Optimization through Simulation: How to improve TMA Operations

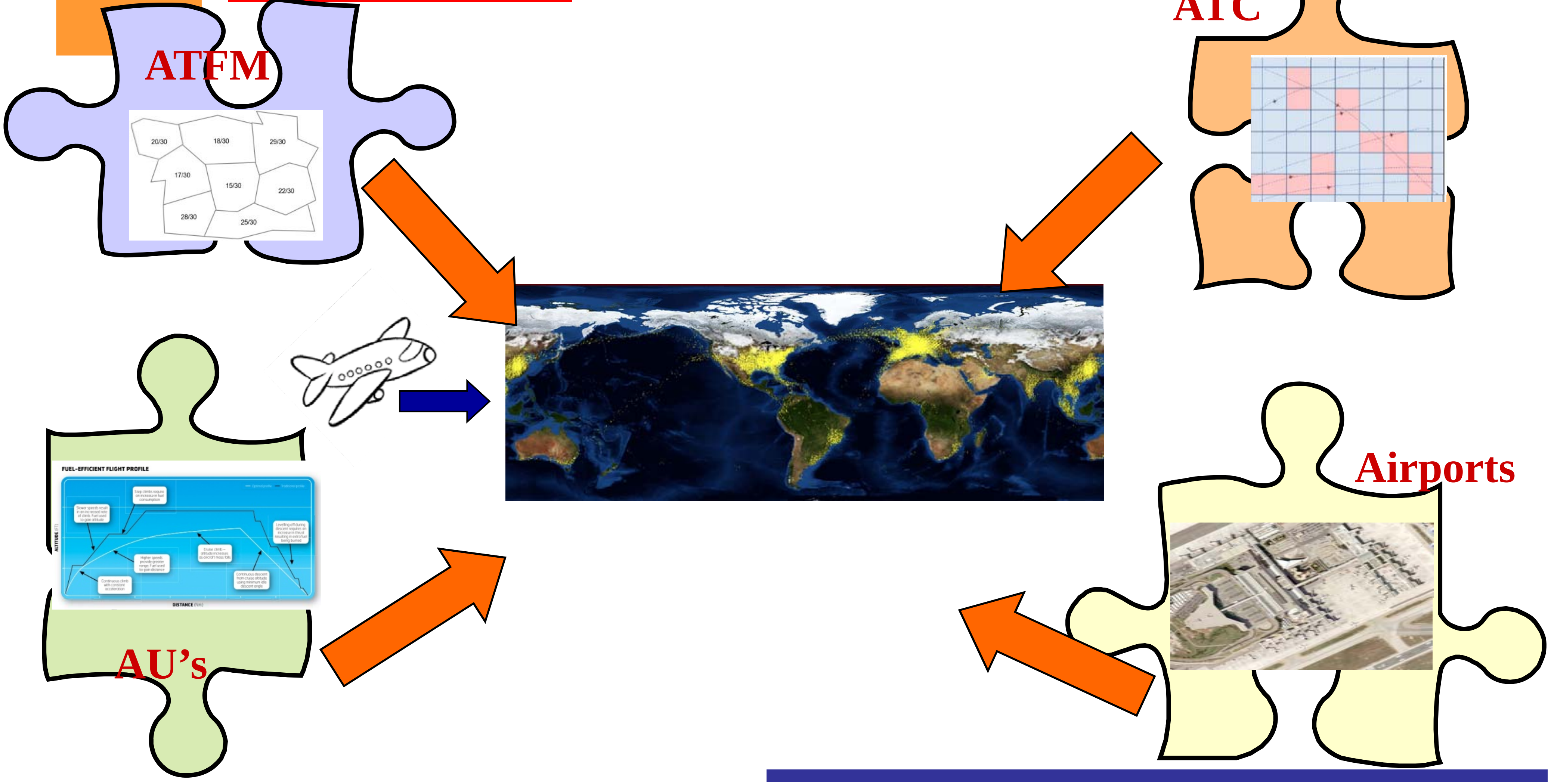
Miquel Angel Piera
MiquelAngel.Piera@uab.cat

Systems Engineering Group
Dept. of Telecomunication
Universitat Autonòma de Barcelona
Barcelona (Spain)

