WP3: Prediction of complex traffic conditions

Review Meeting, EC, Brussels
September 29, 2009

Maria Prandini

Politecnico di Milano

Objectives & Structure of WP3

"study and develop methods for the timely prediction of potentially complex traffic conditions"

Organized in two tasks:

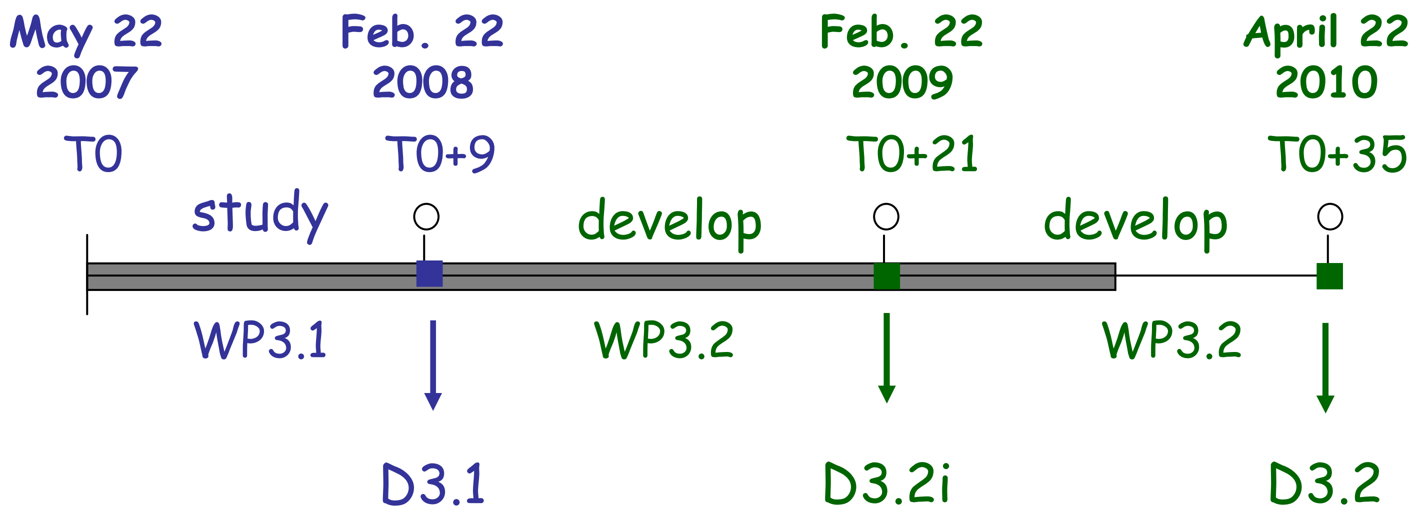
WP3.1: Comparative study of complexity metrics

- Deliverable 3.1: "Complexity metrics applicable to autonomous aircraft"

WP3.2: Timely predicting complex conditions

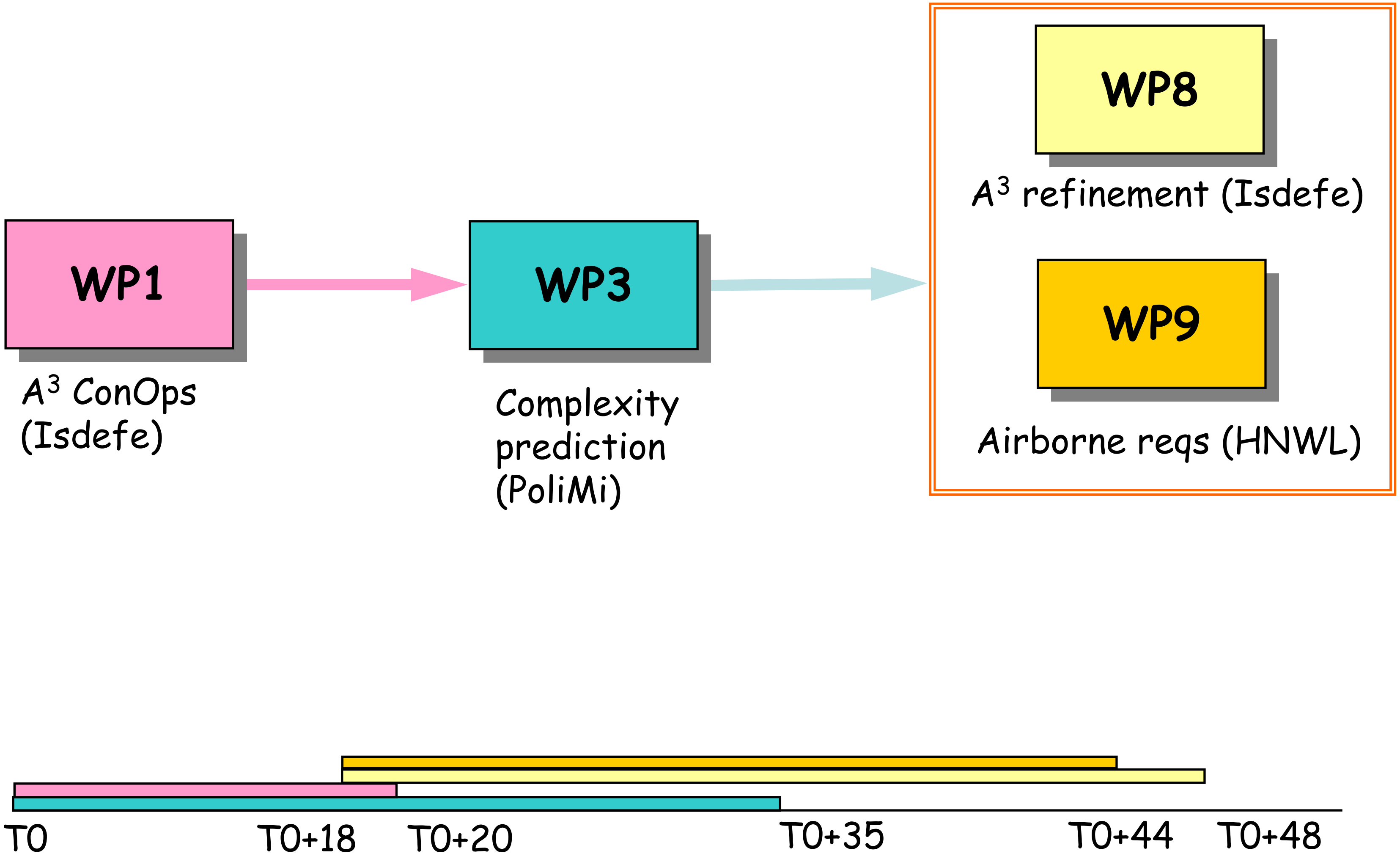
- Deliverable 3.2i: "Timely prediction of complex conditions for en-route aircraft" (intermediate)"
- Deliverable 3.2: "Timely prediction of complex conditions for en-route aircraft" (final)"

