



INTERFACING

An INteracTion mEtRic For An effiCient traffic demaNd
manaGement: requirements for the design of data-
driven protection mechanisms

Aslogic

Engage TC2 Workshop. Athens
2 of December 2019



Founding Members



An Interaction Metric for an Efficient Traffic Demand Management : requirements for the design of data-driven protection mechanisms

Project data

- Title: *An Interaction Metric for an Efficient Traffic Demand Management : requirements for the design of data-driven protection mechanisms*
- Duration: 12 Months
- Participant: Aslogic
- Start date: 22 May 2019
- Call identifier: Thematic challenge 2: Data-driven trajectory prediction
- Grant Agreement reference:-----

Outline

Introduction

Problem definition

Interaction zone characterization

Proposed Interaction metrics

Achievements and V&V

Project goal and objectives

GOAL

To enhance Demand Capacity Balancing with a digitalization tool to gain a better understanding of the efficiency of the regulations

O1: To identify Interaction Zones

O2: Identify Interaction Zones interdependencies

O3: Local and Distributed Interaction Metric

O4: Efficient Regulation support

O5: Baseline for protection Mechanisms

Project goal and objectives

O1: To identify Interaction Zones

- Spatio-temporal identification of airspace volumes in which more than one aircraft could co-exist

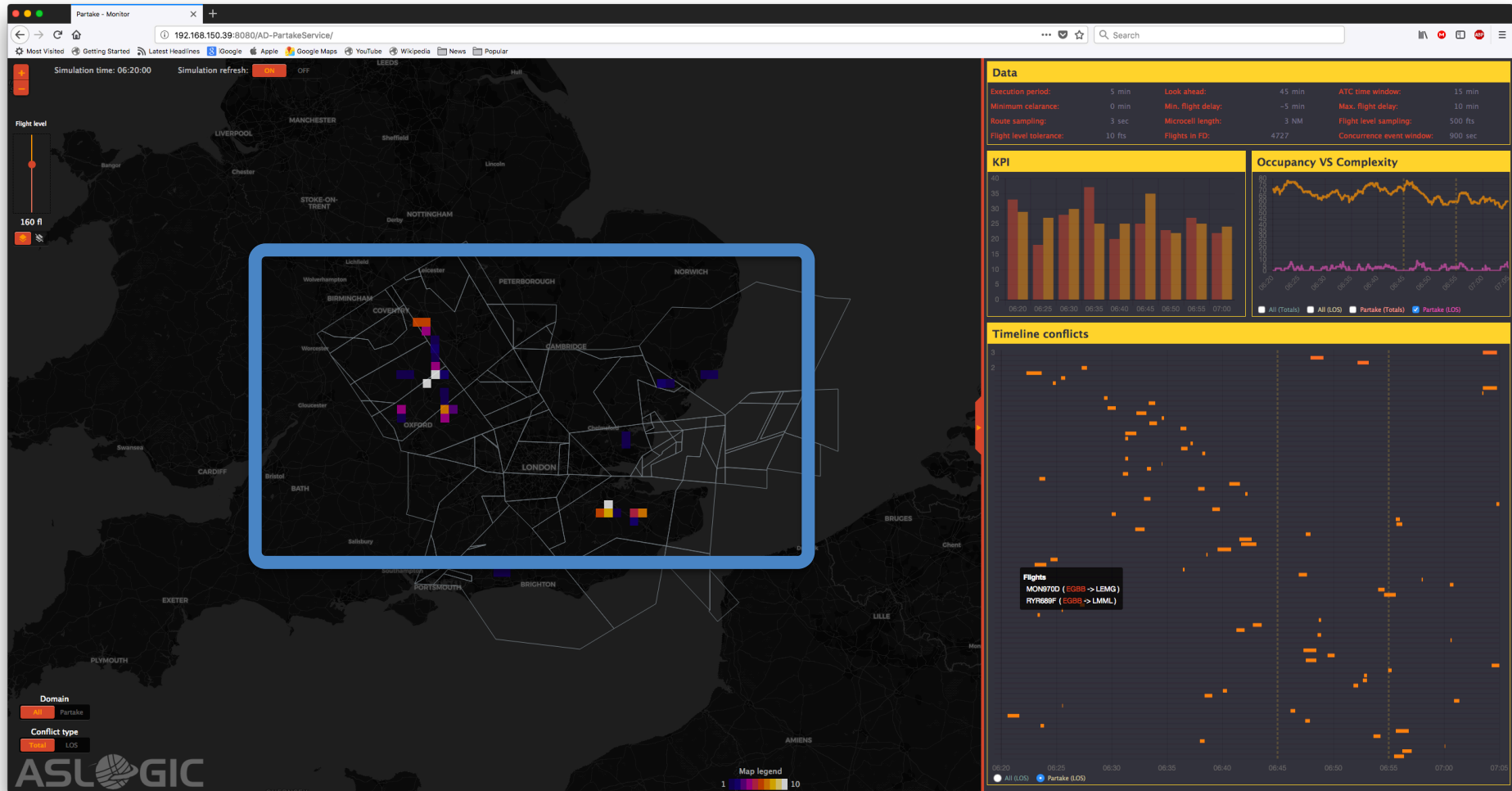
O2: Identify Interaction Zones interdependencies

O3: Local and Distributed Interaction Metric

O4: Efficient Regulation support

O5: Baseline for protection Mechanisms

O1: To identify Interaction Zones



Project goal and objectives

O1: To identify Interaction Zones

O2: Identify Interaction Zones interdependencies

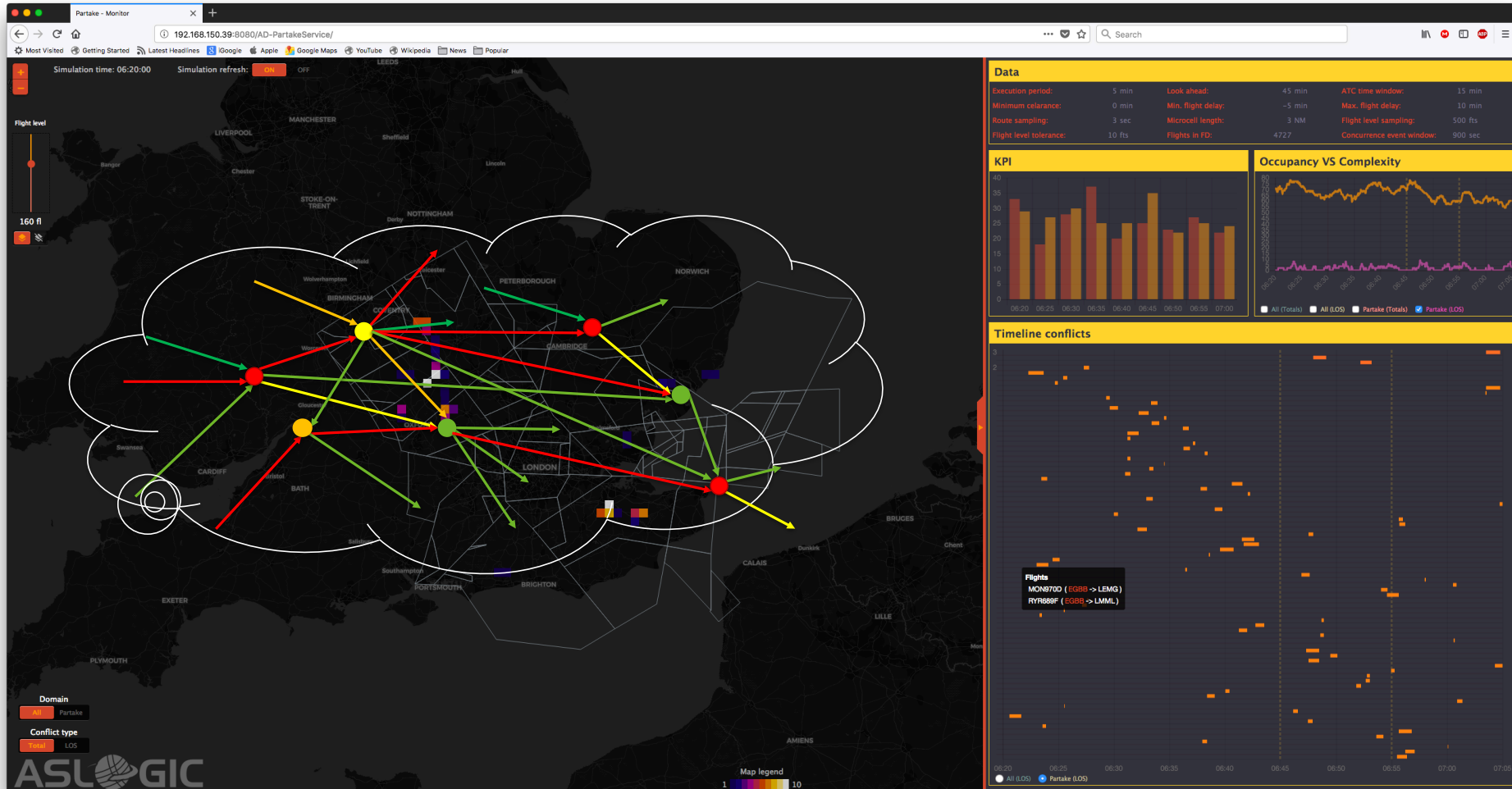
- Analysis of the spatio-temporal interdependencies among Interaction Zones

