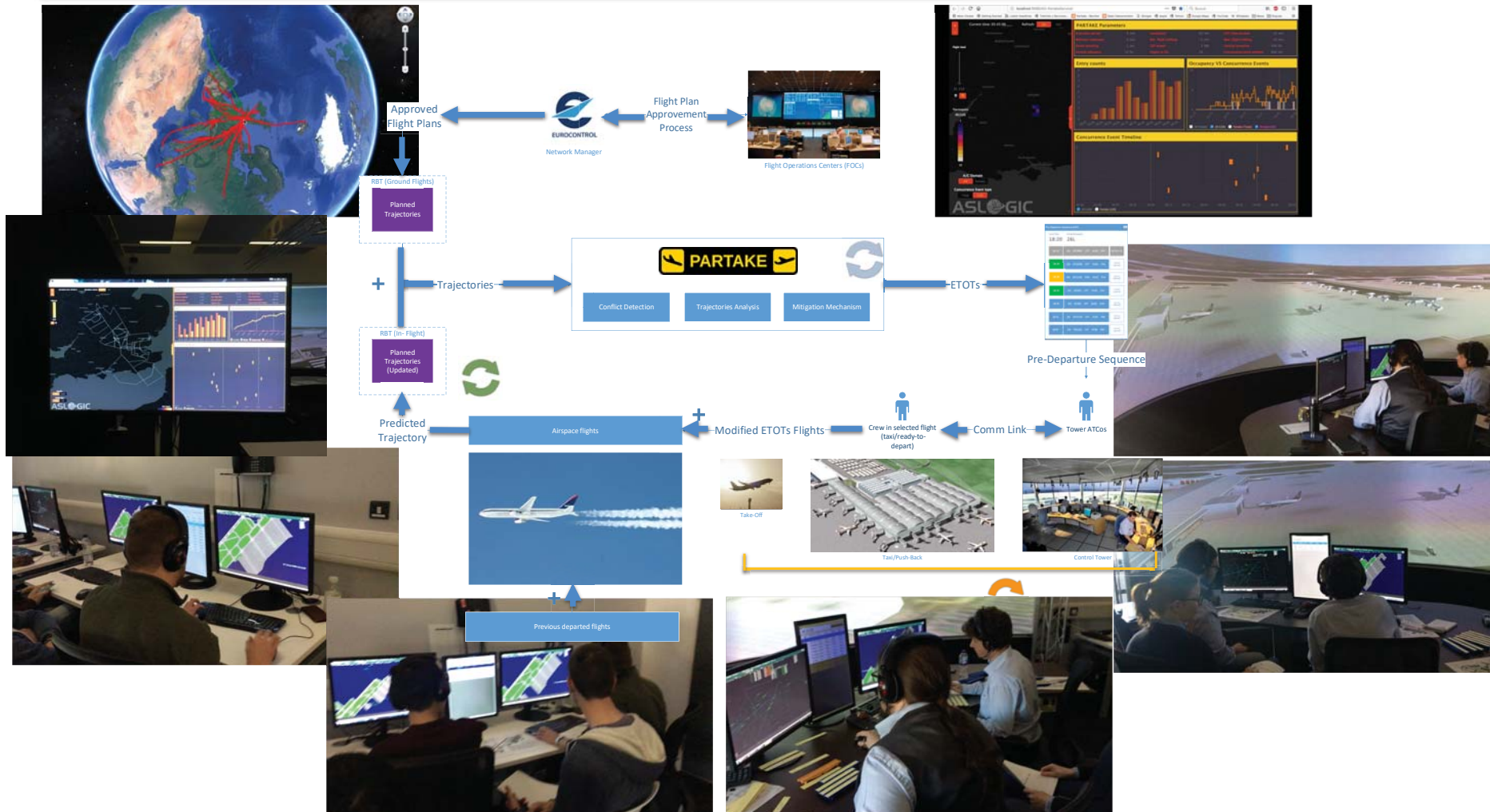
$$t_c + l \leq P$$

$$L \geq t_{ATC} + 2P + \delta_m + \delta_M$$

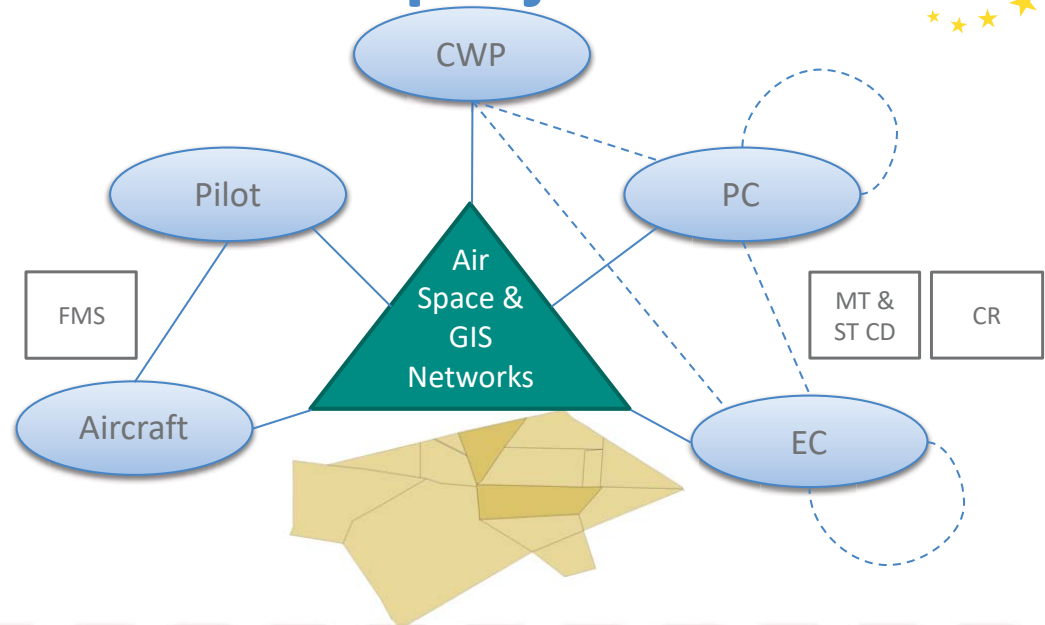
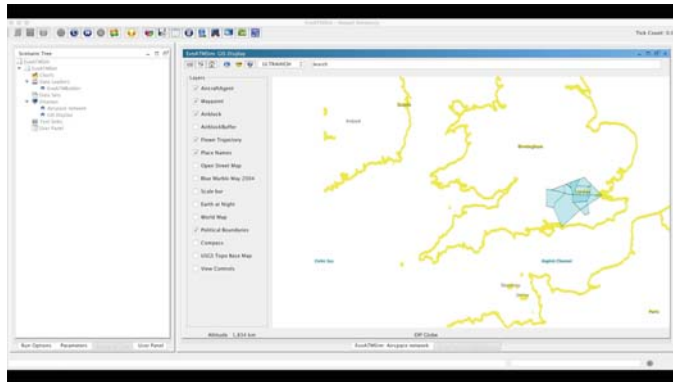
$$r_c = \left\lceil \frac{t_{ATC} + \delta_m}{P} \right\rceil + 1$$

Main Results: London TMA

- scenario in TMA and surrounding areas
- Evaluation of Entry and Occupancy counts
- Evaluation of the number of potential concurrence events in a sector