Timeline

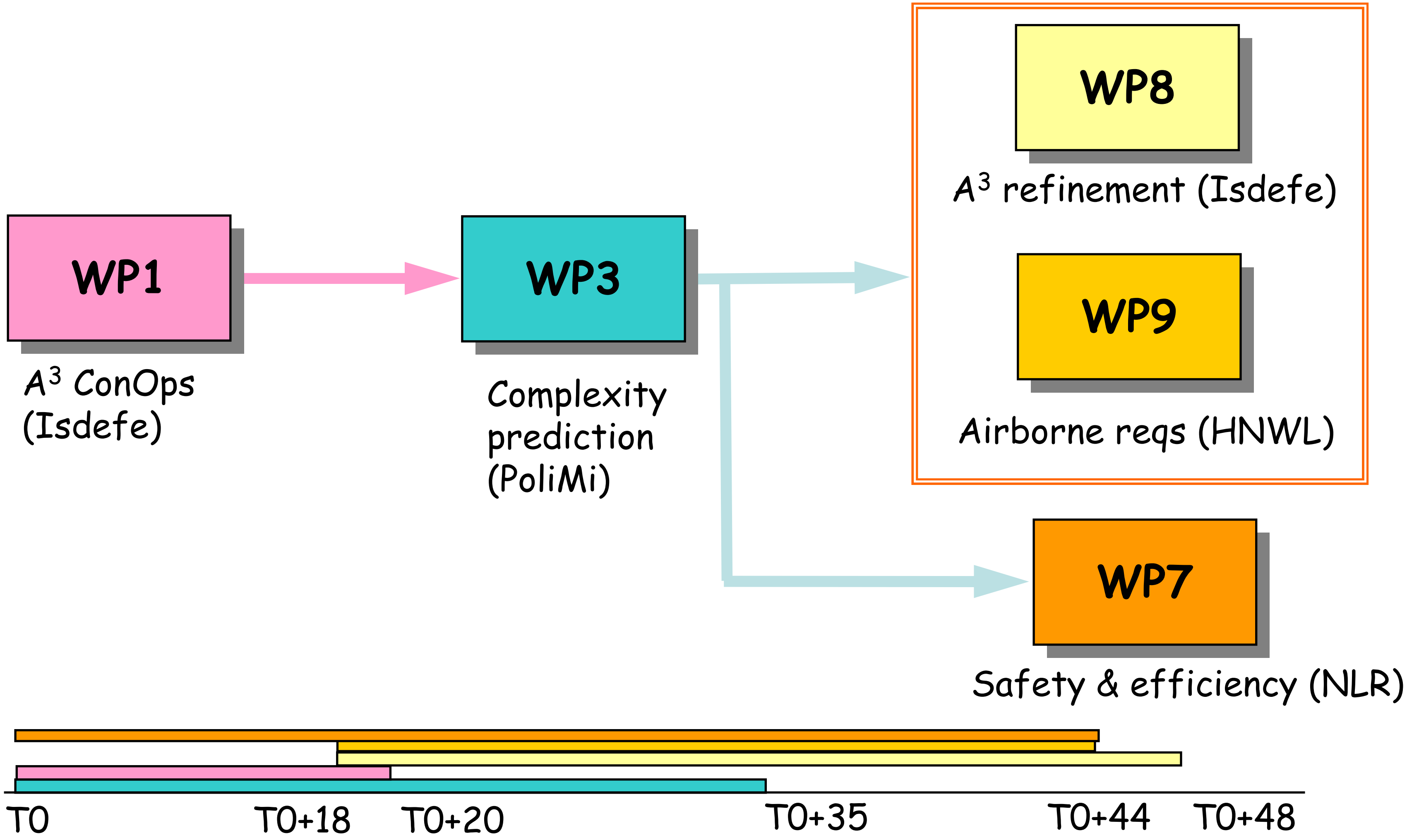


May 22
2007
T0
Feb. 22
2008
T0+9
Feb. 22
2009
T0+21
April 22
2010
T0+35
study
develop
develop
WP3.1
WP3.2
WP3.2
D3.1
D3.2i
D3.2