O3: Local and Distributed Interaction Metric

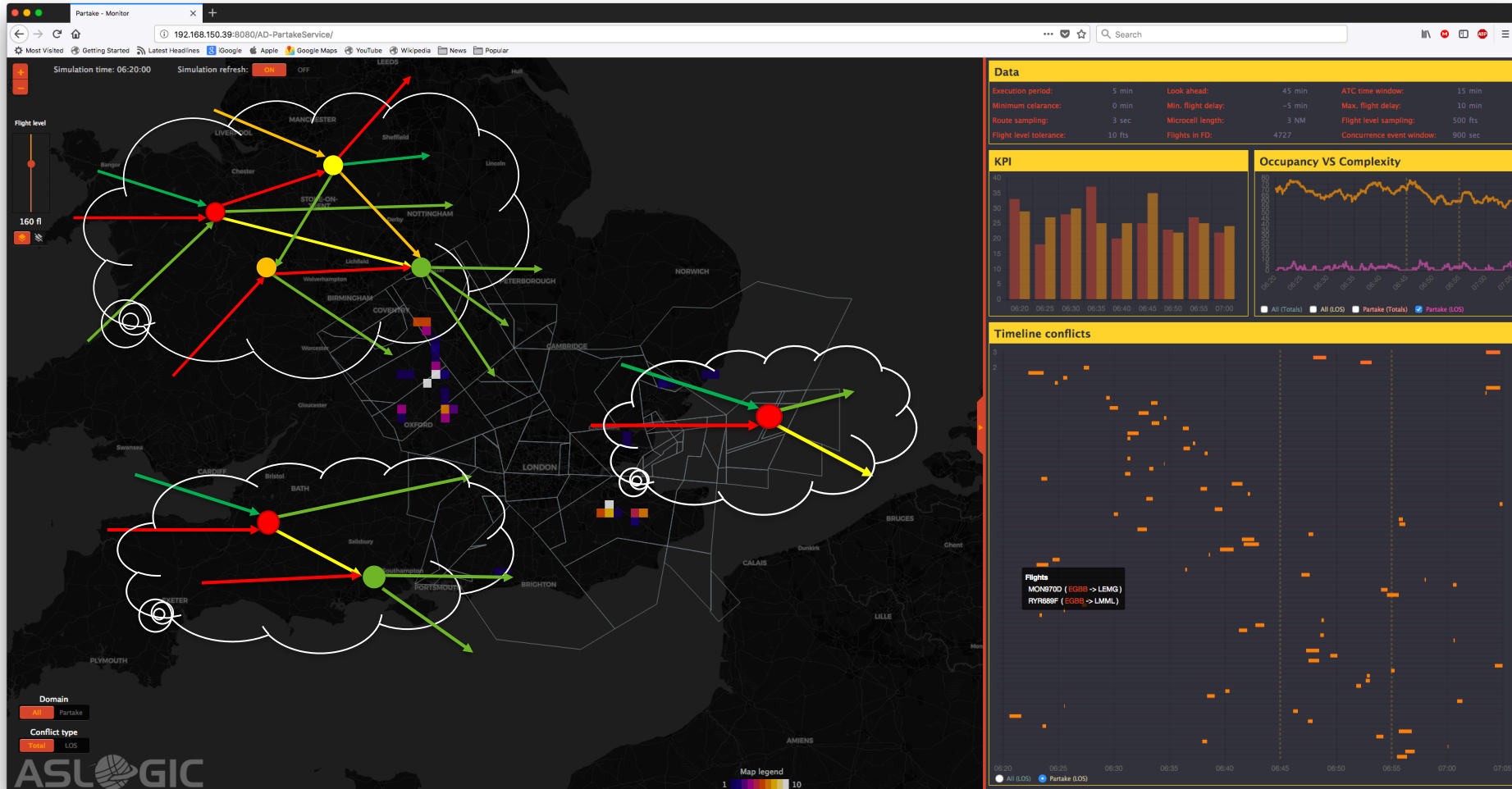
O4: Efficient Regulation support

O5: Baseline for protection Mechanisms

O2: Interaction Zones interdependencies



O2: Interaction Zones interdependencies



Project goal and objectives

O1: To identify Interaction Zones

O2: Identify Interaction Zones interdependencies

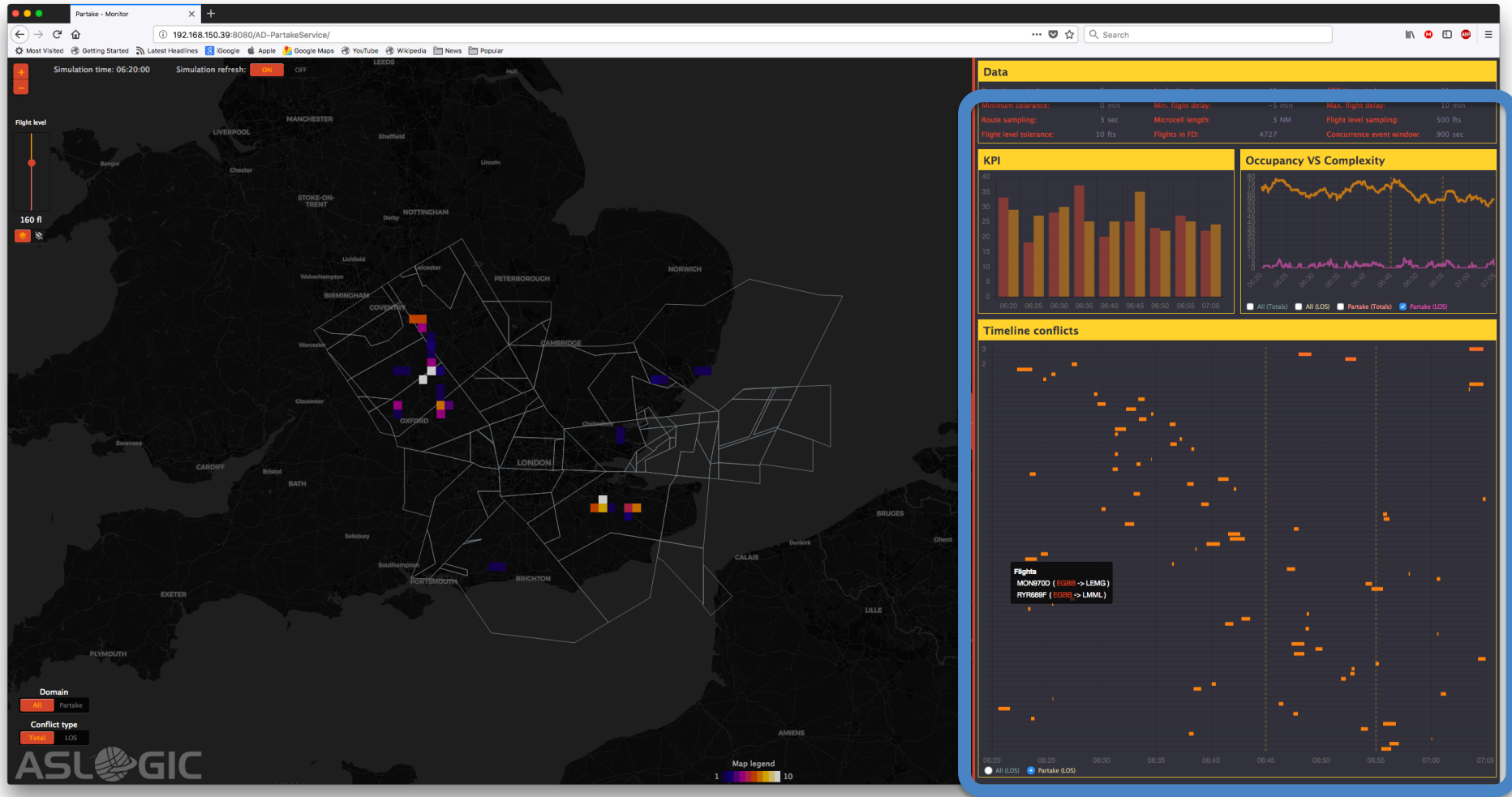
O3: Local and Distributed Interaction Metric

- sector entry and occupancy metrics will be enhanced with the new interaction metrics that provide a spatio-temporal characterization of the interaction Zones

O4: Efficient Regulation support

O5: Baseline for protection Mechanisms

O3: Local & Distributed Interaction Metrics



Project goal and objectives

O1: To identify Interaction Zones

O2: Identify Interaction Zones interdependencies

O3: Local and Distributed Interaction Metric

O4: Efficient Regulation support

- PARTAKE tools will be updated to enhance Demand Capacity Balancing with a supporting tool to predict the positive and negative impact of upstream and downstream Interaction Zones dynamics

O5: Baseline for protection Mechanisms

Project goal and objectives

O1: To identify Interaction Zones

O2: Identify Interaction Zones interdependencies

O3: Local and Distributed Interaction Metric

O4: Efficient Regulation support

O5: Baseline for protection Mechanisms

- A try-and-error approach will allow NM to experiment with different adjustments applied at trajectory level.

Background & Expected Impact

Extend PARTAKE to **implement a new interaction metric**

- data-driven methods
- detection
- analysis tools

Expected impact

- Enhancement of the DCB for ATC Minimum Intervention
- On efficiency of DCB network services, by a proper integration between the ATFCM and ANSP regulation procedures

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Introduction

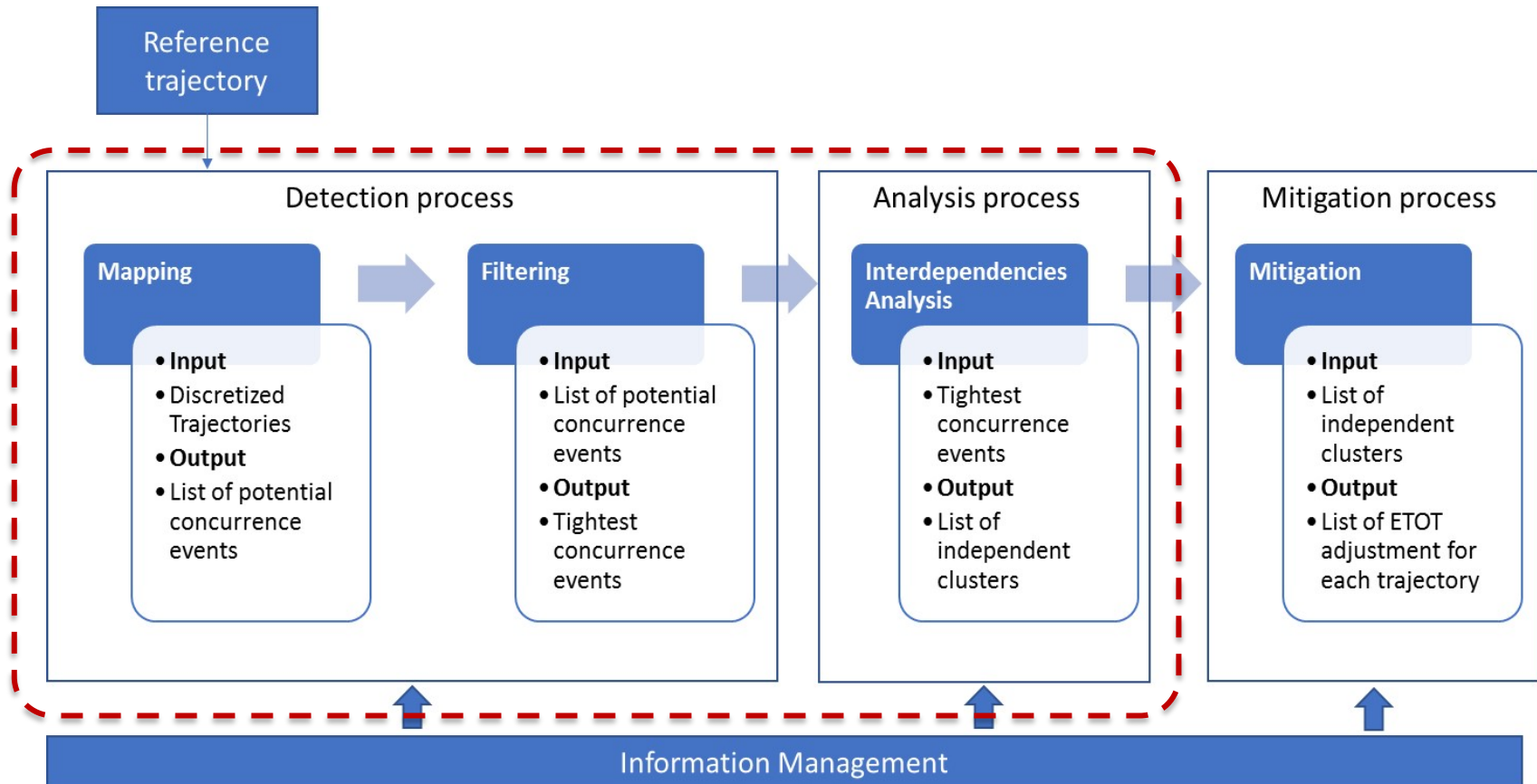
Problem definition

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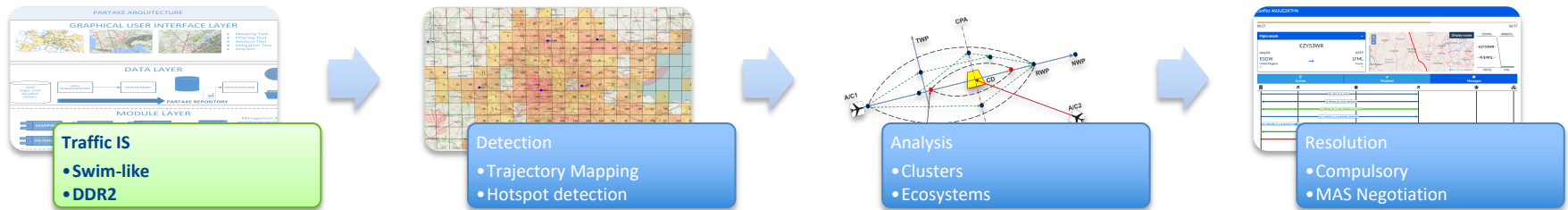
Proposed Interaction metrics