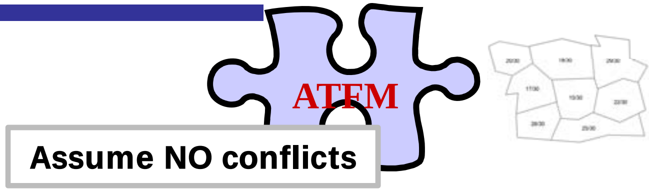
Outline

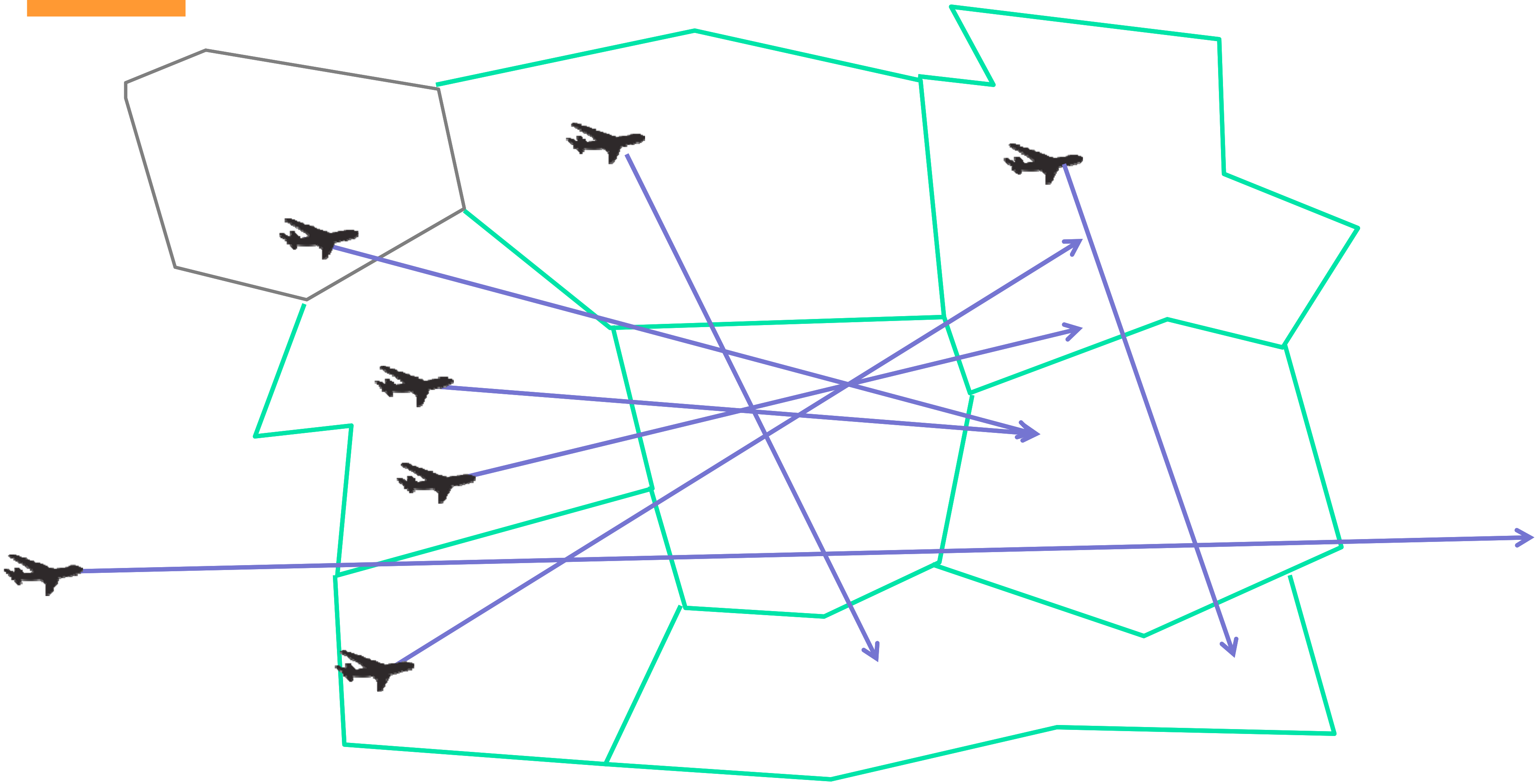
- Introduction to the ATM Systems
- SESAR
- Decision Support Systems
- Managing System Complexity using Causal Formalism
- Case Studies: Boeing, AENA,Indra, EuroControl, AirEuropa,…
- Conclusions