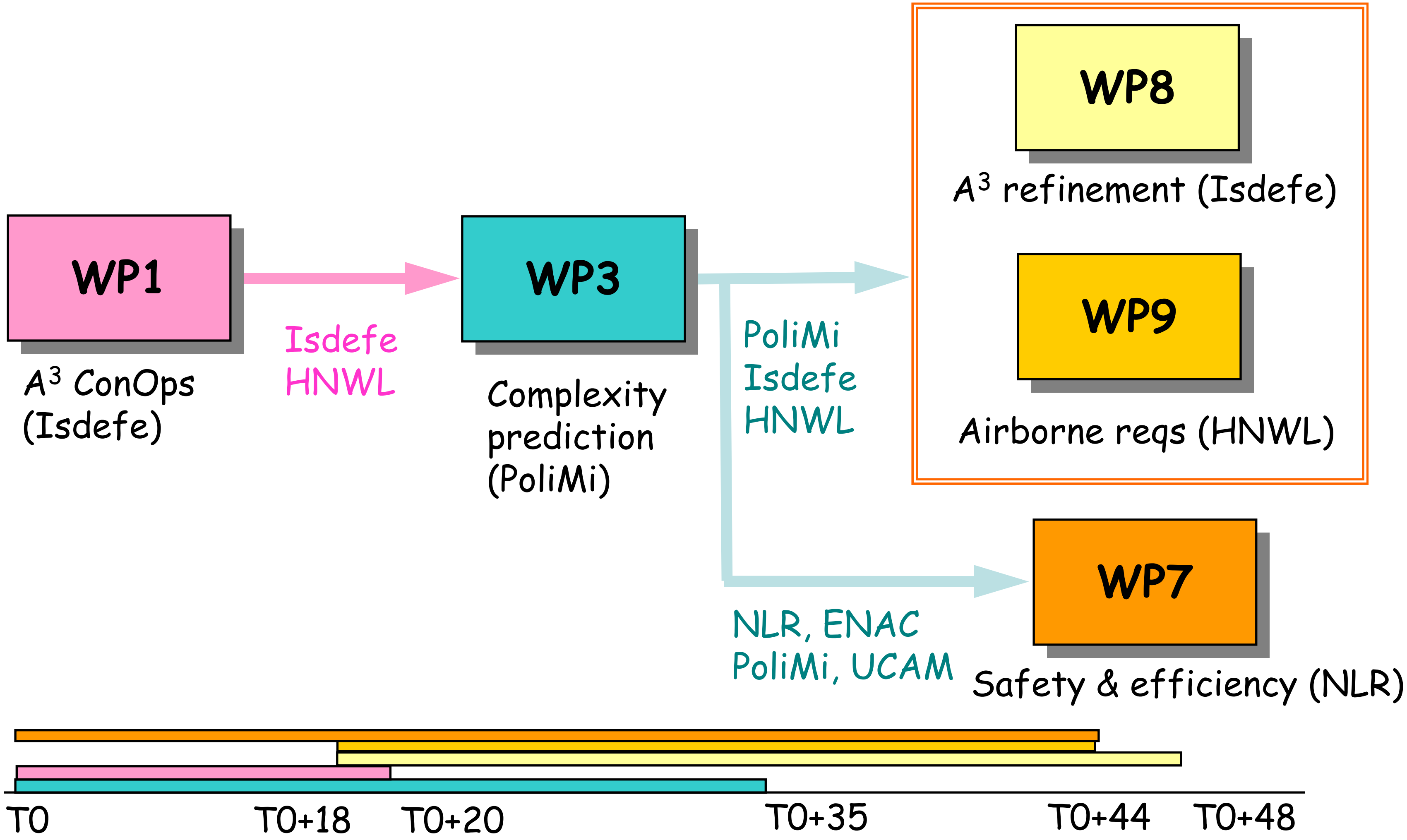
Links


WP1
A³ ConOps
(Isdefe)
WP3
Complexity
prediction
(PoliMi)
WP8
A³ refinement (Isdefe)
WP9
Airborne reqs (HNWL)
T0
T0+18
T0+20
T0+35
T0+44
T0+48

Links


WP1
A^3 ConOps (Isdefe)
WP3
Complexity prediction (PoliMi)
WP8
A^3 refinement (Isdefe)
WP9
Airborne reqs (HNWL)
WP7
Safety & efficiency (NLR)
T0
T0+18
T0+20
T0+35
T0+44
T0+48

Contributing partners & Links



WP3.1: achievements

The work under WP3.1 on "Comparative study of complexity metrics" was completed.