Achievements and V&V

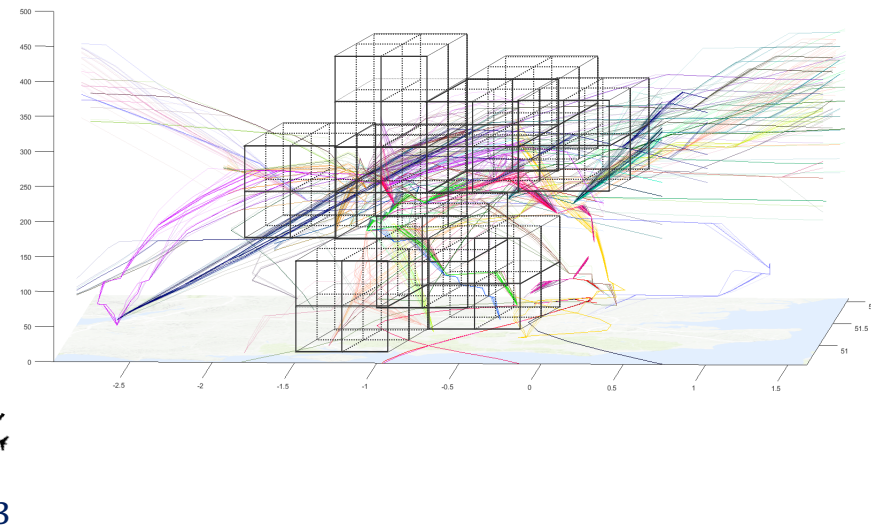
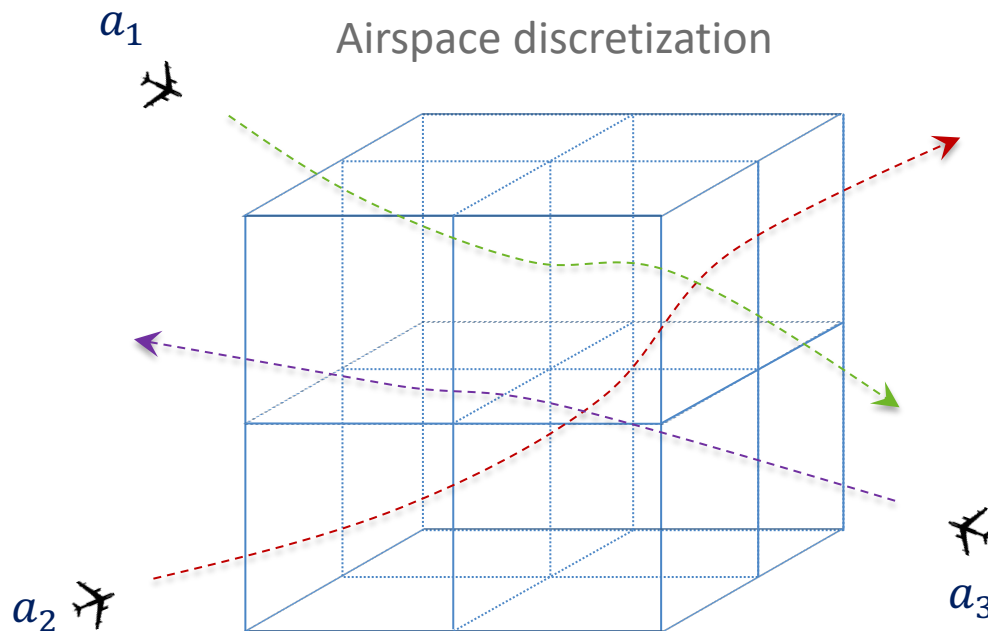
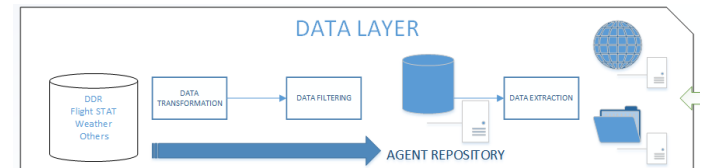
Background: PARTAKE Methodology



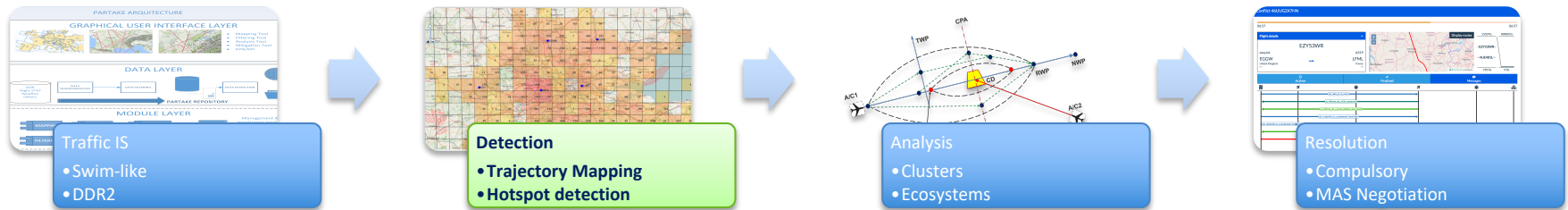
PARTAKE Digitalization: Trajectory mapping



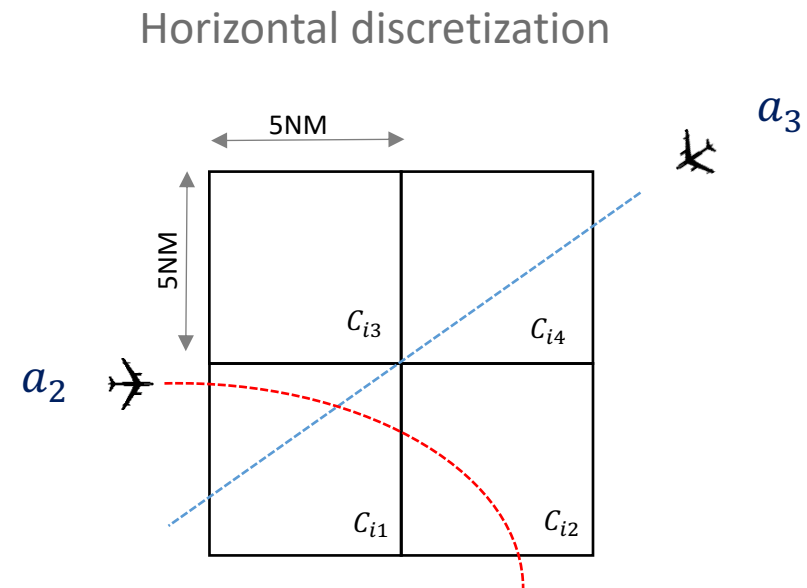
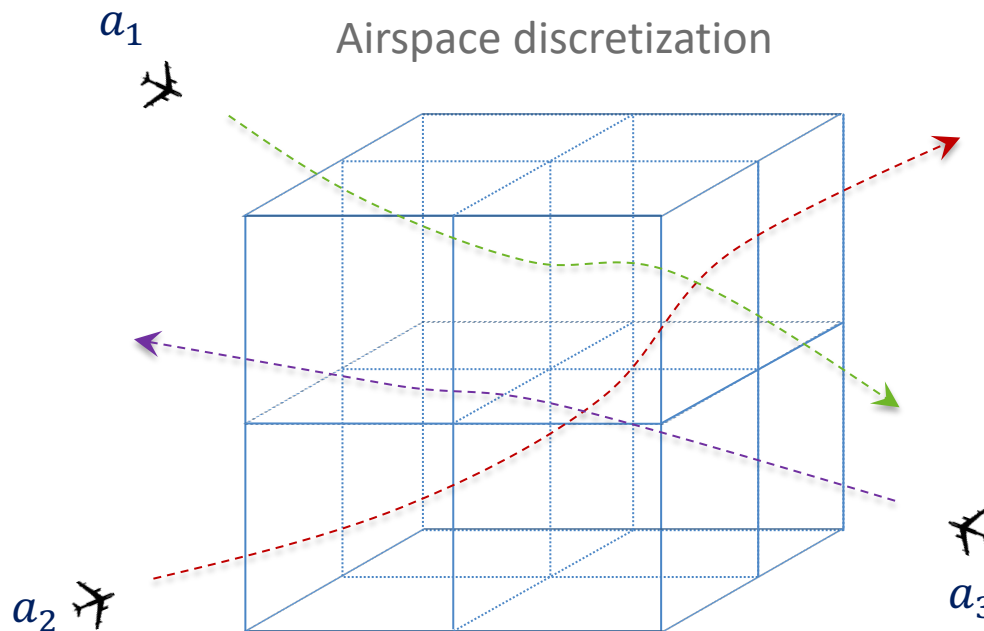
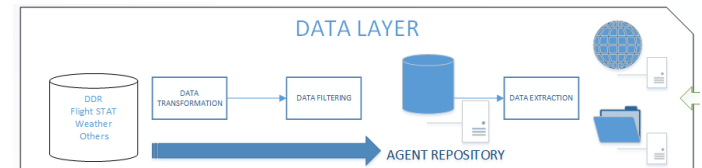
Traffic scenarios are created from RBT's (e.g. DDR2 data)



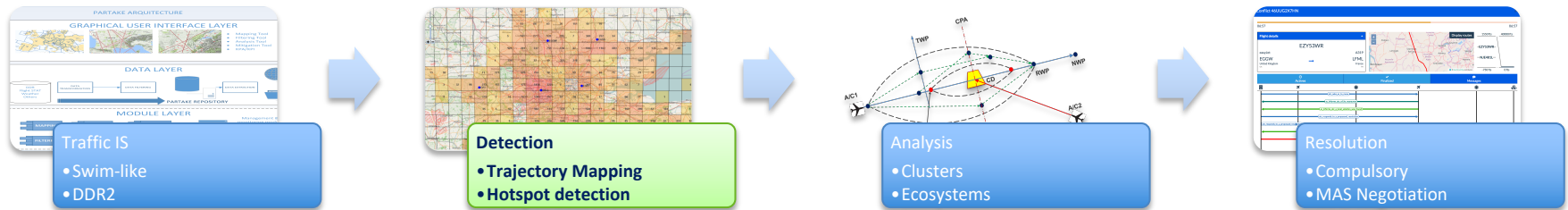
PARTAKE Digitalization: Trajectory mapping



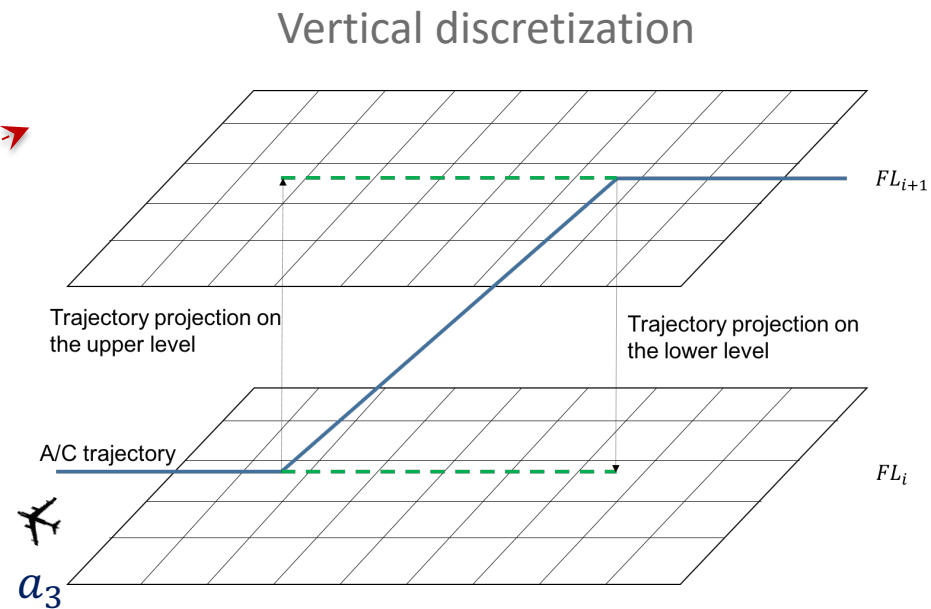
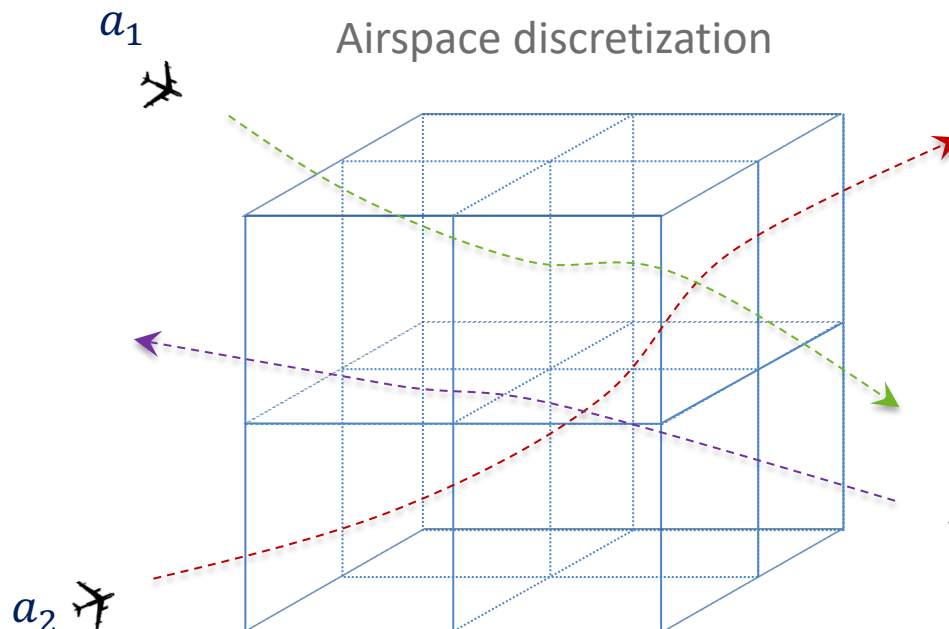
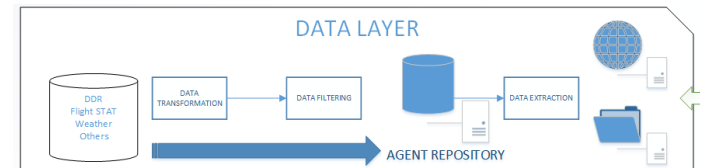
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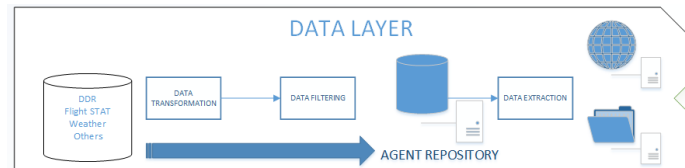
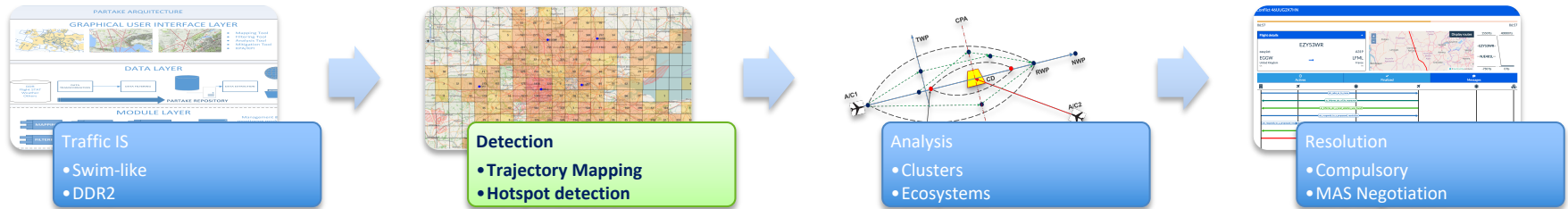
PARTAKE Digitalization: Trajectory mapping



