



Identification of Spatiotemporal Interdependencies and Complexity Evolution in a Multiple Aircraft Environment

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Founding Members



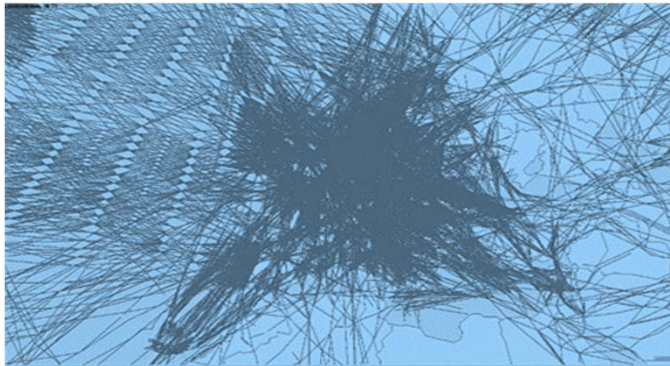
Outline



- 1 ■ Introduction
- 2 ■ Problem definition
- 3 ■ STI identification
- 4 CRT generation
- 5 Simulation results
- 6 Conclusions and follow-up research



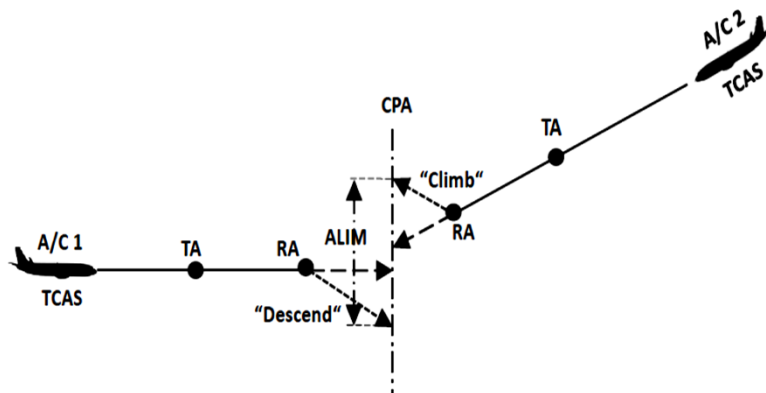
Introduction (I)



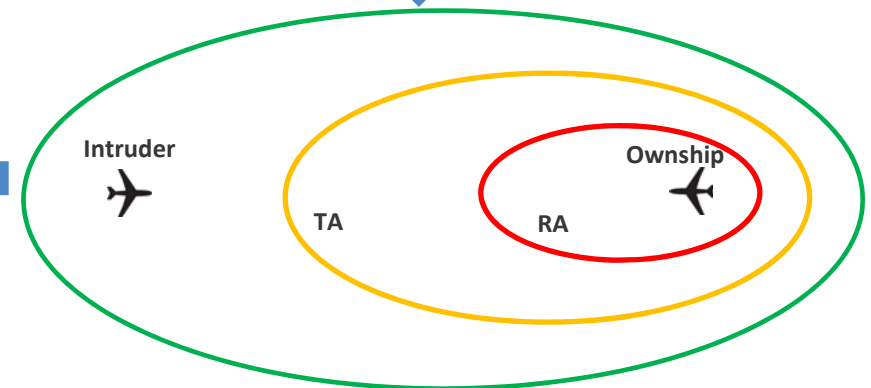
Increased traffic demand: 50% increase in flights by 2035 comparing to 2012



Continuous pressure on ACC for SM provision



CA usually produces inefficient trajectory resolutions: higher vertical rate)



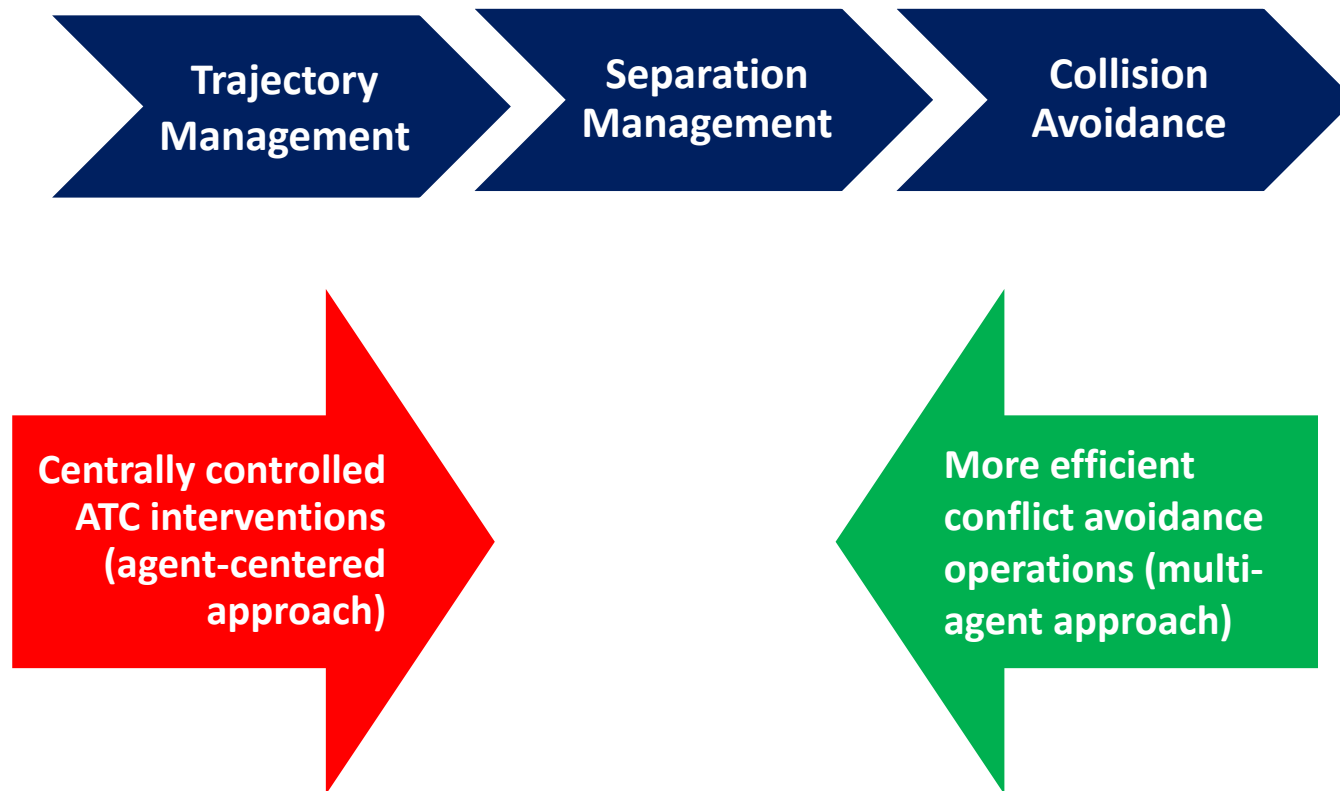
Missed provision due to increased ATC workload & insufficient time for reaction: CA activation