D3.1 was prepared, which involved:

- critically reviewing of the existing literature on air traffic complexity
- pointing out those approaches that are portable to the iFly Autonomous Aircraft Advanced operational concept (A^3 ConOps)

authors: M. Prandini (PoliMi), L. Piroddi (PoliMi), S. Puechmorel (ENAC), S.L. Brázdilová (HNWL)

WP3.2: achievements

The work under WP3.2 on "Timely predicting complex conditions" is ongoing.

D3.2i was prepared, which involved:

- clarifying the requirements stemming from possible applications within the iFly A^3 ConOps ✓
- drawing conclusions from the survey work in D3.1 ✓
- introducing complexity metrics tailored to the long and mid term horizons ✓

authors: M. Prandini (PoliMi), L. Piroddi (PoliMi), S. Puechmorel (ENAC), P. Cásek (HNWL)

Outline of the presentation

D3.2i

- Possible applications and related requirements on complexity metrics for the A^3 ConOps
- Outcome of the survey work in D3.1
- Long term complexity evaluation
- A probabilistic approach to mid term complexity evaluation
- A dynamical system approach to mid term complexity evaluation
- Current status
- Documentation
- Future plans

Outline of the presentation

D3.2i

- Possible applications and related requirements on complexity metrics for the A^3 ConOps
- Outcome of the survey work in D3.1
- Long term complexity evaluation
- A probabilistic approach to mid term complexity evaluation
- A dynamical system approach to mid term complexity evaluation
- Current status
- Documentation
- Future plans

Applications within A³ ConOps

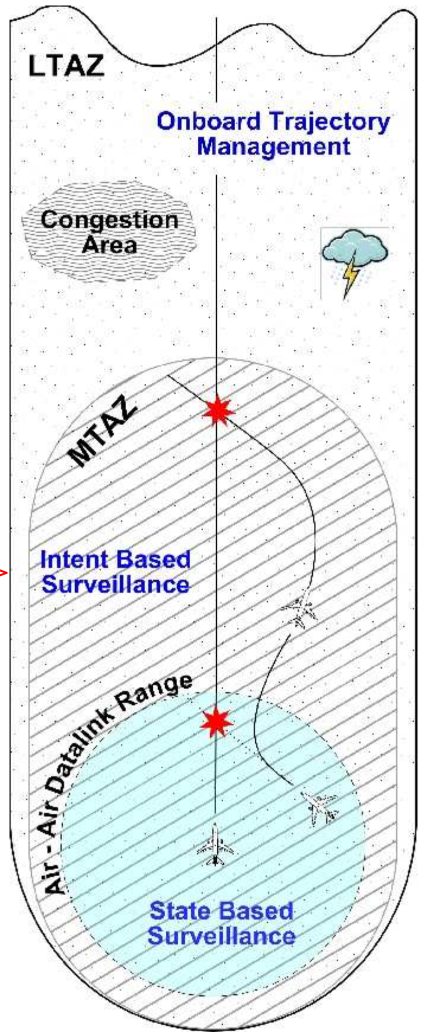
Three potential applications for the traffic complexity prediction were identified:

- airborne trajectory management — long term complexity
- intent-based conflict detection
- intent-based conflict resolution

$\left.\begin{array}{l}\text{intent-based conflict detection}\\ \text{intent-based conflict resolution}\end{array}\right\}$ mid term complexity

Applications within A^3 ConOps

mid term



long term

Applications within A^3 ConOps

Complexity for trajectory management:

prediction of congested areas for supporting onboard trajectory management

- long term time horizon (> 30 minutes, all flight duration within the Self Separating Airspace (SSA))
- computed on the ground and distributed by SWIM to the airborne systems
- based on the Reference Business Trajectories (RBTs)

Applications within A^3 ConOps

Complexity for intent-based conflict detection:

prediction of situations that could overwhelm the mid term conflict resolution module.

- mid term time horizon (10-20 minutes)
- computed on board
- based on state and intent info

Applications within A^3 ConOps

Complexity for intent-based conflict resolution:

evaluation of the complexity associated with different candidate resolution maneuvers. Used to choose the optimal one.

- mid term time horizon (10-20 minutes)
- computed on board
- based on state and intent info

Same complexity measure can be used for the intent-based conflict detection & resolution applications

Outcome of the survey work in D3.1

Air traffic complexity is a general (and generic) term for a measure of the difficulty to safely handle an air traffic situation.