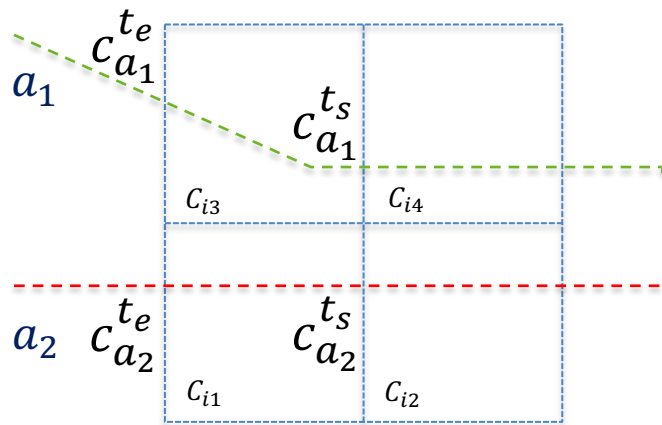
Traffic scenarios are created from RBT's (e.g. DDR2 data)



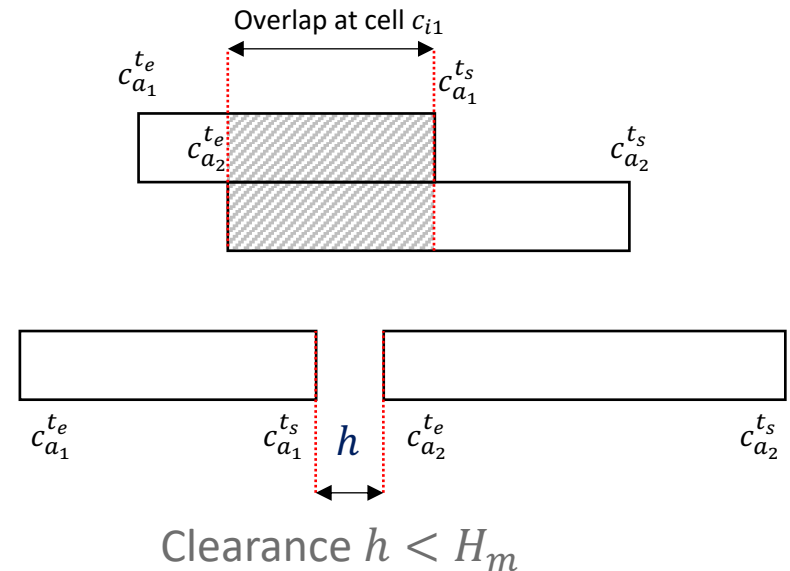
PARTAKE Interdependency detection



Digitalization: time discretization

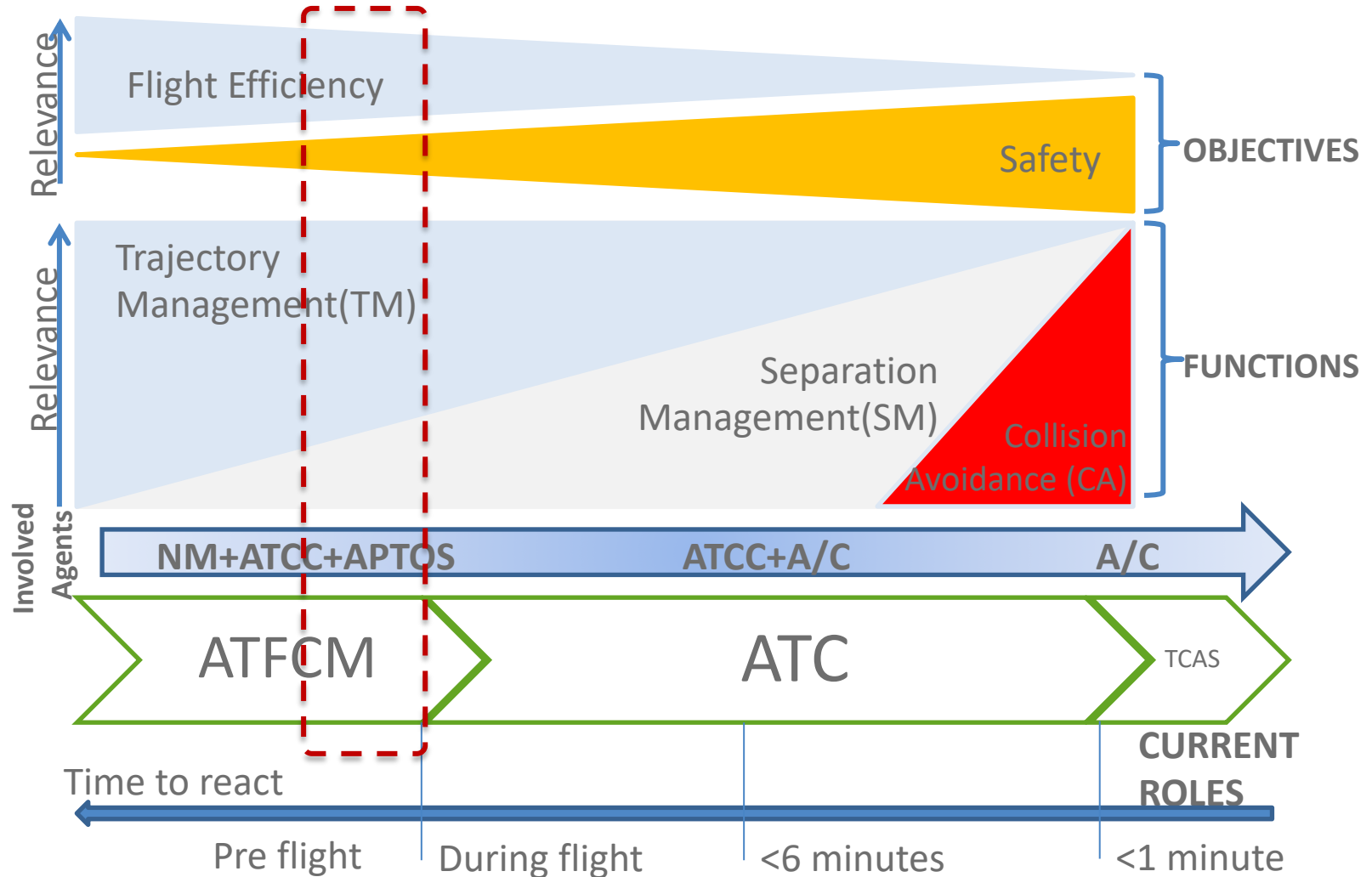


Potential Concurrence Event
Loss of separation minima

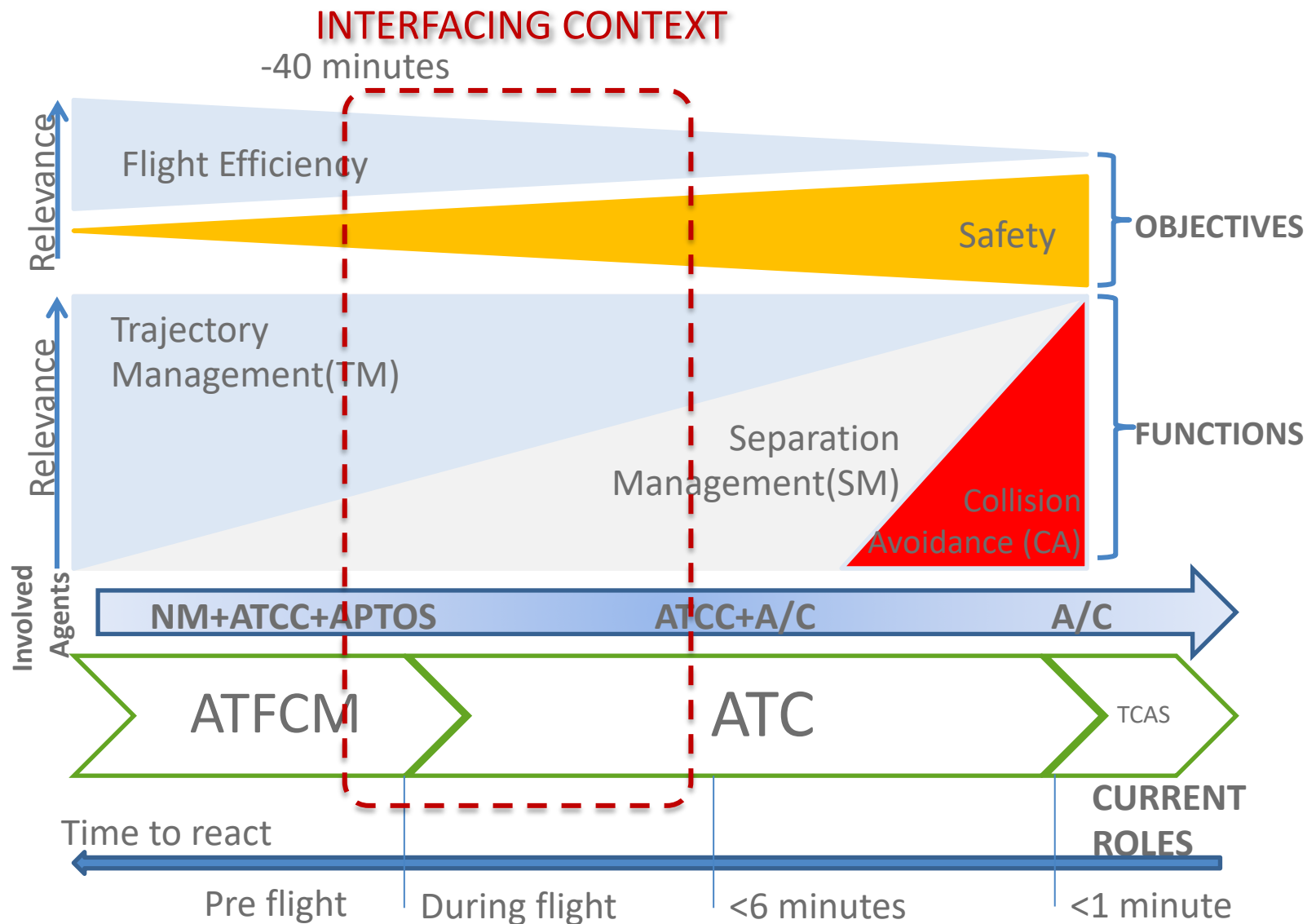


ATM Context

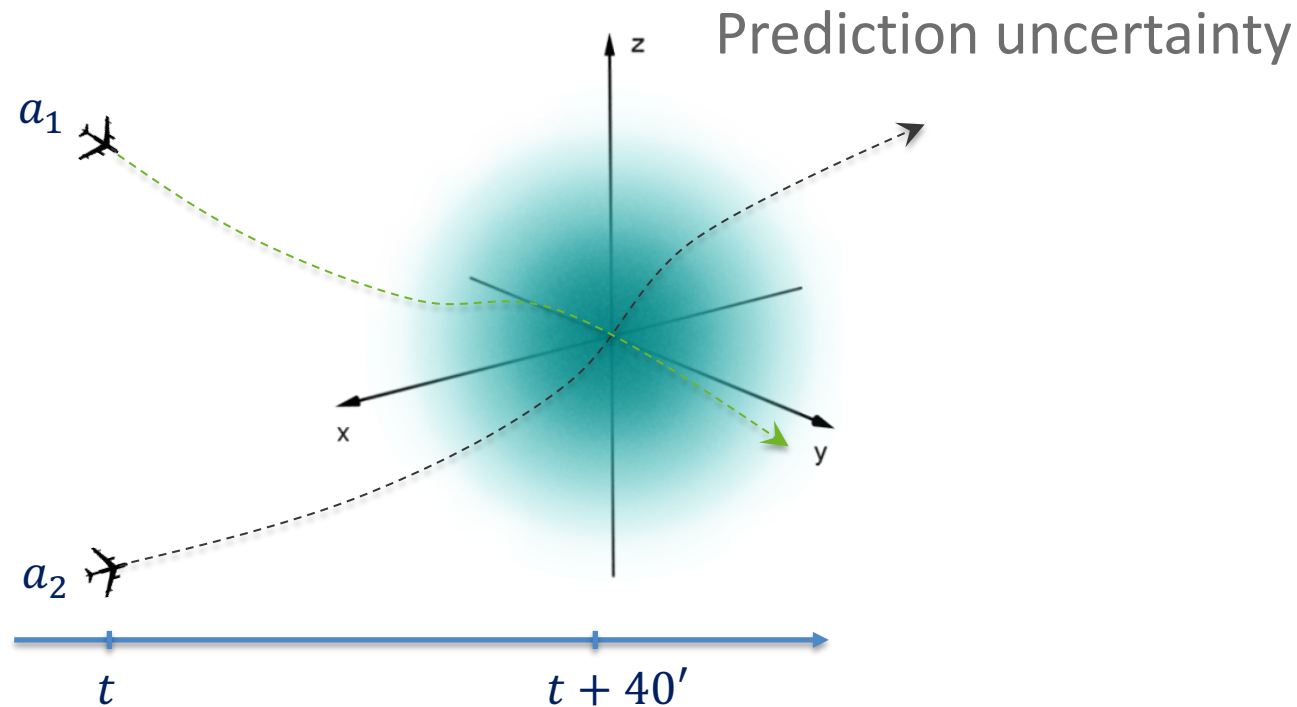
PARTAKE CONTEXT



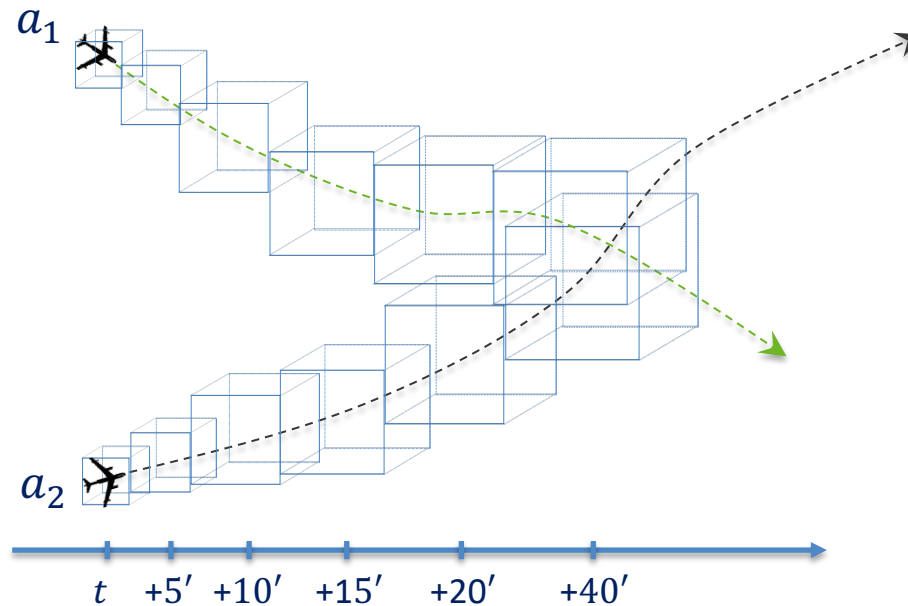
ATM Context



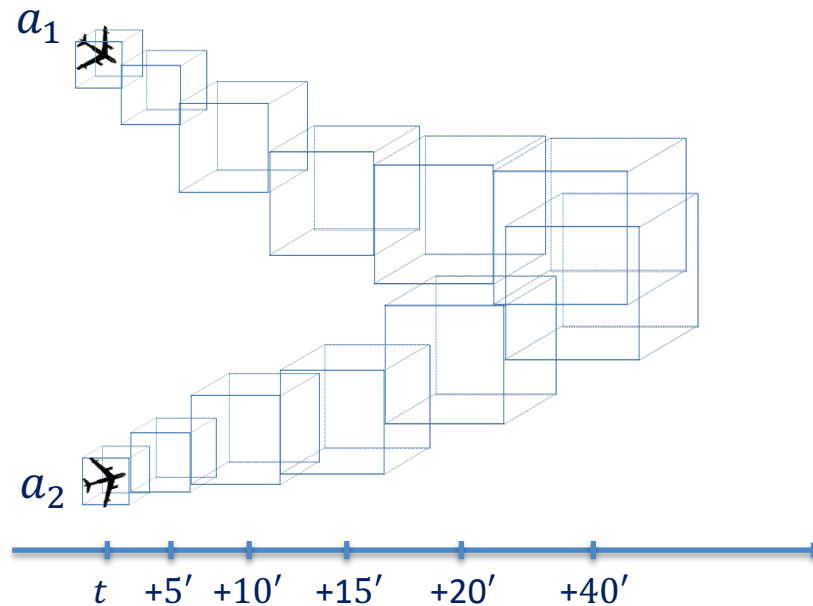
Interaction Zone as generalization of the Potential Concurrence Event



Interaction Zone as generalization of the Potential Concurrence Event

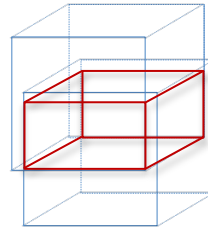


Interaction Zone as generalization of the Potential Concurrence Event