Introduction : ATM Actors

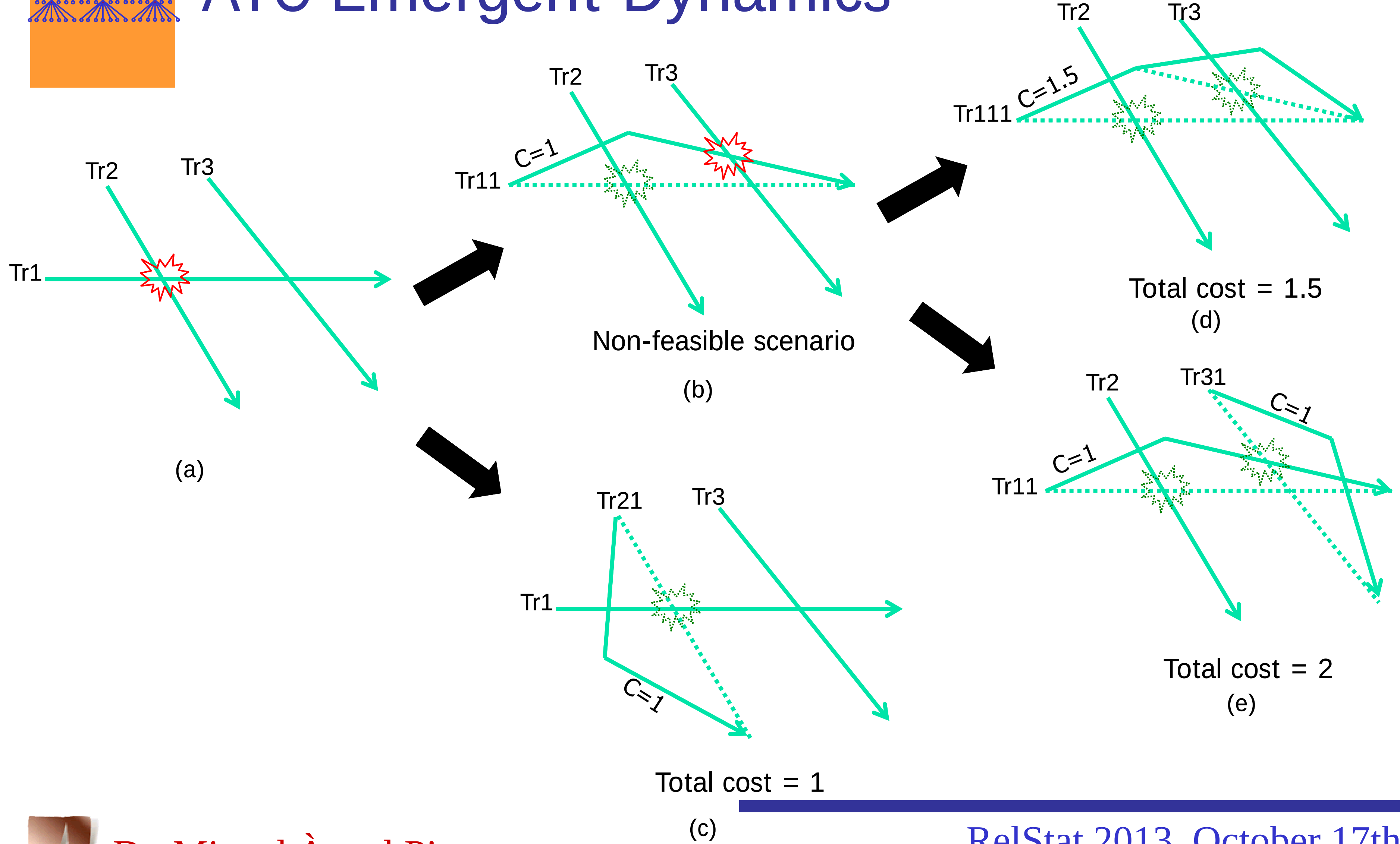


ATFM Emergent Dynamics

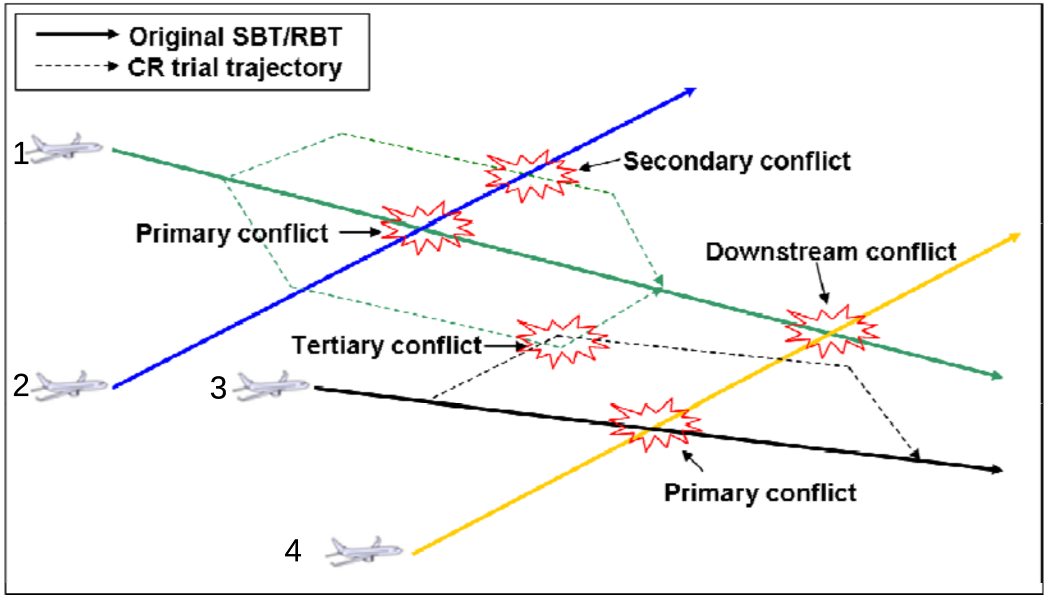


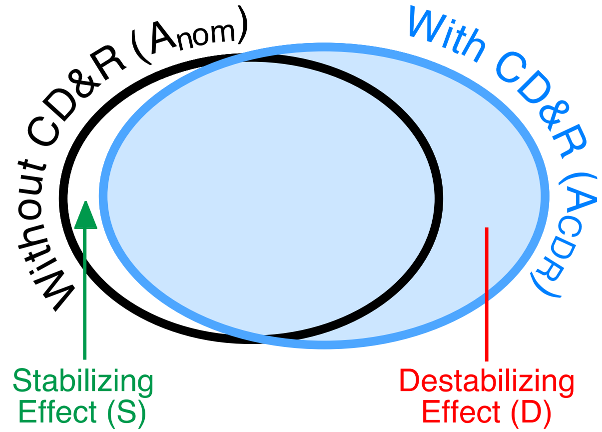


ATC Emergent Dynamics



ATC Emergent Dynamics





* Bilimoria (NASA) performed several experiments that confirms the importance of taking into account the Domino effects of the CR trial trajectories

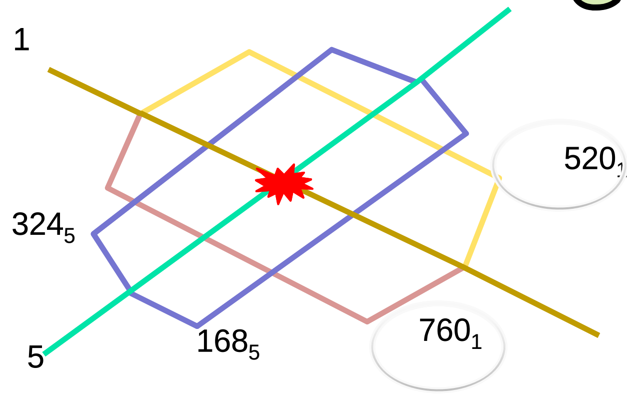
Domino effects

mpr ions

AU's

AIRCRAFT	TRIAL TRAJECTORIES										
1	~~1_1~~	760_1	520_1	231_1	452_1	964_1	741_1	392_1	175_1	712_1	672_1