Most of the available complexity studies:

- address ground-based ATM & aim at evaluating the ATC workload
- incorporate air traffic and ATC workload measurements
- are sector-based
- do not account for uncertainty in trajectory prediction
- overlook the time-dependence aspect

Outcome of the survey work in D3.1

Complexity metrics for A^3 ConOps should

- not incorporate ATC workload measurements
- be independent of the airspace configuration
- be tailored to the reference look-ahead time horizon
- possibly account for uncertainty in trajectory prediction
- not require knowledge of the specific controller in place

"Intrinsic" air traffic complexity metrics (based on air traffic measurements only, indirectly accounting for the controller in place) appear portable to the autonomous aircraft context

Long term complexity

Introduction of novel long term complexity metrics

complexity characterization for onboard trajectory management

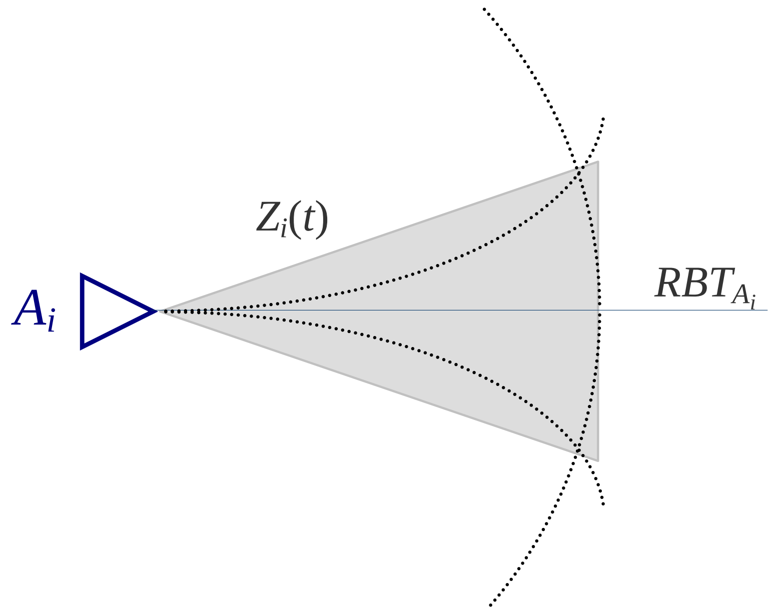
Goal:

- identify highly congested regions
- reveal the presence of critical situations with limited maneuverability along the RBT of each single aircraft

Idea:

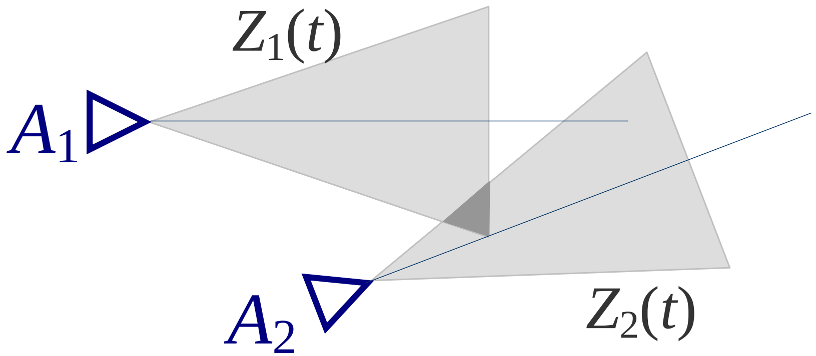
- use the concept of <u>influence zone</u> of an aircraft, which is related to the local aircraft density while accounting for directionality and speed

Long term complexity



Influence zone:
Region of the airspace that can be eventually reached within some short term horizon through ground velocity changes

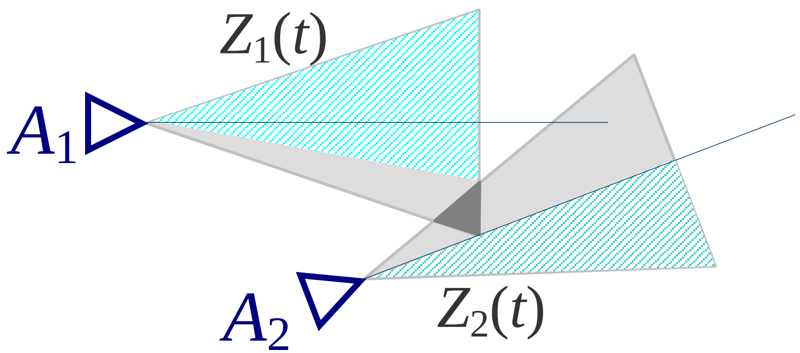
Long term complexity



Complexity map c(x,t):
influence zones overlapping at point x and time t

Scalar indicator of complexity:
integral over space and time of the areas where influence zones overlap

Long term complexity



lateral
maneuverability
75% for A_1
50% for A_2

Long term complexity

Characteristics:

- evaluated based on RBTs
- accounting for both density and organization of the traffic
- rough estimate of trajectory flexibility introduced by NASA

A probabilistic approach to mid term complexity

Introduction of novel mid term complexity metrics

complexity characterization for intent-based conflict detection & resolution

Idea:

identify situations with limited manoeuvrability space through the notion of <u>probabilistic occupancy</u> of the airspace