Interaction Zone as generalization of the Potential Concurrence Event

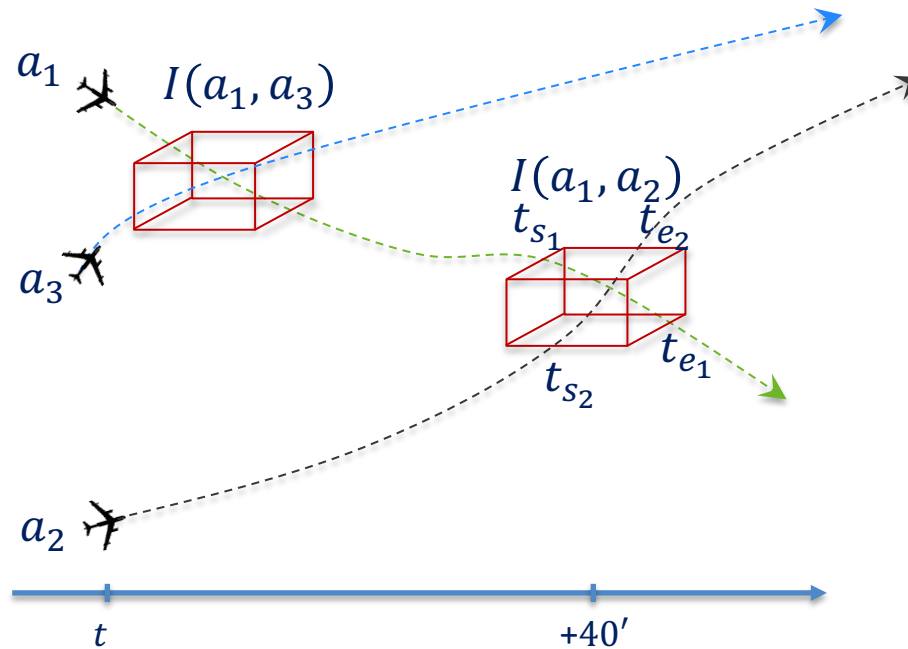
a_1 ✈



a_2 ✈



Interaction Zone as generalization of the Potential Concurrence Event



Characterization

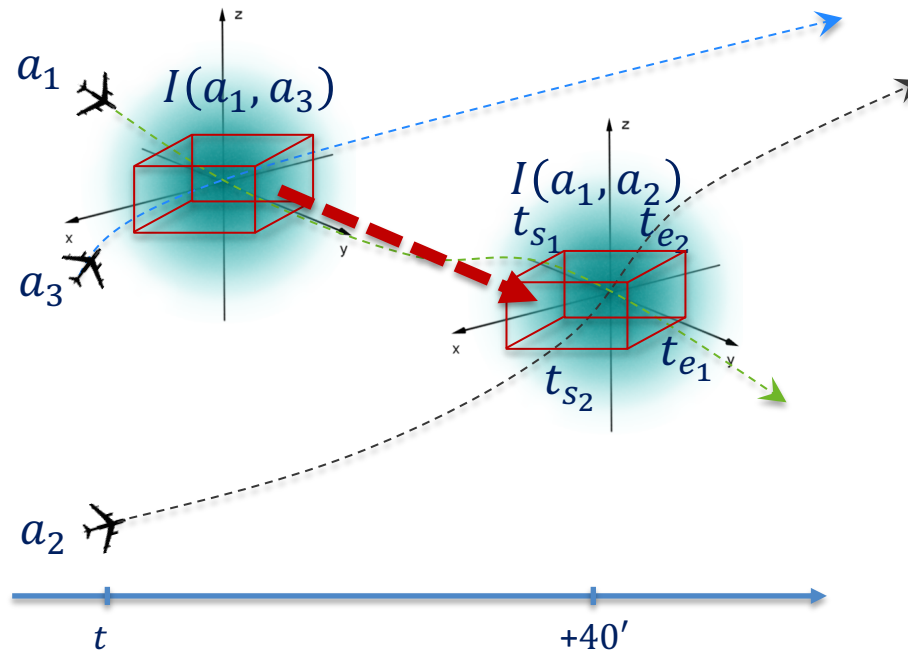
Geometry

Existence Probability

Complexity

Interdependencies

Interaction Zone as generalization of the Potential Concurrence Event



Characterization

Uncertainty

Interaction Zone

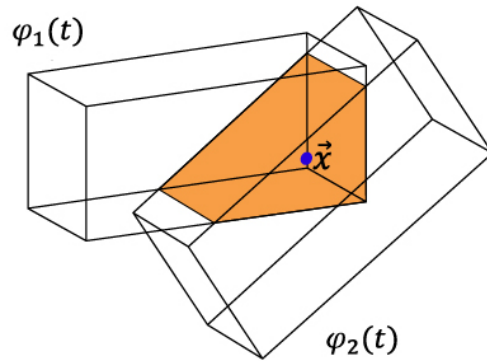
Interdependency

- The predicted position of an aircraft at a given instant can be projected into a volume where it might be
- Is a spatial volume in which during a time interval there is the possibility that two or more aircraft interact
- Is a relationship amongst IZs that can alter their probability of existence or their intrinsic properties