Introduction (II)

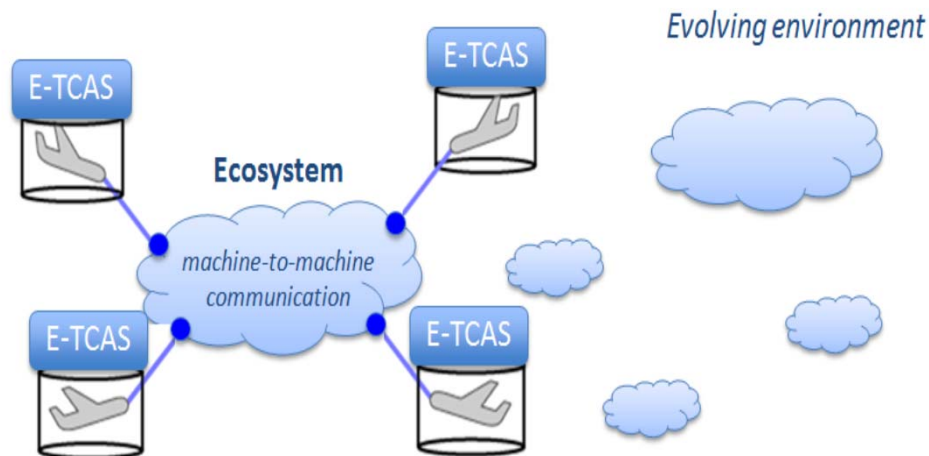
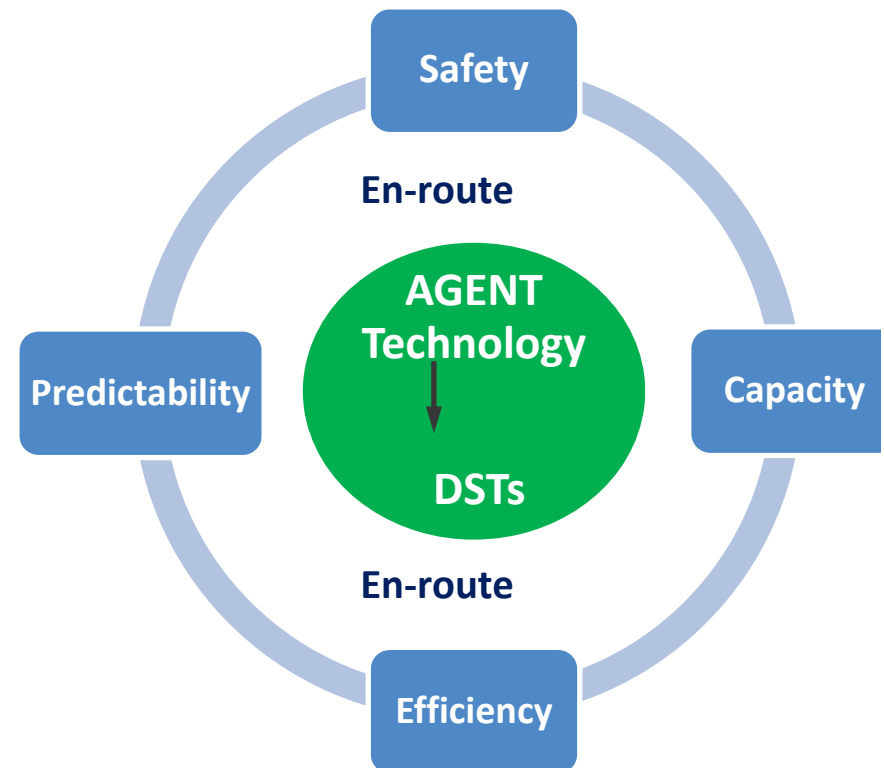


- Goal: SESAR and NextGen toward future harmonization of air traffic operations through development of airborne and ground-based DMTs
- Response: project AGENT seeks for smooth and coherent transition between safety nets



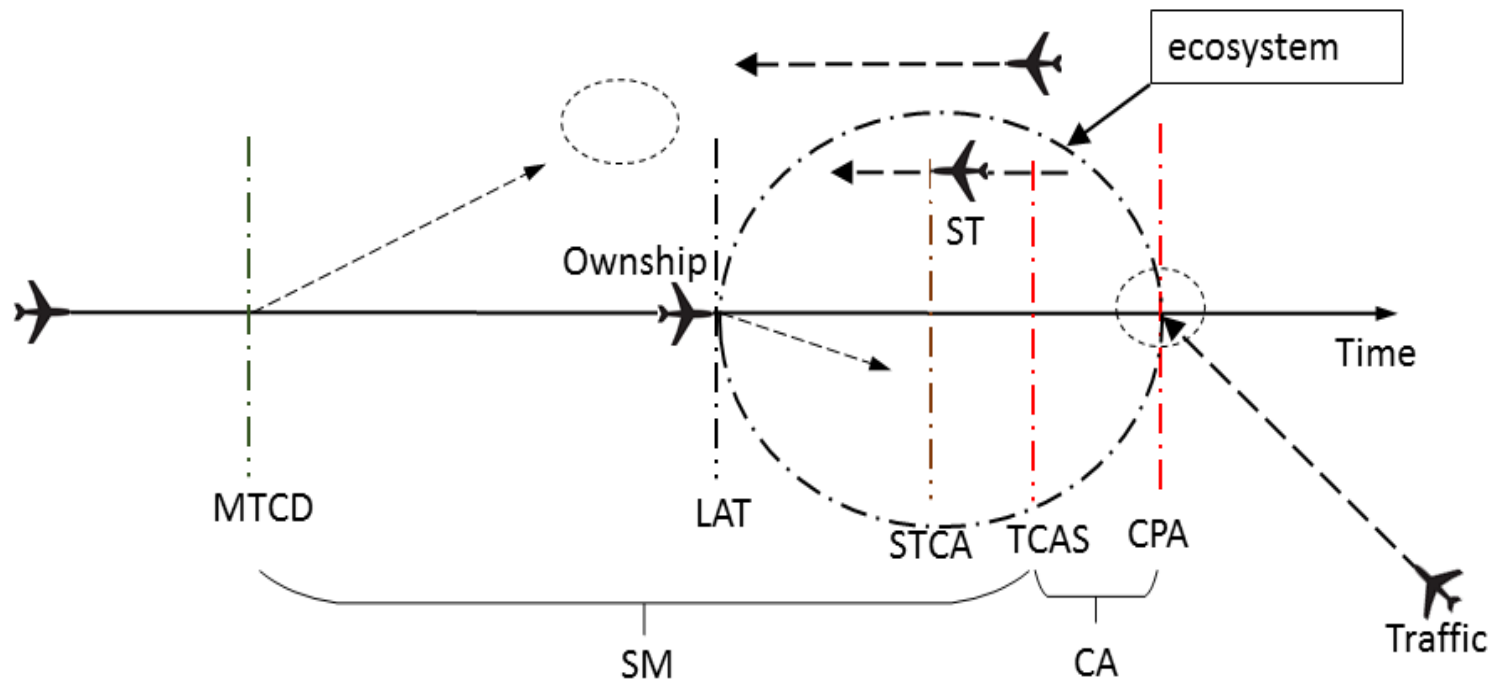
Introduction (III)