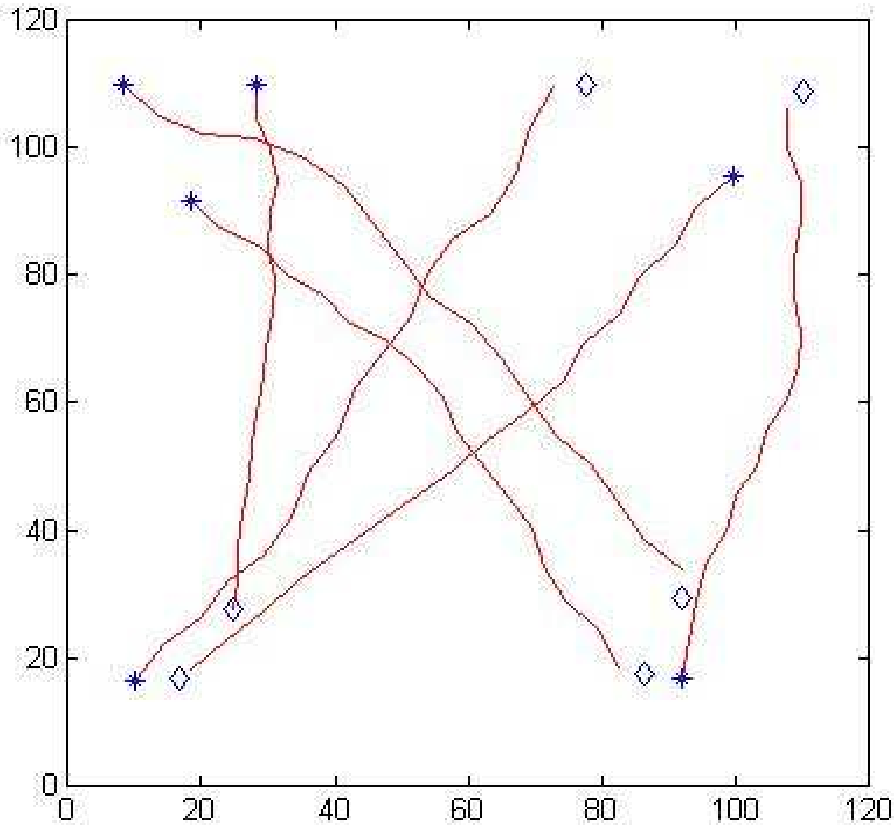
Complexity:

$c_m(x,t)$: probability at least m aircraft will enter a ball of radius r centered at x within $[t, t+\Delta]$

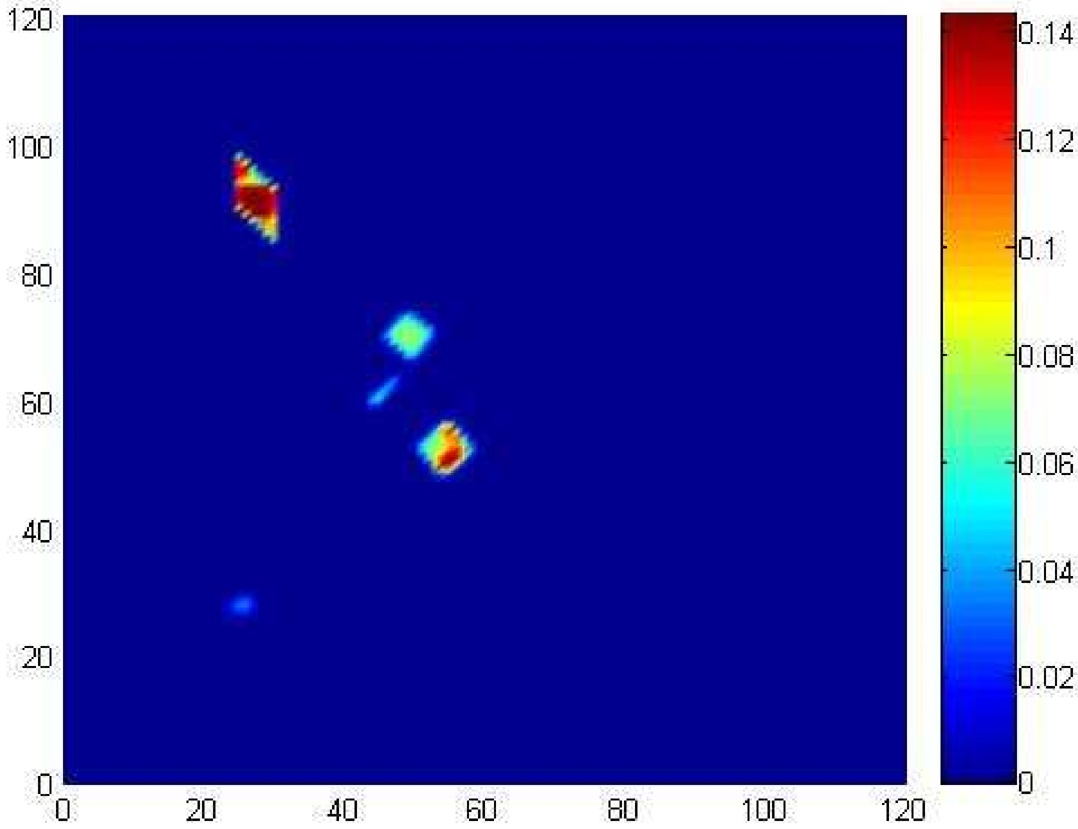
$C_m(x)$: average of $c_m(x,t)$ with respect to time