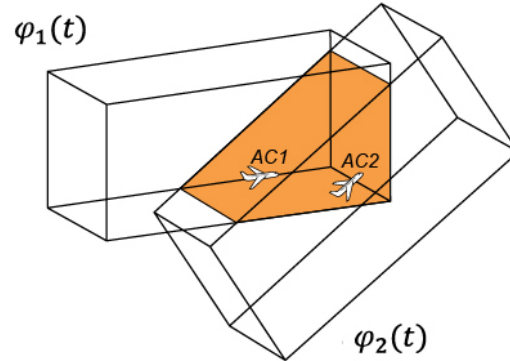
Interaction zone definition

Spatio-temporal concept

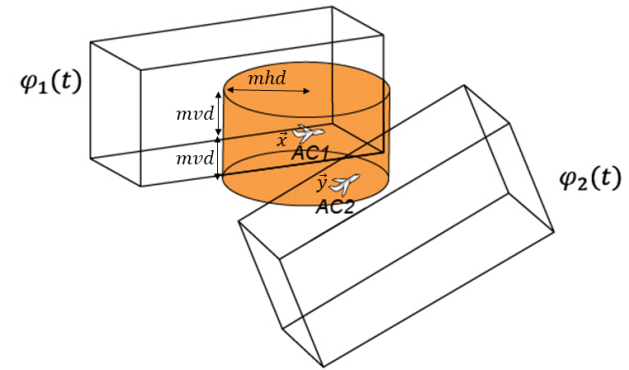
INTERFACING CONTEXT



(A) Collision



(B) Coexistence



(C) Loss of Separation

Existence Probability

AC1 and AC2 being together
at \vec{x} for every \vec{x} in the
intersection

AC1 and AC2 are inside the
intersection, not necessarily
in the same point

AC1 being at some point and
AC2 being at the same time
in the safety buffer of AC1

Outline

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Problem definition

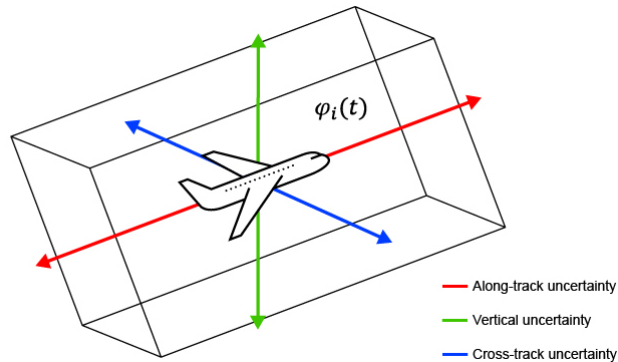
Interaction zone characterization

Proposed Interaction metrics

Achievements and V&V

Pairwise Interaction Zone

Spatial Characterization

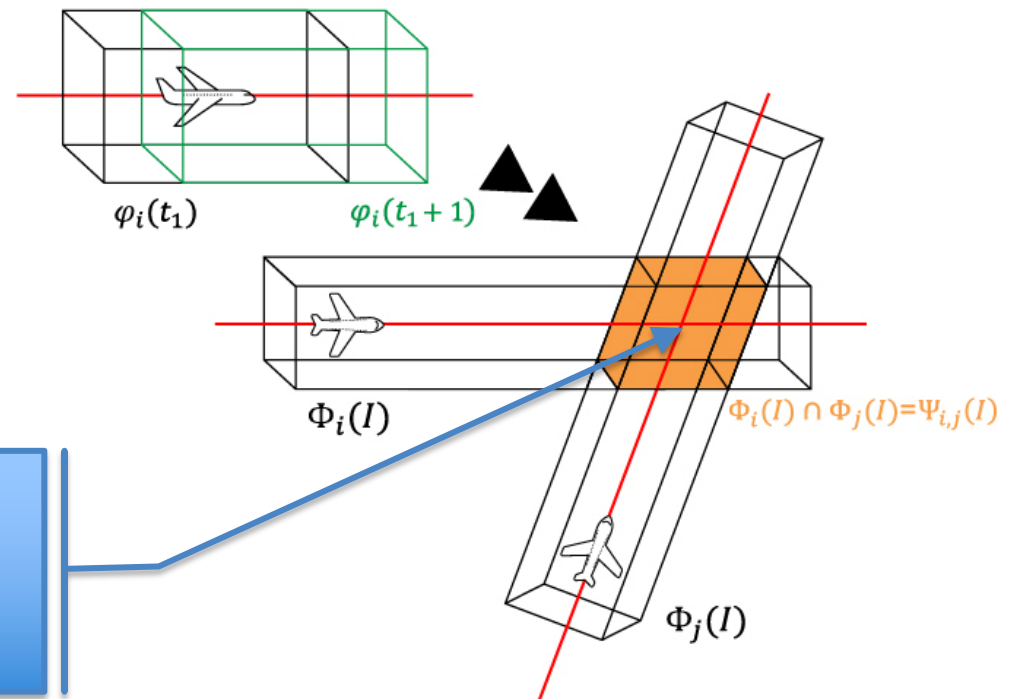


$$\varphi_i(t): \mathbb{R} \rightarrow U_i \subseteq \mathbb{R}^3$$

Spatio-temporal Characterization

$$I = [t_{i+k}, t_{i+(k+l)}] \quad \text{with} \quad k + l \leq th$$

$$\Phi_i(I) = \bigcup_{t \in I} \varphi_i(t)$$



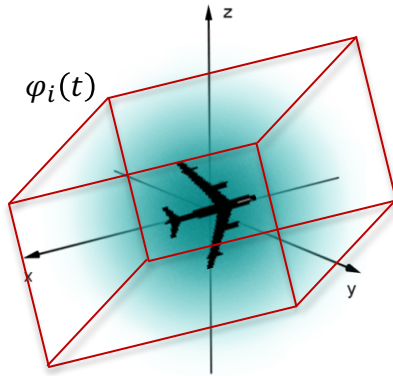
Pairwise
Coexistence
Interaction
Zone

Pairwise Interaction Zone

Probabilistic Characterization



Existence Probability

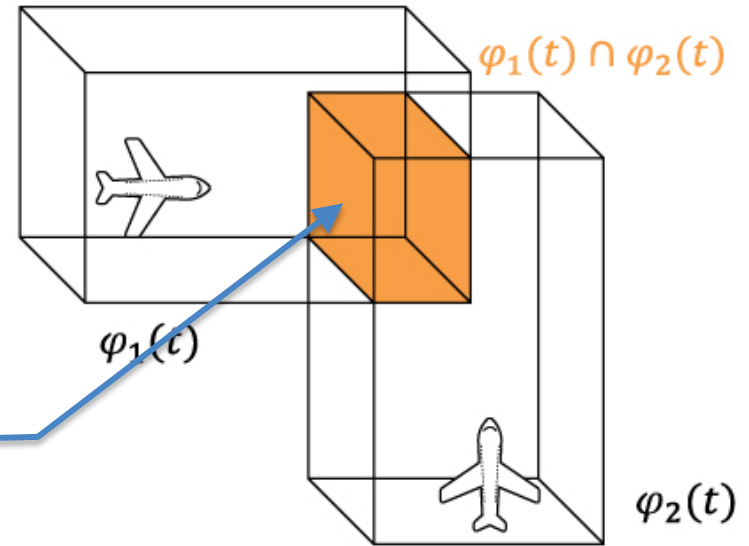


$$\varphi_i(t): \mathbb{R} \rightarrow U_i \subseteq \mathbb{R}^3$$

$$\int_{\varphi_i(t)} p_i(t, \vec{x}) d\vec{x} = 1$$

Pairwise
Coexistence
Interaction
Zone

$$I = [t_{i+k}, t_{i+(k+l)}] \quad \text{with} \quad k + l \leq th$$

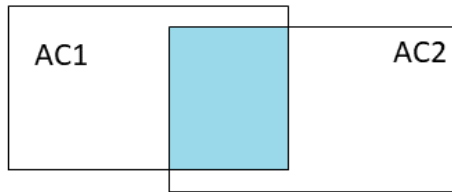


$$EP(t) = \int_{\varphi_1(t) \cap \varphi_2(t)} p_1(t, \vec{x}) d\vec{x} \cdot \int_{\varphi_1(t) \cap \varphi_2(t)} p_2(t, \vec{x}) d\vec{x} \quad (1)$$

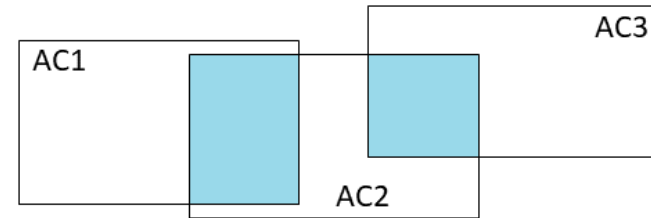
Generalized Interaction Zone

Spatial Characterization

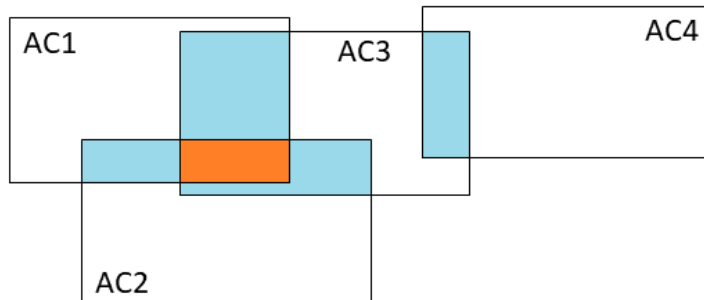
G_{IZ_1}



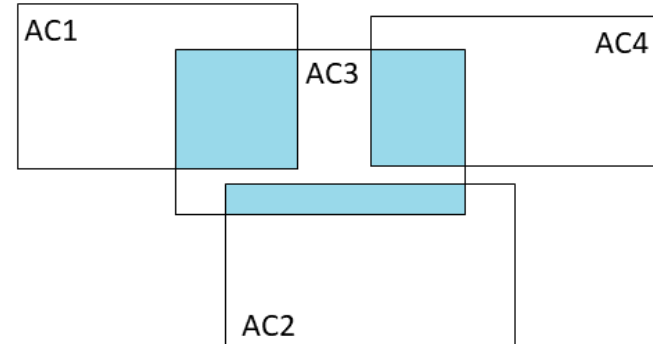
G_{IZ_2}



G_{IZ_4}

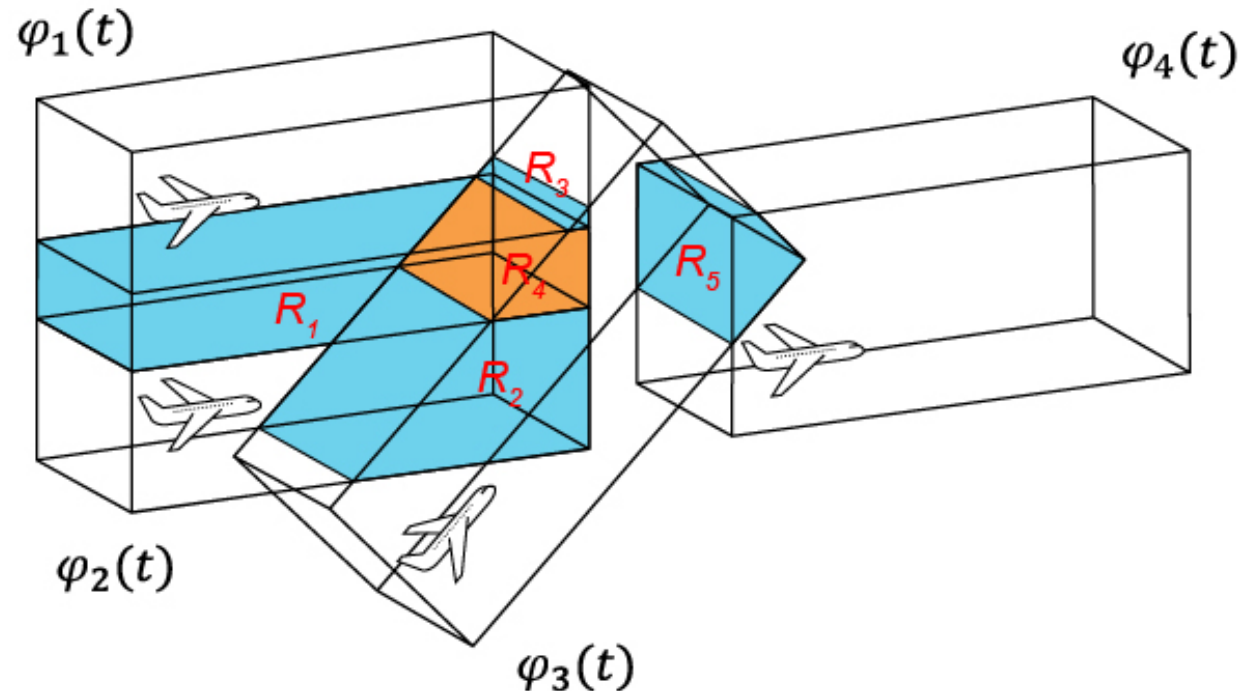
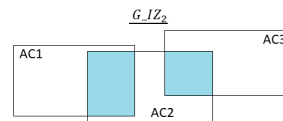
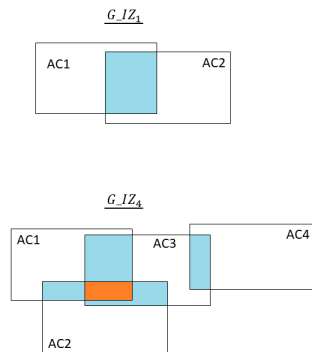