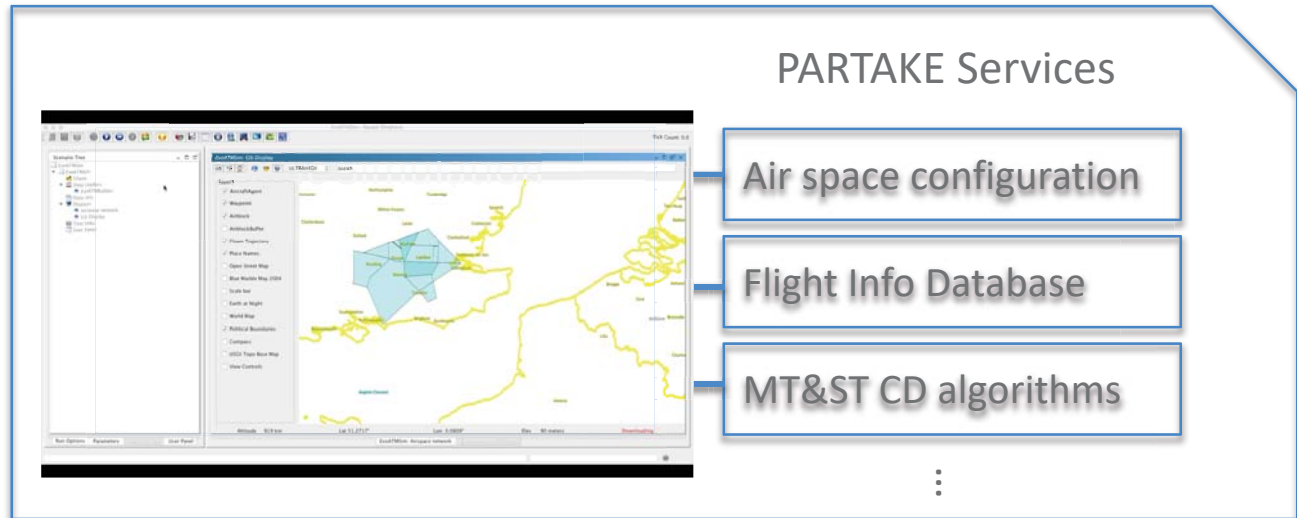
Application to EvoATM SJU ER project



EvoATM ABS



EvoATM
libraries
based on
PARTAKE
Services



Application to EuroDRONE

Funded at U-Space call CEF-SESAR-2018-1

U1

- e-registration,
- e-identification,
- geofencing



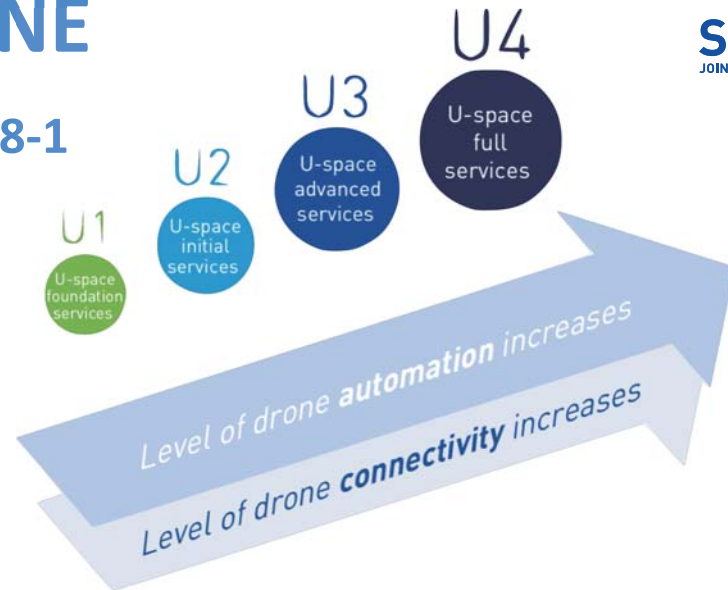
U2

- Flight Planning
- Flight Approval
- Tracking
- Airspace dynamic information
- Procedural interfaces with air traffic control