- AGENT claims for the collaborative and proactive SM system considering a socio-technological approach: multi-agent system (MAS)
- Driven by the certain SESAR KPIs
- ER-TRL 1: no ATC position fully considered



Introduction (IV)

- State-based CD function at strategic level and MAS-based CR algorithm at tactical level
- Assumptions:
 - Lookahead time (LAT): 5'-to-CPA
 - No uncertainty at TM level: a linearity of the trajectory segments within LAT



Problem definition (I)

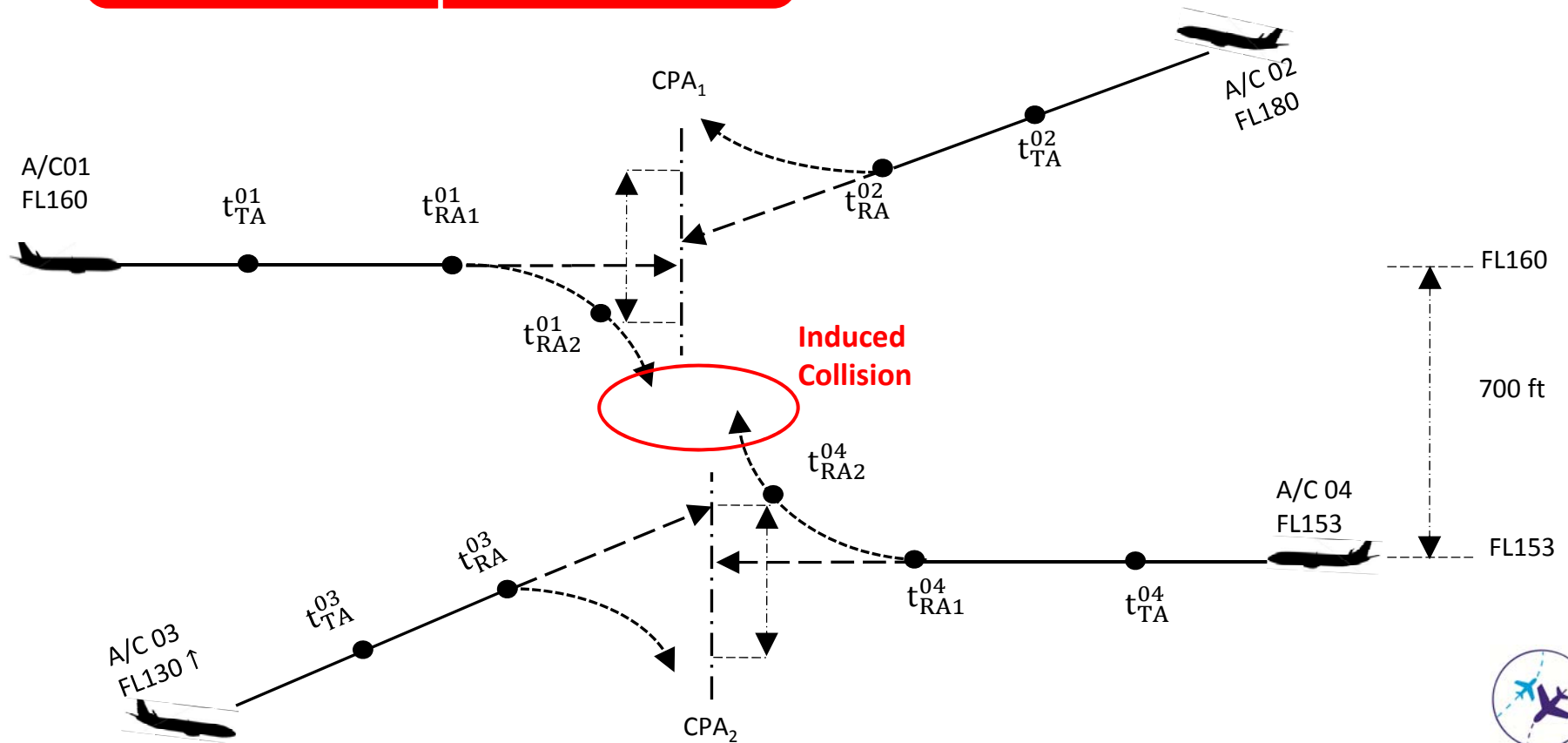
Designed for operations in
traffic densities of
 0.3 ac/NM^2