G_{IZ_5}



Generalized Interaction Zone

Spatial Characterization

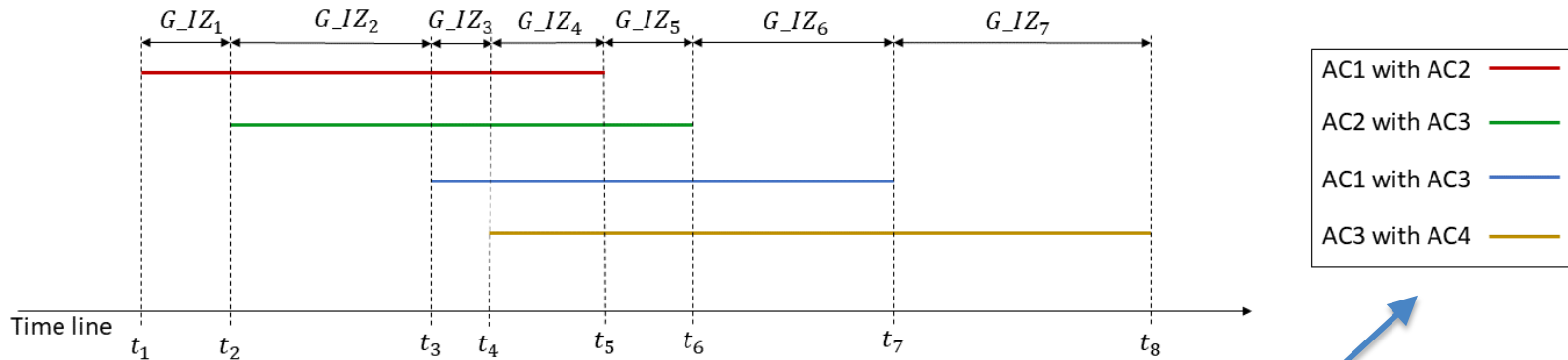
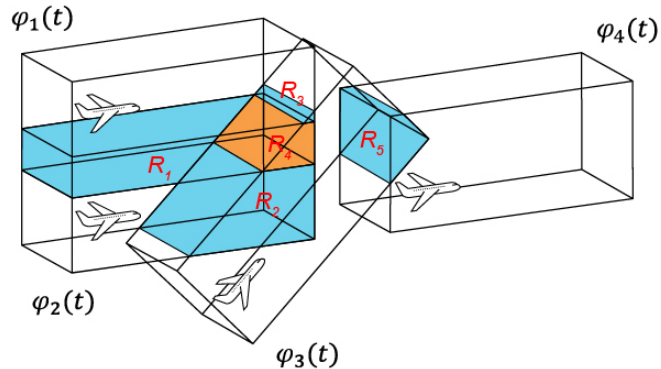


Generalized Interaction Zone

Spatial Characterization



Spatio-temporal Characterization



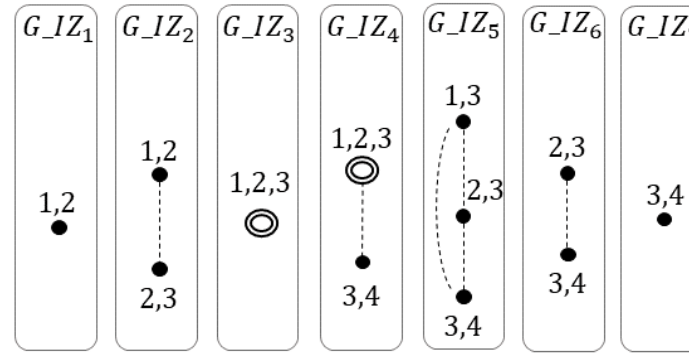
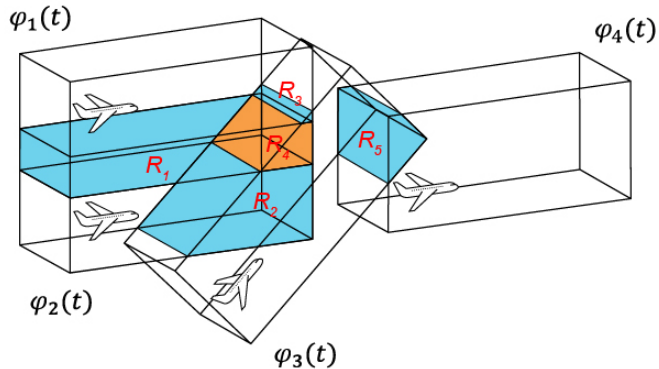
Pairwise
Interaction Zones

Interaction Zone Graph

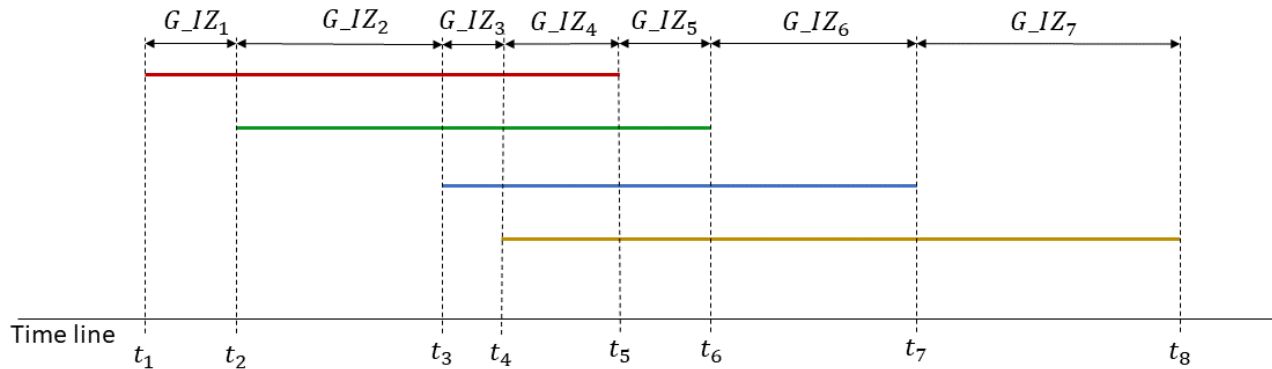
Spatio-temporal Characterization



Intrinsic structure (Nodes)



● Simple node
⊙ Complex node



AC1 with AC2 — Red
AC2 with AC3 — Green
AC1 with AC3 — Blue
AC3 with AC4 — Yellow

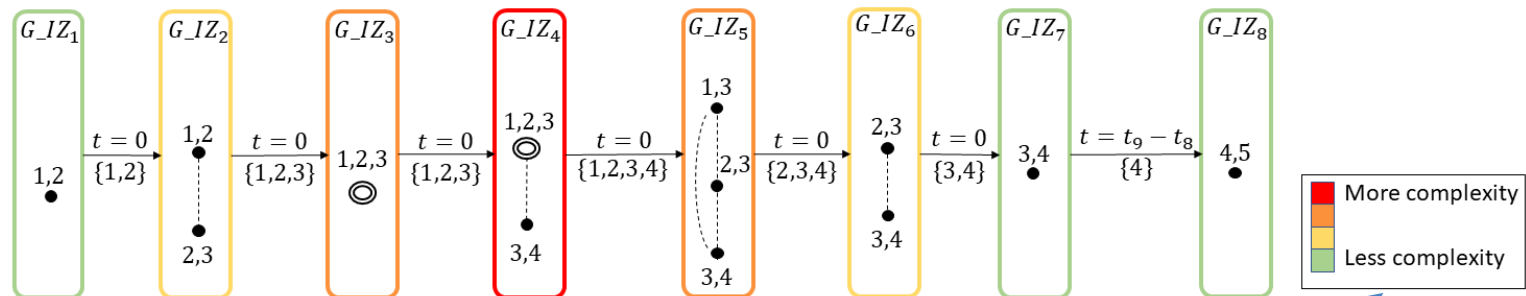
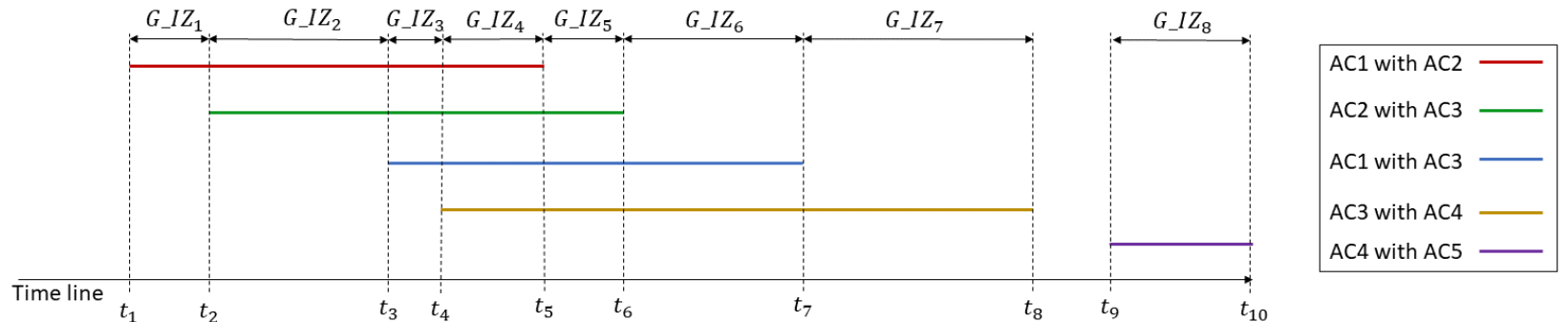
Pairwise
Interaction Zones

Interaction Zone Graph

Intrinsic structure (Nodes)



Interaction Zone Complexity

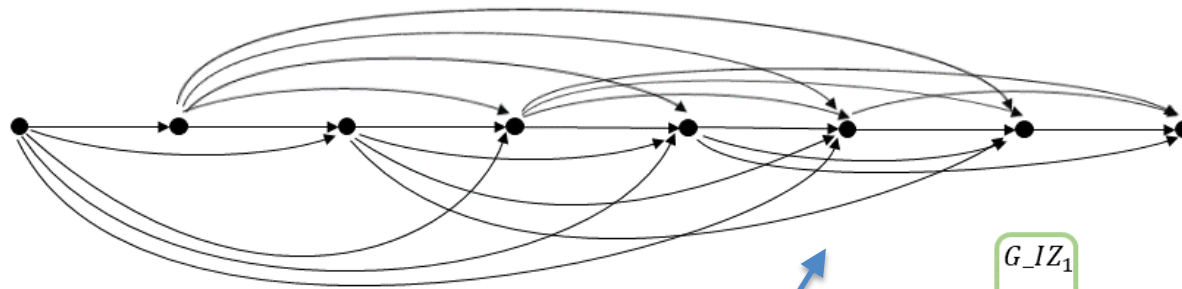
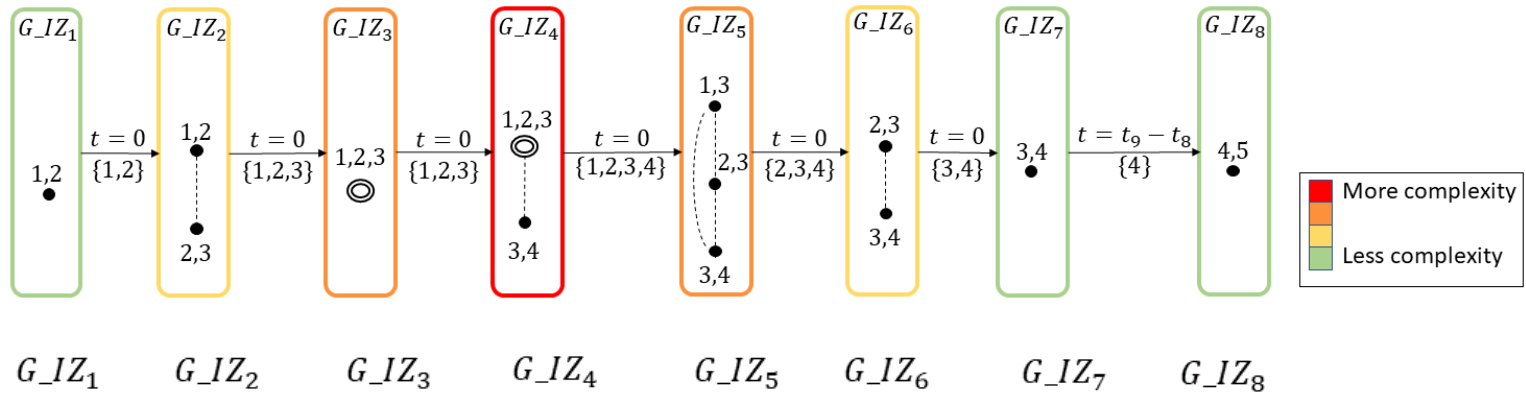