scalar indicators of the aircraft spacing can be derived

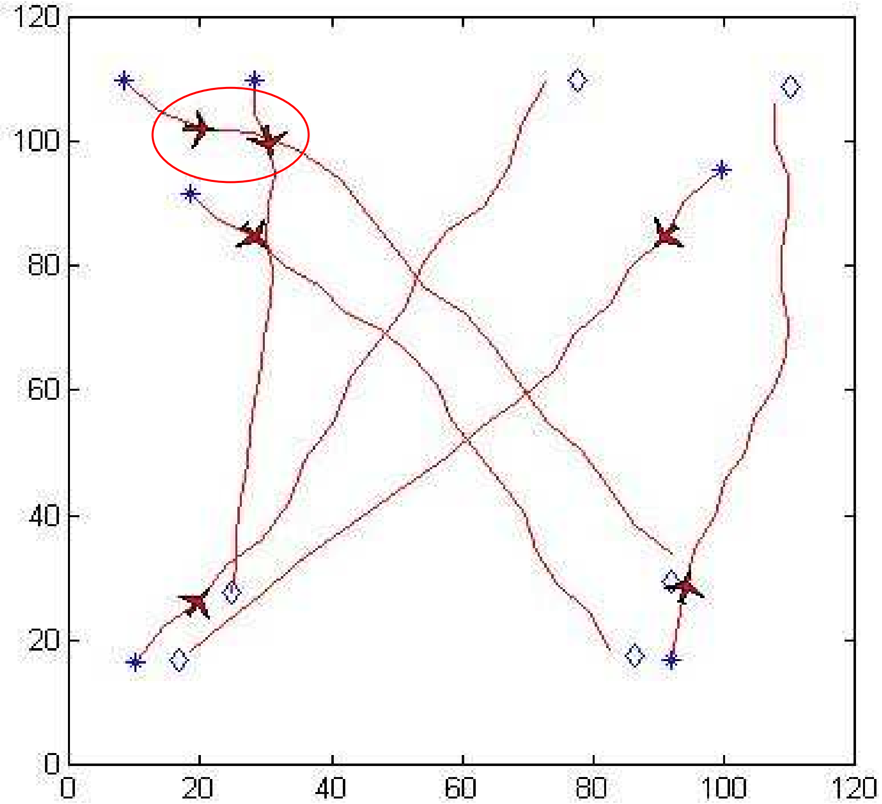
A probabilistic approach to mid term complexity



A probabilistic approach to mid term complexity



A probabilistic approach to mid term complexity



A probabilistic approach to mid term complexity

Characteristics:

- evaluated based on state and intent info
- possibility of tuning to actual mid term conflict resolution capabilities of solving multi-aircraft conflicts
- both spatial and timing information can be extracted
- uncertainty in trajectory prediction is accounted for

A dynamical system approach to mid term complexity

Further development of intrinsic complexity measure

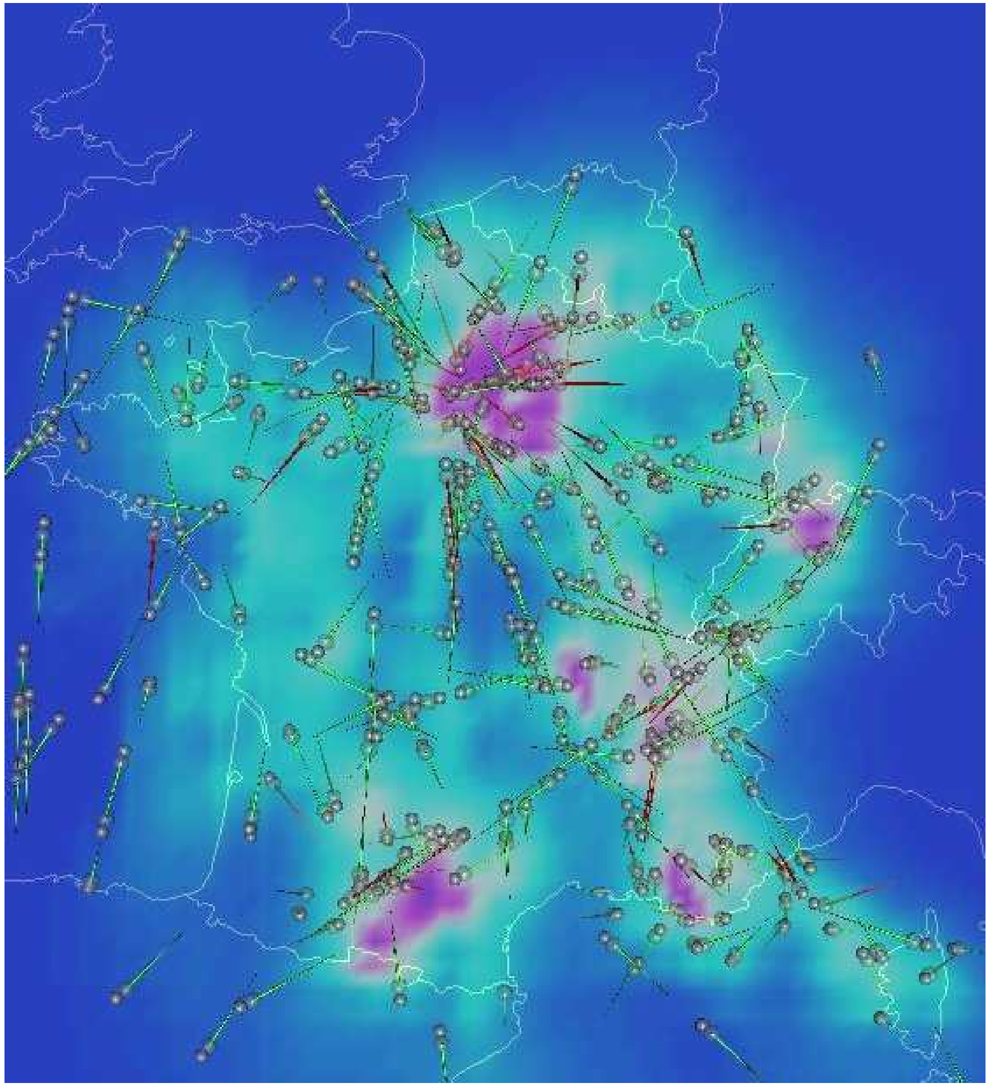
complexity characterization for intent-based conflict detection & resolution