Excellent performances for
pair-wise encounters

TCAS II v 7.1

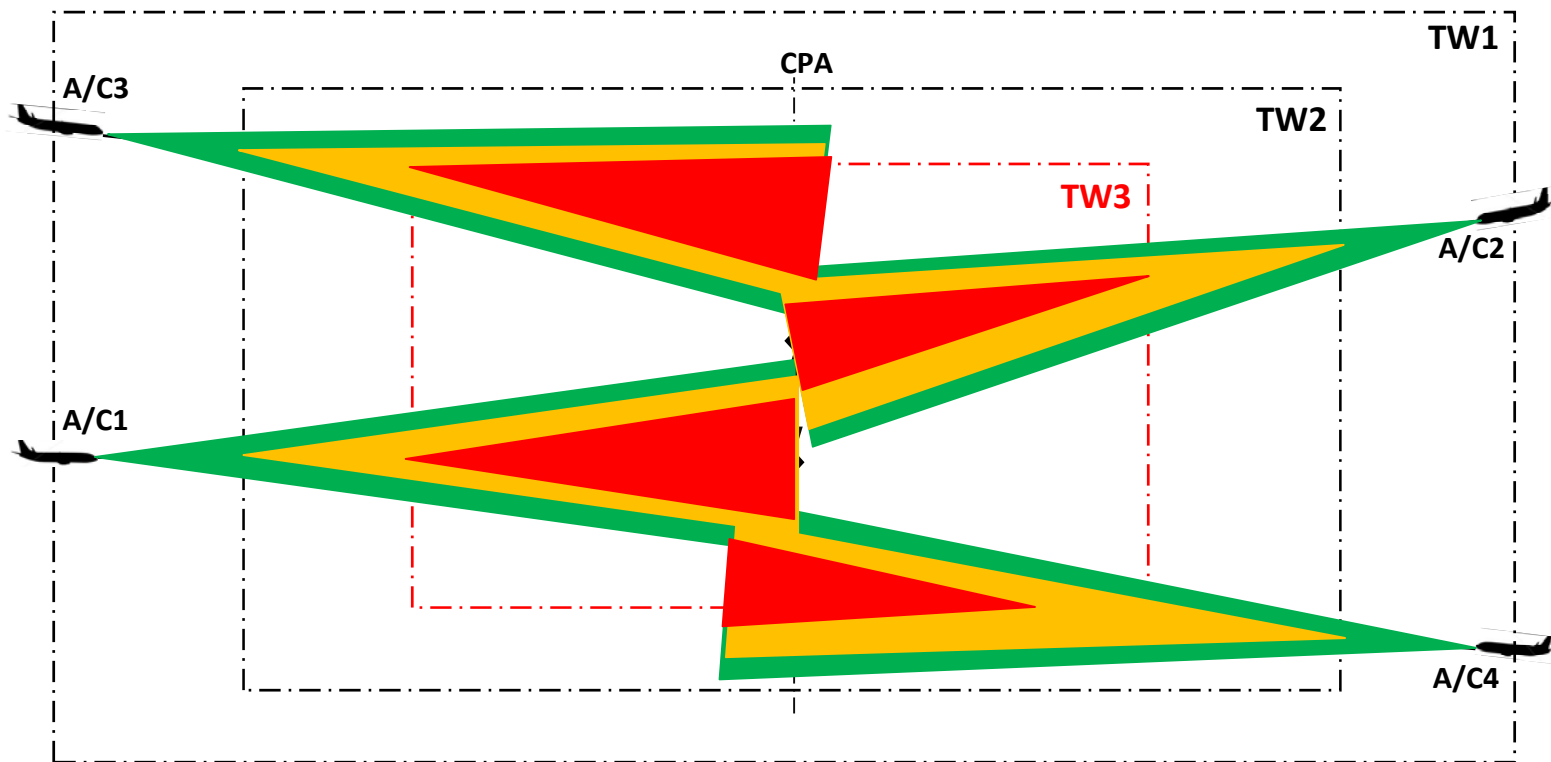
Logic drawbacks due to
induced collisions in
complex traffic scenarios

System-variant for closure
rate changes towards CPA

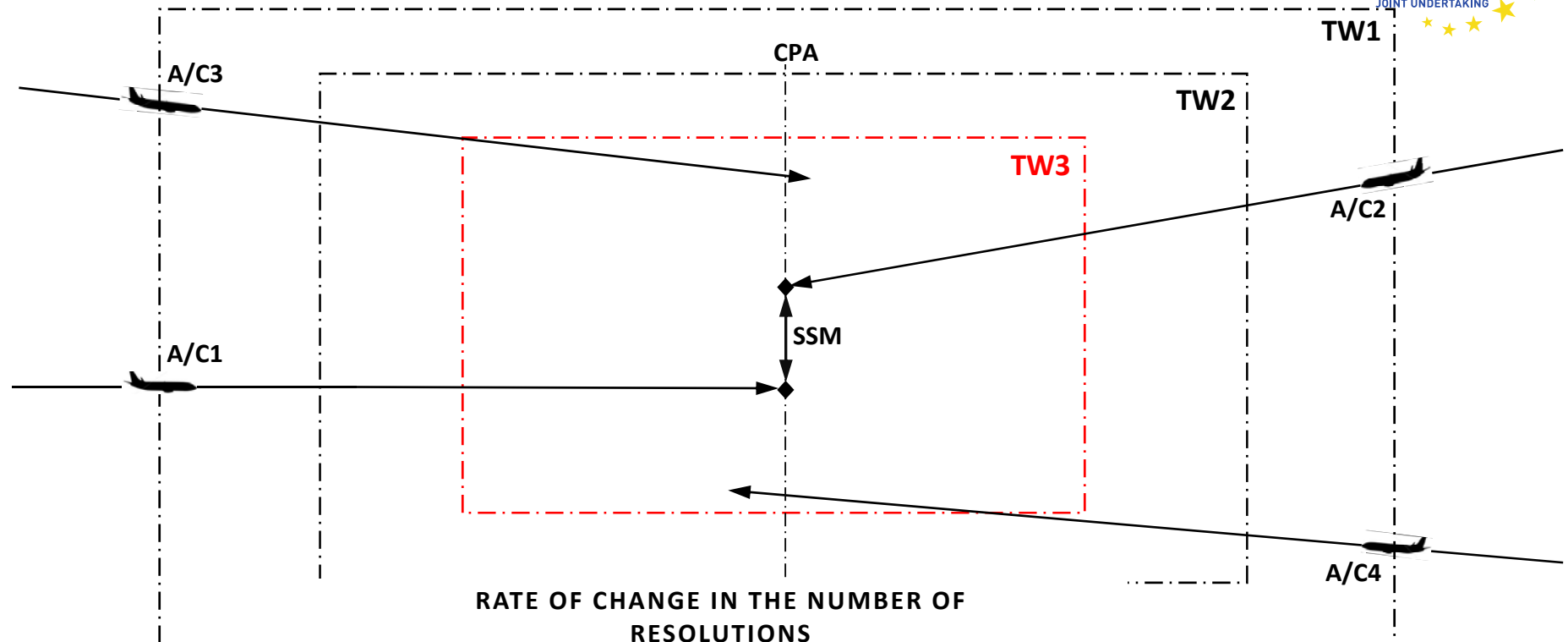
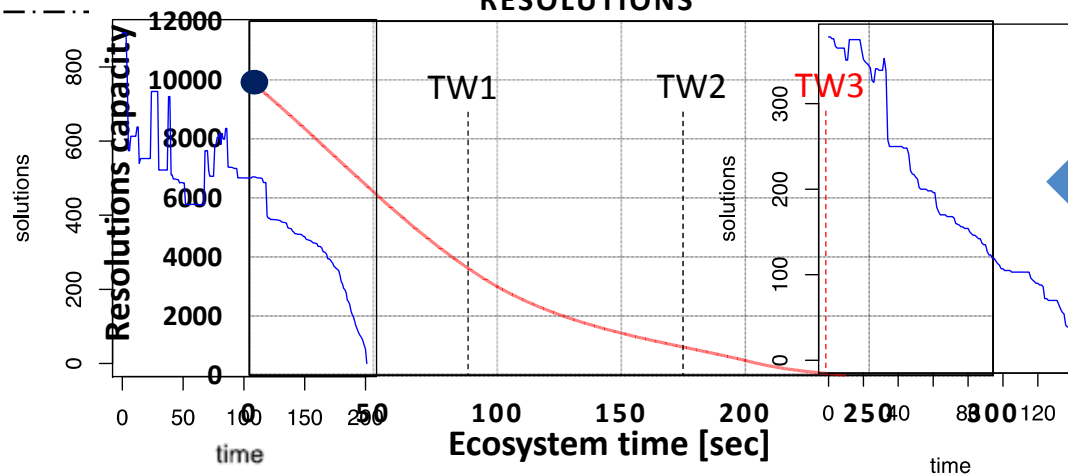