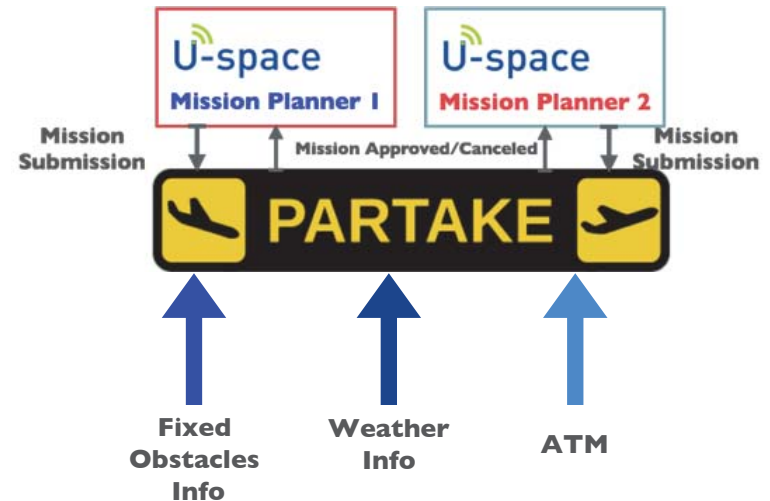


U3

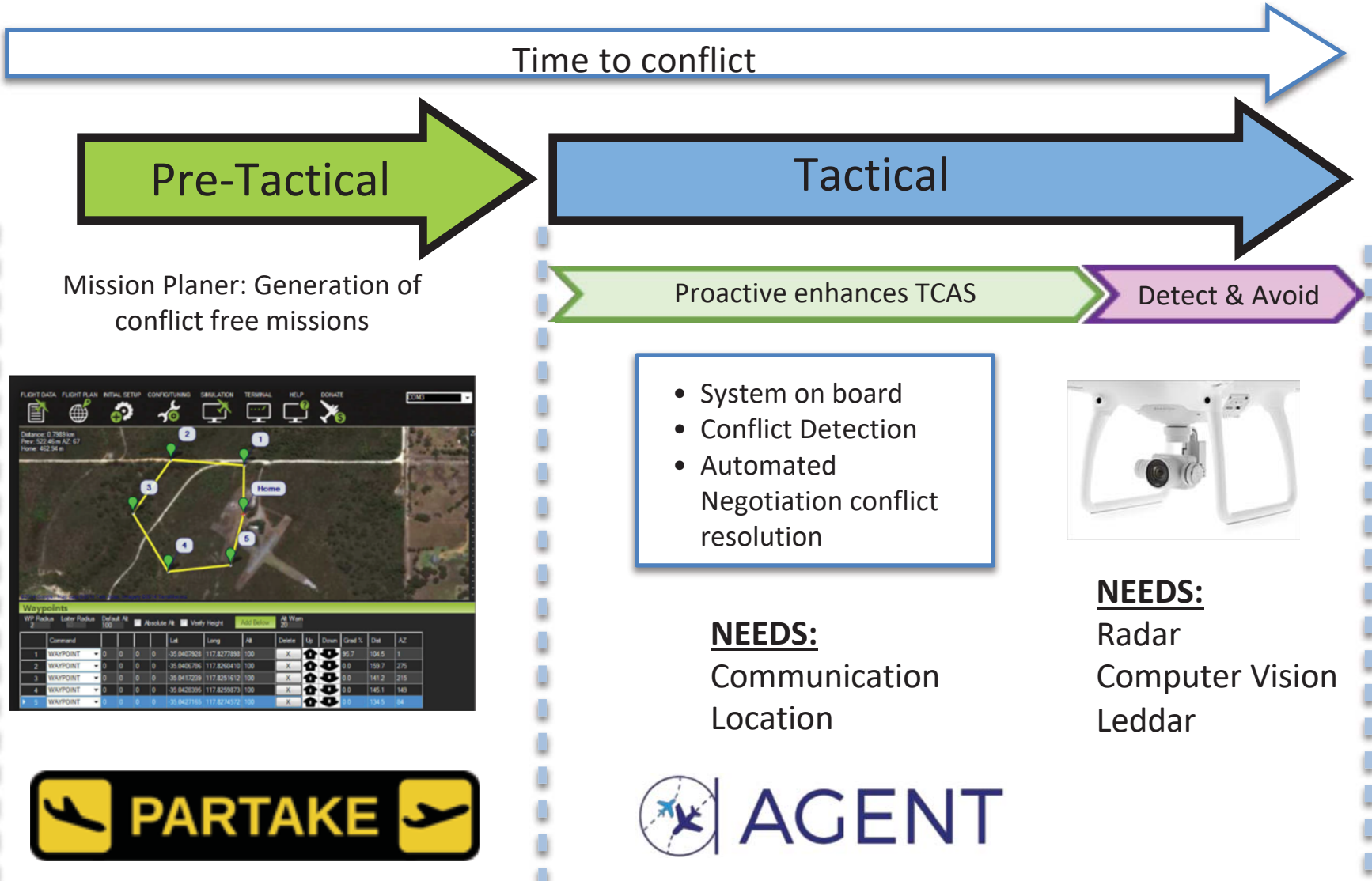
- Capacity management
- Conflict Detection
- Detect & Avoid
- More reliable means of communications



PARTAKE Detection, Analysis and Mitigation tools



PARTAKE & FUTURE UTM



Future Challenges

New application domains

- New metrics for Free Route Airspace
- Synchronization mechanisms for Extended AMAN
- Multi-sector planning: minimize domino effects

Dealing with TBO uncertainty

- Trajectory analysis from big data perspective: self-tuning of detection and mitigation parameters
- Probabilistic analysis of potential concurrence events for better mitigation measures

Technical (Real time and operational concerns)

- Access to the most up-to-date trajectory prediction
- Integration with AMAN-DMAN for better coordination measures



PARTAKE

Results, achievements and identified challenges

More details at <http://www.partake-aero.eu>

Thank you very much for your attention!



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Founding Members



EUROPEAN UNION



EUROCONTROL