Idea:

complexity relates to the local density evolution in time, which allows to interpret traffic as <u>flow of a vector field</u>

Lyapunov exponents of the identified dynamical system measure level of order/disorder

A dynamical system approach to mid term complexity



Complexity map produced over France: hot spots are identified

A dynamical system approach to mid term complexity

Characteristics:

- evaluated based on state and intent info
- deterministic approach
- spatial information can be extracted on high complexity regions

Outline of the presentation

D3.2i

- Possible applications and related requirements on complexity metrics for the A^3 ConOps
- Outcome of the survey work in D3.1
- Long term complexity evaluation
- A probabilistic approach to mid term complexity evaluation
- A dynamical system approach to mid term complexity evaluation
- Current status
- Documentation
- Future plans

Current status

WP3.1 completed

- D3.1: final version posted on the iFly web-site

WP3.2 in progress

- D3.2i: version 1.0 delivered to EC
- D3.2: TBD
- A further approach to long term complexity has been developed by HNWL
- Ongoing activities:
  - Refinement
    - Development of computational efficient procedures
    - 3D extension

Current status

WP3.1 completed

- D3.1: final version posted on the iFly web-site

WP3.2 in progress

- D3.2i: version 1.0 delivered to EC
- D3.2: TBD
- A further approach to long term complexity has been developed by HNWL
- Ongoing activities:
  - Assessment:
    - Correlation with the control effort involved in handling the traffic safely (number of maneuvers, amount of deviation, …) on simulated data generated based on real flight plans of hot spots over France, with & without control (centralized algorithm by N. Durand, ENAC)
    - Correlation with the notion of trajectory flexibility (with NASA)

Documentation

Deliverables (2):

- D3.1: version 1.1 posted on iFly website
- D3.2i: version 1.0 delivered to EC

Journal papers (3):

- Application of Reachability Analysis for Stochastic Hybrid Systems to Aircraft Conflict Prediction, IEEE TAC (PoliMi)
- A probabilistic measure of air traffic complexity in three-dimensional airspace, submitted to IJACSP (PoliMi)
- Towards air traffic complexity assessment in new generation air traffic management systems, submitted to IEEE TITS (PoliMi, ENAC, HNWL)

Conference papers (10):

- Application of Reachability Analysis for Stochastic Hybrid Systems to Aircraft Conflict Prediction, IEEE CDC 2008 (PoliMi)
- An approximate dynamic programming approach to probabilistic reachability for stochastic hybrid systems, IEEE CDC 2008 (PoliMi)
- A probabilistic approach to air traffic complexity evaluation, IEEE CDC 2009 (PoliMI)

Documentation

- Complexity in Air Traffic Management, Siam Conference on Control Theory, 2009 (ENAC)
- A New Algorithm for Automated Aircraft Conflict Resolution, Siam Conference on Control Theory, 2009 (ENAC)
- Distributed Trajectory Flexibility preservation helps mitigate traffic complexity, ATM Seminar, Napa 2009 (ENAC & NASA)
- Describing air traffic flows using stochastic programming, AIAA GNC conference, Chicago 2009 (ENAC)
- New trends in air traffic complexity, EIWAC 2009 (ENAC)
- Dynamical Systems Complexity with a view towards air traffic management applications, IEEE CDC 2009 (ENAC)
- Airspace Complexity for Airborne Self Separation, CEAS European Air & Space Conference, 2009 (HNWL)

Master thesis (1):

- Methods for reachability analysis of stochastic hybrid systems (PoliMi)

Future plans

Work on WP3.2

→ WP7

Provide metrics to identify multi-aircraft configurations that contribute to the collision risk so as to speed up the interacting particle system algorithm for risk assessment

→ WP8 & WP9

Evaluate the impact of complexity metrics on trajectory management and mid term conflict resolution

to be included in the final Deliverable 3.2

WP3: Prediction of complex traffic conditions

Review Meeting, EC, Brussels
September 29, 2009

Maria Prandini
Politecnico di Milano