Problem definition (II)

Scenario evolution towards Ecosystem Deadlock Event (TW1 --- TW2 --- TW3)



Problem definition (III)

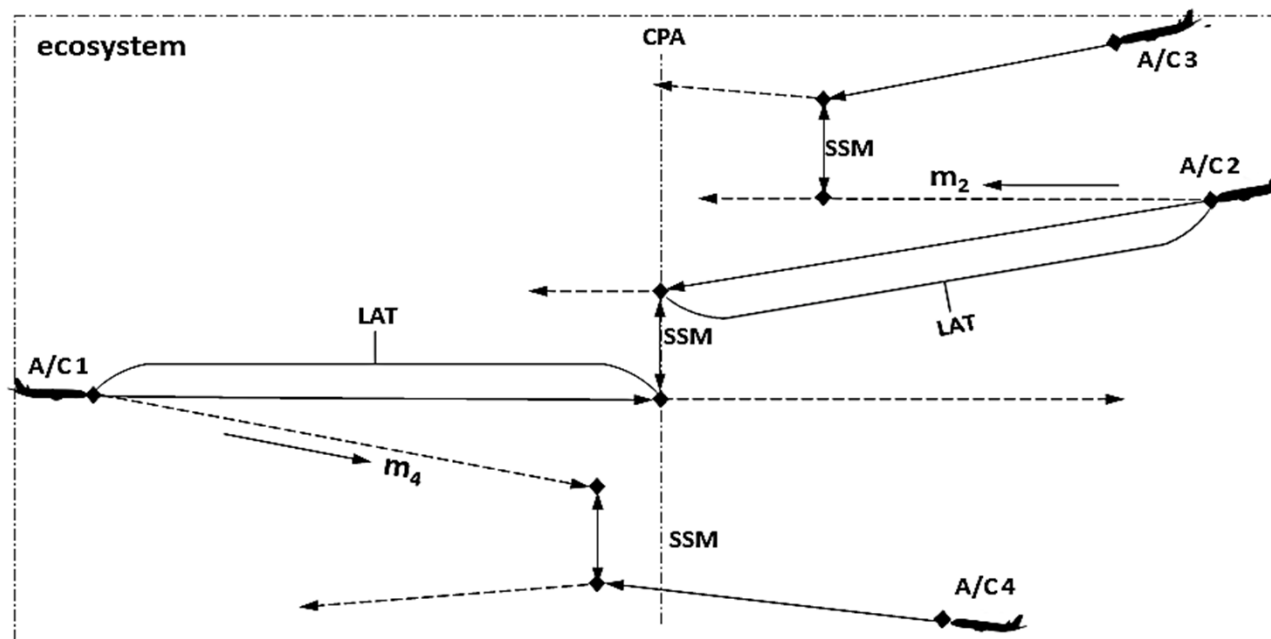


Rate of change in number of resolutions: amending capacity over ecosystem time

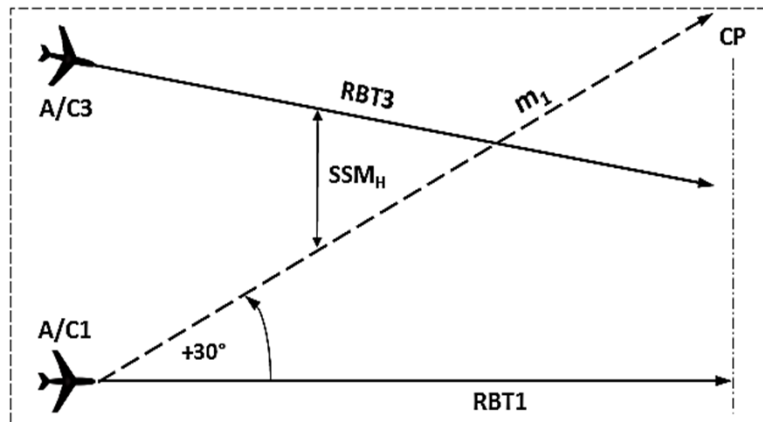
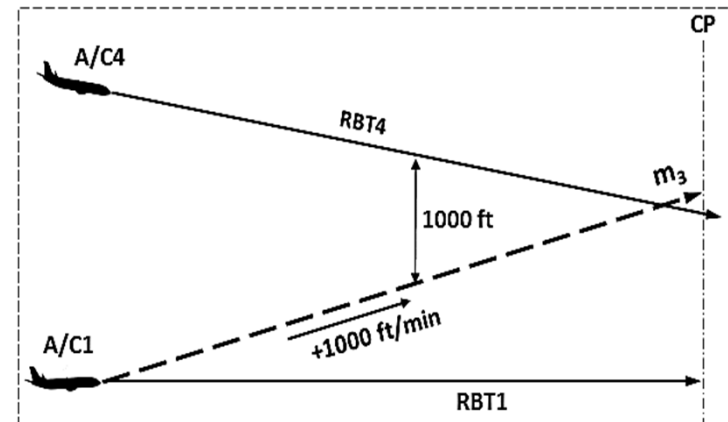