Interaction Zone
Complexity

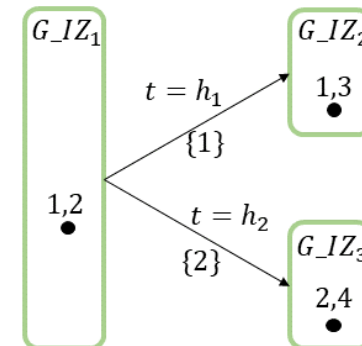
Interaction Zone Graph

Graph nodes

Interaction Zone Interdependencies



Interaction Zone
Interdependency Flows



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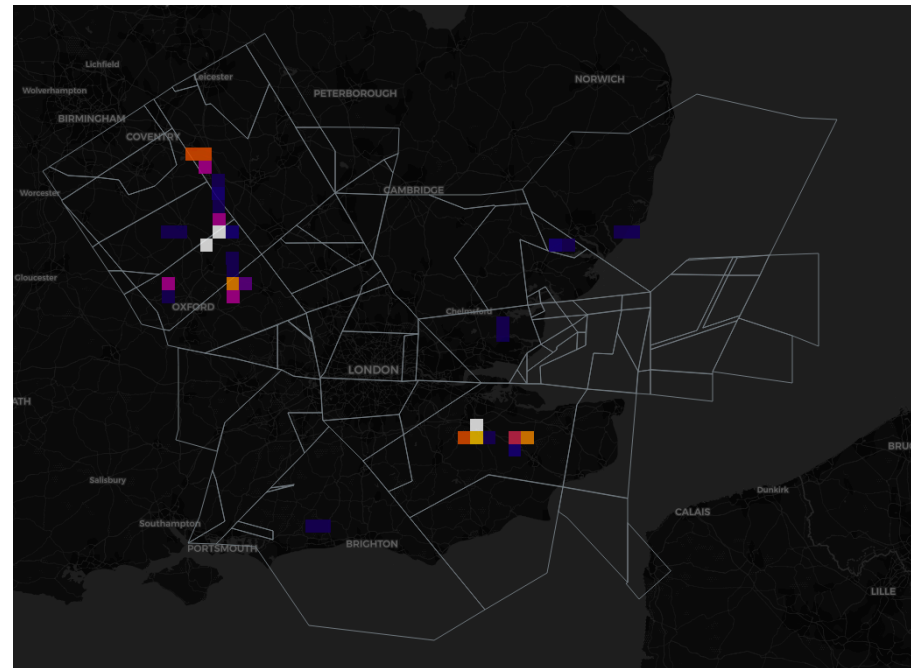
Achievements and V&V

Interaction Zone Metrics

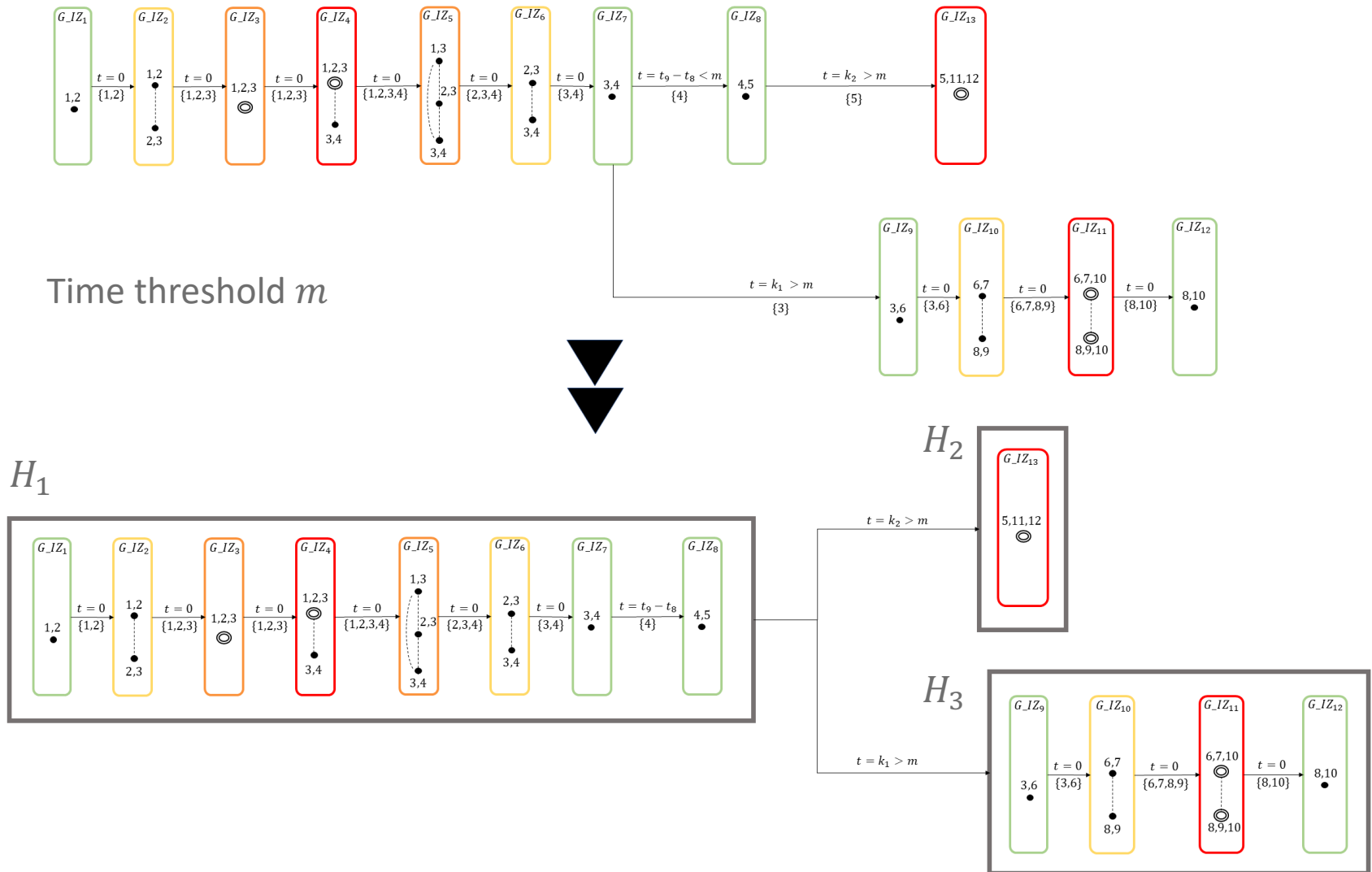
KPI	Name	Description
M1	Spatio-temporal characterization	time interval when an <i>IZ</i> occurs and the airspace location where it happens
M2	Existence probability	the probability of an <i>IZ</i> to actually occur
M3	Involved Aircrafts	number of aircrafts that are interacting in a <i>IZ</i>
M4	Complexity	Calculated from the intrinsic structure (graph nodes) at the <i>IZ</i>

These metrics can be aggregated for airspace volumes.

For example, an airspace sector can be analysed with the aggregated information of all the *IZs* it contains.



Interaction Zone aggregation (Hotspot)



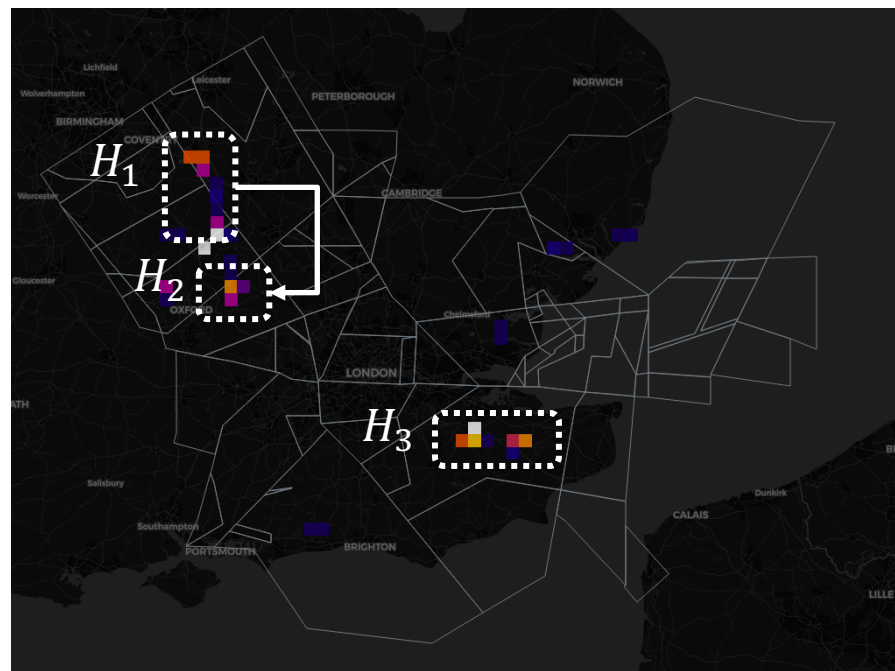
Hotspot Metrics

KPI	Name	Description
M5	Elapsed time	time calculated as the difference between first <i>I</i> Z start and last <i>I</i> Z end
M6	Time separation	Time separation between hotspots that are related because of sharing aircrafts
M7	Shared Aircrafts	Which and how many aircraft are shared amongst hotspots
M8	Persistence	Areas where a number of hotspots tend to happen recurrently

A hotspot lasting for too long might require specific measures on the involved aircrafts

Time separation might be useful to analyse the downstream effect of mitigation measures.

A hotspot area persisting for too long might require specific measures on the involved traffic flows



Project objectives and proposed metrics

	Objective	Metrics
O1	To identify Interaction Zones	M1, M2, M3, M4
O2	Identify Interaction Zones interdependencies	M5, M6, M7
O3	Local and Distributed Interaction Metric	M2, M3, M4, M8

O4: Efficient Regulation support

- The proposed metrics provide a measure of the positive and negative impact of upstream and downstream Interaction Zones dynamics

O5: Baseline for protection Mechanisms

- A try-and-error approach allows NM to experiment with different adjustments applied at trajectory level

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Achievements and V&V

- PARTAKE concepts and methods have been extended for the Interaction Zone analysis.
- The Interaction Zone concept has been mathematically formalized together with the analysis methods.
- The algorithm implementation details and computational efforts have been deeply analysed to ensure the practical applicability of the proposed concept of operations.
- Positive feedback received from NM about both the proposed concept of operation and the Interaction Zone metrics.
- The designed methods are parametrized (e.g. predicted position geometry and size, pdfs, interdependency time threshold, etc.) for better reliability of metrics. ML is envisaged for the fine tuning.
- Ongoing work in collaboration with NM to setup the right V&V exercises, also from ATC perspective.



INTERFACING

An Interaction Metric for an Efficient Traffic Demand Management:
requirements for the design of data-driven protection mechanisms

Thank you very much for your attention!



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Founding Members



EUROPEAN UNION



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