STI identification (I)

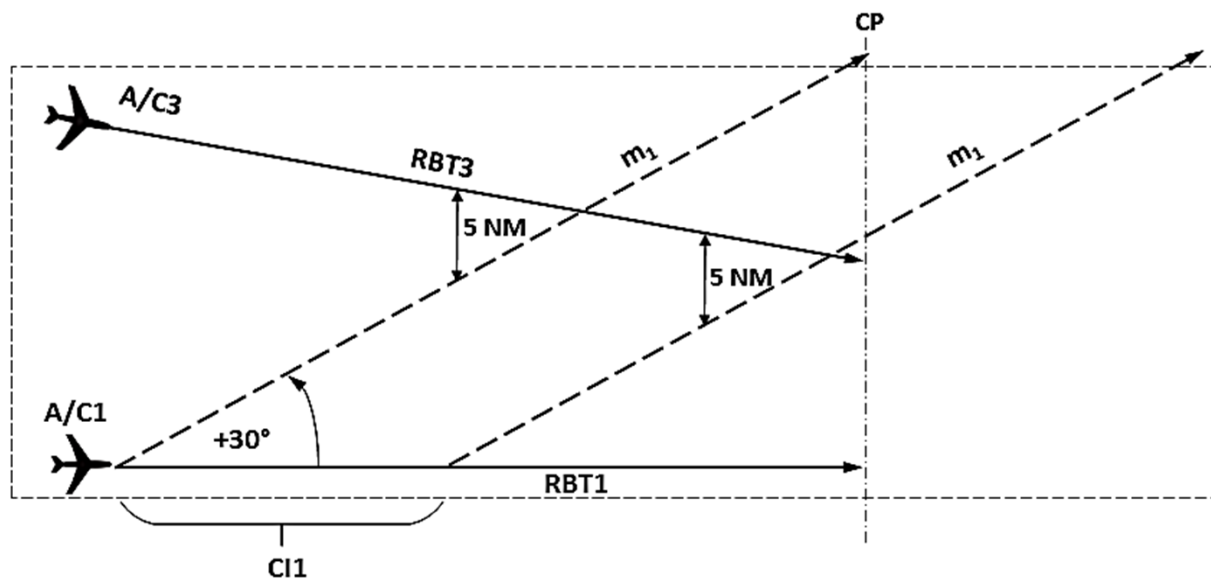
- DEF: set of aircraft inside computed airspace volume, with the trajectory-amendment, decision-making capability, causally involved in safety event
- STI parameters:
 1. m_0 : RBT follow-up
 2. m_1 : left HDG-C with DA of $+30^\circ$
 3. m_2 : right HDG-C with DA of -30°
 4. m_3 : climb at VR of $+1000$ ft/min and FPA of $+2^\circ$
 5. m_4 : descent at VR of -1000 ft/min and FPA of -2°



STI identification (II)



→ Identification of two ST aircraft: A/C3 through HDG-C and A/C4 through VR

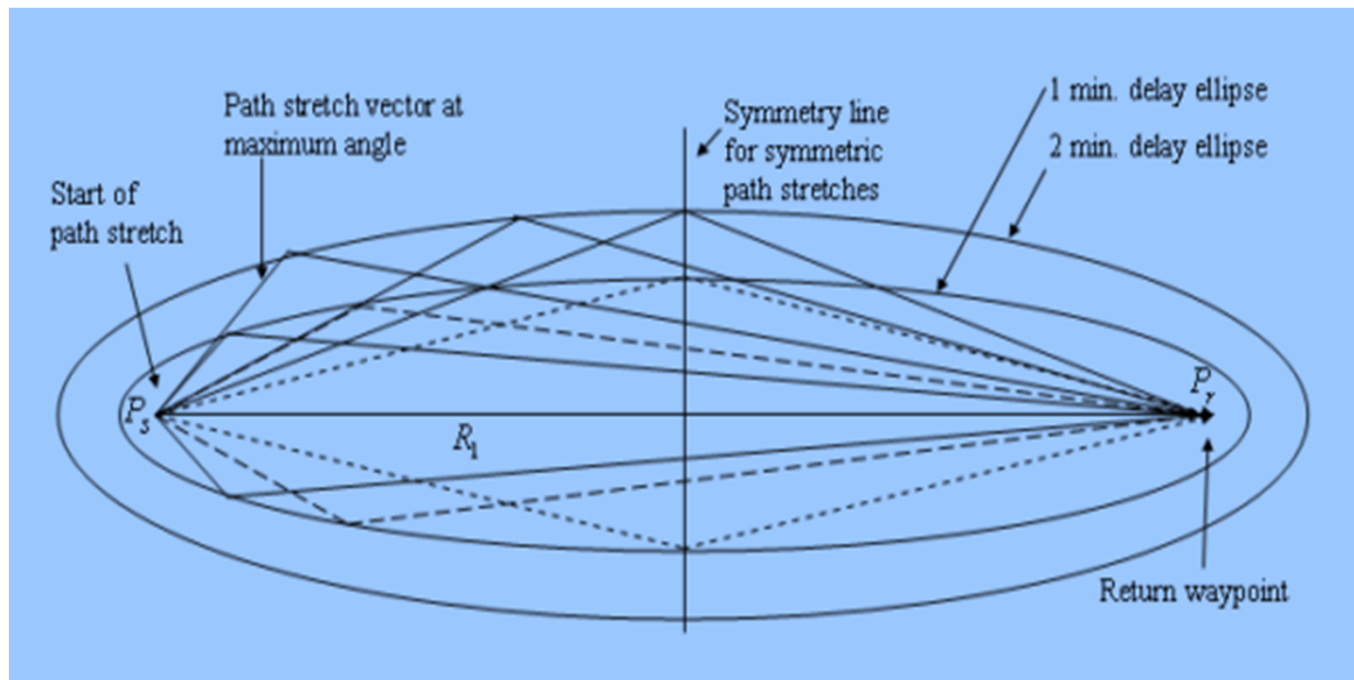


→ CI for a single RBT applying a DA of $+30^\circ$



CRT generation

- Complexity of ecosystem evolution based on decreasing/perishable rate in number of CRTs over time
- CRT generation: set of TWP + RWP to RBT
- CRTs evaluated one against another by computation of intrinsic complexity (complexity value larger than the values analogous to the TCAS TAs: proposal rejected)



→ Locus of tactical waypoints for introducing delay to resolution



Simulation results (I)

- Historical traffic dated on 24/08/2017: DDR2_M1.so6 data format (flight plans)
- Traffic extraction in the selected period: 08:00 – 09:00
- Operational environment: ECAC en-route airspace above FL300
- Ecosystem test case: nominal structure (4 members)

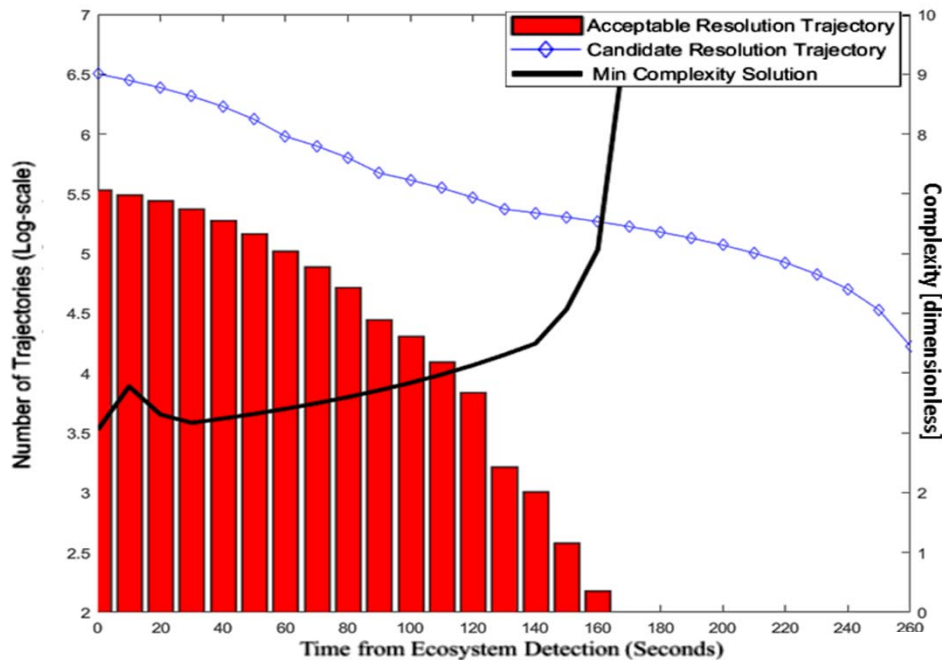
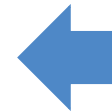
Flight ID	4D structure of ecosystem trajectories							
	$\varphi_1 [^\circ]$	$\lambda_1 [^\circ]$	$h_1 [ft]$	$t_1 [sec]$	$\varphi_2 [^\circ]$	$\lambda_2 [^\circ]$	$h_2 [ft]$	$t_2 [sec]$
A/C1	39.0000	-3.542	36000	0.00	39.5278	-3.489	36000	262.29
A/C2	39.0462	-3.874	36000	0.00	39.5506	-3.593	36000	262.29
A/C3	39.1109	-4.334	36000	0.00	39.5142	-3.814	36000	262.29
A/C4	39.7103	-4.075	39000	0.00	39.2788	-4.448	39000	262.29
A/C5	38.9277	-4.570	36000	0.00	39.3302	-4.052	36000	262.29

Ecosystem STI output			
STI_ID	Interdependent aircraft	Maneuvering combination	Conflict interval [sec]
STI_1	A/C1 – A/C2	m0 – m0	0.00 – 188.26
	A/C1 – A/C2	m0 – m3	0.00 – 188.26
	A/C1 – A/C2	m0 – m4	0.00 – 188.26
	A/C1 – A/C2	m2 – m1	0.00 – 188.26
	A/C1 – A/C2	m3 – m0	0.00 – 188.26
	A/C1 – A/C2	m3 – m3	0.00 – 188.26

Ecosystem STI output			
STI_ID	Interdependent aircraft	Maneuvering combination	Conflict interval [sec]
	A/C1 – A/C2	m3 – m4	0.00 – 188.26
	A/C1 – A/C2	m4 – m0	0.00 – 188.26
	A/C1 – A/C2	m4 – m3	0.00 – 188.26
	A/C1 – A/C2	m4 – m4	0.00 – 188.26
STI_2	A/C2 – A/C3	m0 – m1	0.00 – 51.48
	A/C2 – A/C3	m0 – m3	0.00 – 51.48
	A/C2 – A/C3	m0 – m4	0.00 – 51.48
	A/C2 – A/C3	m3 – m0	0.00 – 51.48
	A/C2 – A/C3	m3 – m3	0.00 – 51.48
	A/C2 – A/C3	m3 – m4	0.00 – 51.48
	A/C2 – A/C3	m4 – m0	0.00 – 51.48
	A/C2 – A/C3	m4 – m3	0.00 – 51.48
STI_3	A/C2 – A/C5	m2 – m0	120.00 – 130.28
	A/C2 – A/C5	m2 – m3	120.00 – 130.28
	A/C2 – A/C5	m2 – m4	120.00 – 130.28
STI_4	A/C3 – A/C4	m2 – m4	90.00 – 91.01

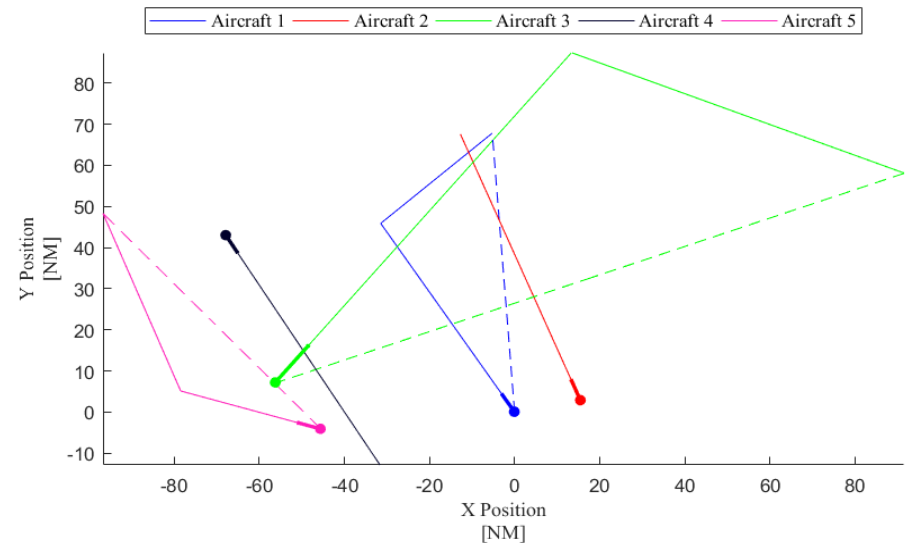


Simulation results (II)

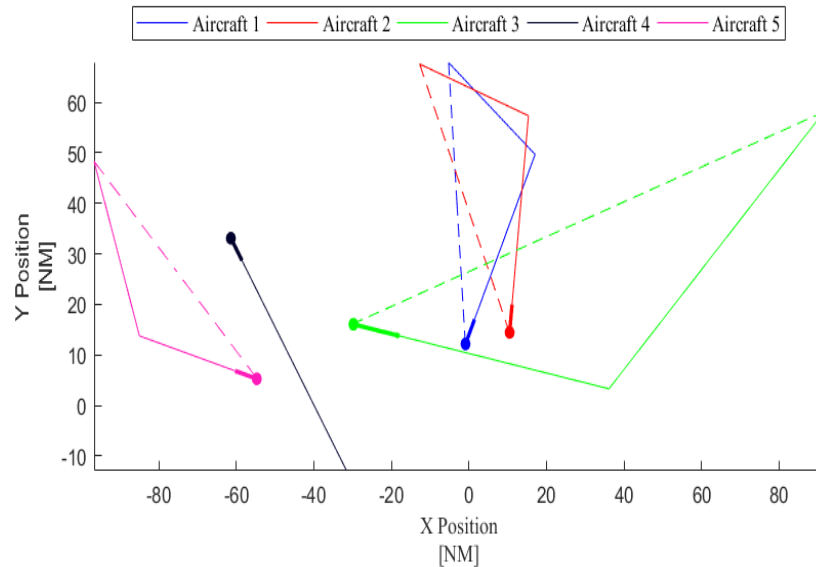


Evolution of acceptable and candidate RTs and complexity of the minimal complexity solution

Resolutions scenario I:
Timestamp 0, lower
complexity level

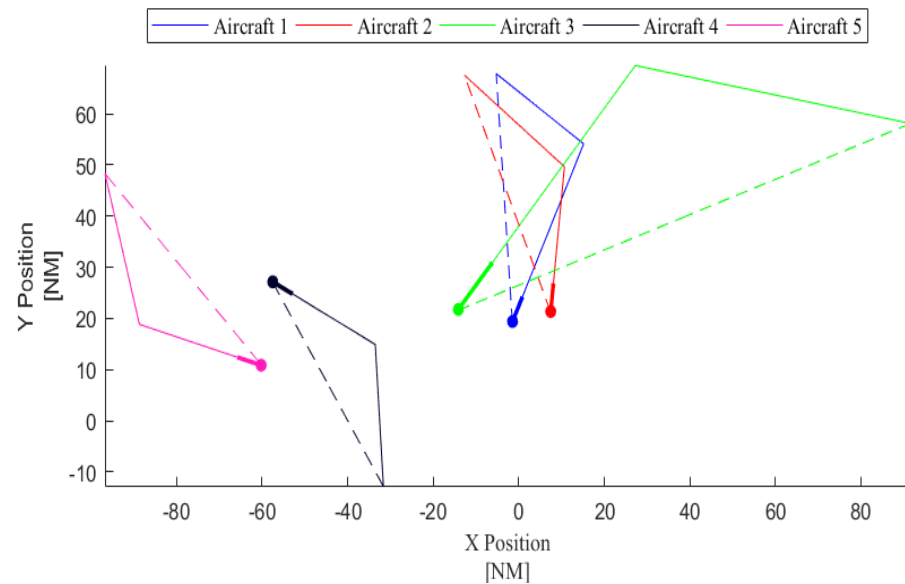


Simulation results (III)



Resolutions scenario II:
Timestamp 100-seconds,
medium complexity level
(A/C1 and A/C2)

Resolutions scenario III:
Timestamp 160-seconds,
maximum complexity level
(A/C1, A/C2 and A/C3)



Conclusions & follow-up research (I)



- ✓ Ecosystems creation to support automation at tactical level in the monitored airspace volume
- ✓ Analysis of the complexity levels coming from different traffic scenarios to increase the system robustness
- ✓ Smooth transition from the ecosystem membership identification to the acceptable candidate resolutions generation provides very valuable insight of the STI structure and a complexity level at a certain moment in a time evolution
- ✓ Number of the available RTs drops over time, for a fixed returning point of the intended trajectory; an exponential complexity trend due to chosen metric in evaluation
- ✓ Solutions can be compared on basis of the heading changes and delay propagation, followed by the minimal complexity value; prevention of the separation infringements in the horizontal plane, and provision of the compatible aircraft states with TCAS function in which the TAs would not be triggered



Conclusions & follow-up research (II)



- ❖ Analysis of the multi-thread conflicts with respect to time to the CPA
- ❖ Reduction of the computational time and an incorporation of the fine trajectory predictions for the ecosystem detection and resolution algorithms
- ❖ Extension of the parametric values for more robust STI testing
- ❖ Development of the agents' negotiation process and a deterministic prediction of the EDE





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Thank you for your attention!
Questions?



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<https://www.sesarju.eu/sesarinnovationdays>

Radanovic M, Eroles MA, Koca T, Verdonk Gallego CE, Nieto FJ, Identification of spatiotemporal interdependencies and complexity evolution in a multiple aircraft environment, Proceedings of 7th SESAR Innovation Days, 2017 (SIDS), 28-30 November 2017, Belgrade, Serbia