2	2_2	784_2	027_2	146_2							
3	3_3	2045_3									
4	4_4	562_4	543_4	876_4	436_4	644_4					
5	5_5	324_5	168_5								
⋮	:	658	588	108	649	455	876	855	244	333	
⋮	:	765	257	848	478						
⋮	:	536									
⋮	:	651	342								
⋮	:	056	780	454	852	923					
⋮	:	246									
⋮	:	538	099	654							
⋮	:	976	576	374	456	984	194				
⋮	:	123	830	012	681	354	951	787			
N-1	$N\text{-}1_{N-1}$	766_{N-1}	511_{N-1}								
N	N_N	856_N	555_N	786_N	487_N	018_N					

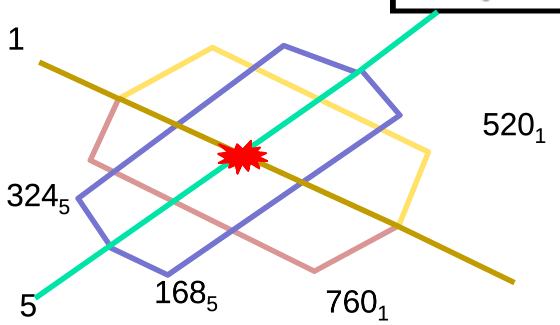
CONFLICTS	
idt1	idt2
~~1_1~~	5_5



New Pareto-efficient solution:

$[760_1, 2_2, 3_3, 4_4, 5_5 \ldots, N\text{-}1_{N-1}, N_N]$

CONFLICTS	
idt1	idt2
1_1	~~5_5~~



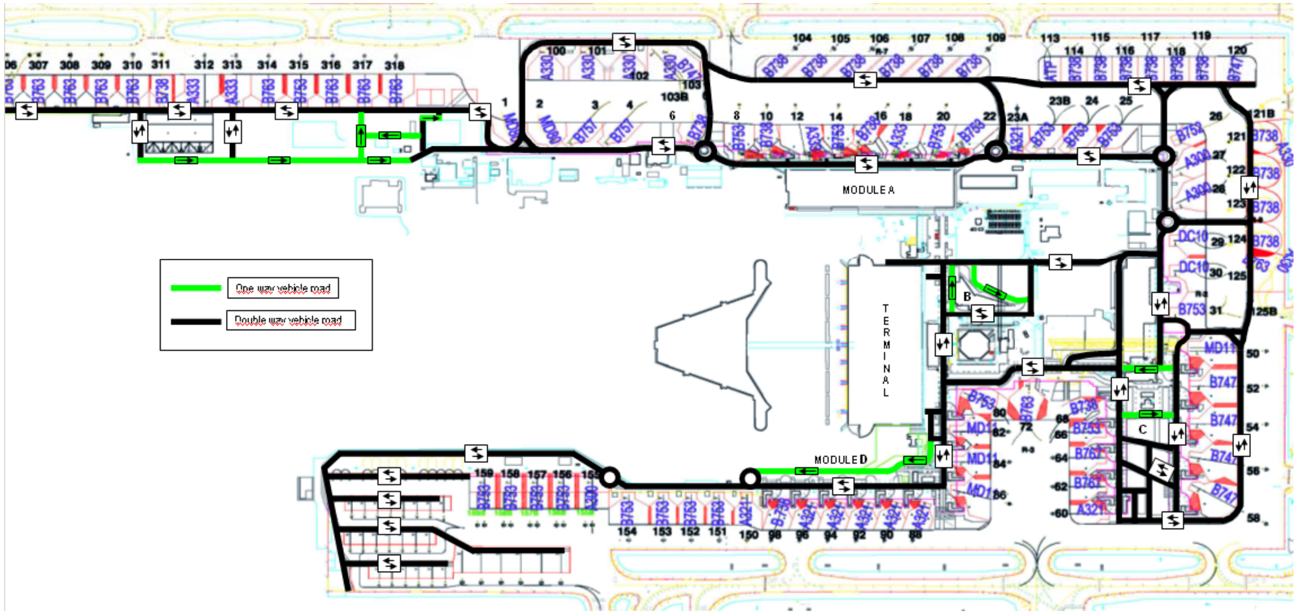
New Pareto-efficient solution:

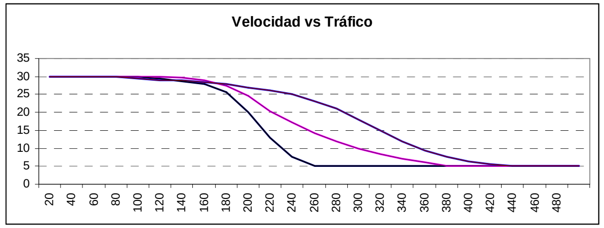
$[1_1, 2_2, 3_3, 4_4, 324_5 \ldots, N\text{-}1_{N-1}, N_N]$

AIRCRAFT	TRIAL TRAJECTORIES										
1	1_1	760_1	520_1	231_1	452_1	964_1	741_1	392_1	175_1	712_1	672_1
2	2_2	784_2	027_2	146_2							
3	3_3	2045_3									
4	4_4	562_4	543_4	876_4	436_4	644_4					
5	~~5_5~~	324_5	168_5								
⋮	:	658	588	108	649	455	876	855	244	333	
⋮	:	765	257	848	478						
⋮	:	536									
⋮	:	651	342								
⋮	:	056	780	454	852	923					
⋮	:	246									
⋮	:	538	099	654							
⋮	:	976	576	374	456	984	194				
⋮	:	123	830	012	681	354	951	787			
N-1	$N\text{-}1_{N-1}$	766_{N-1}	511_{N-1}								
N	N_N	856_N	555_N	786_N	487_N	018_N					

Airports

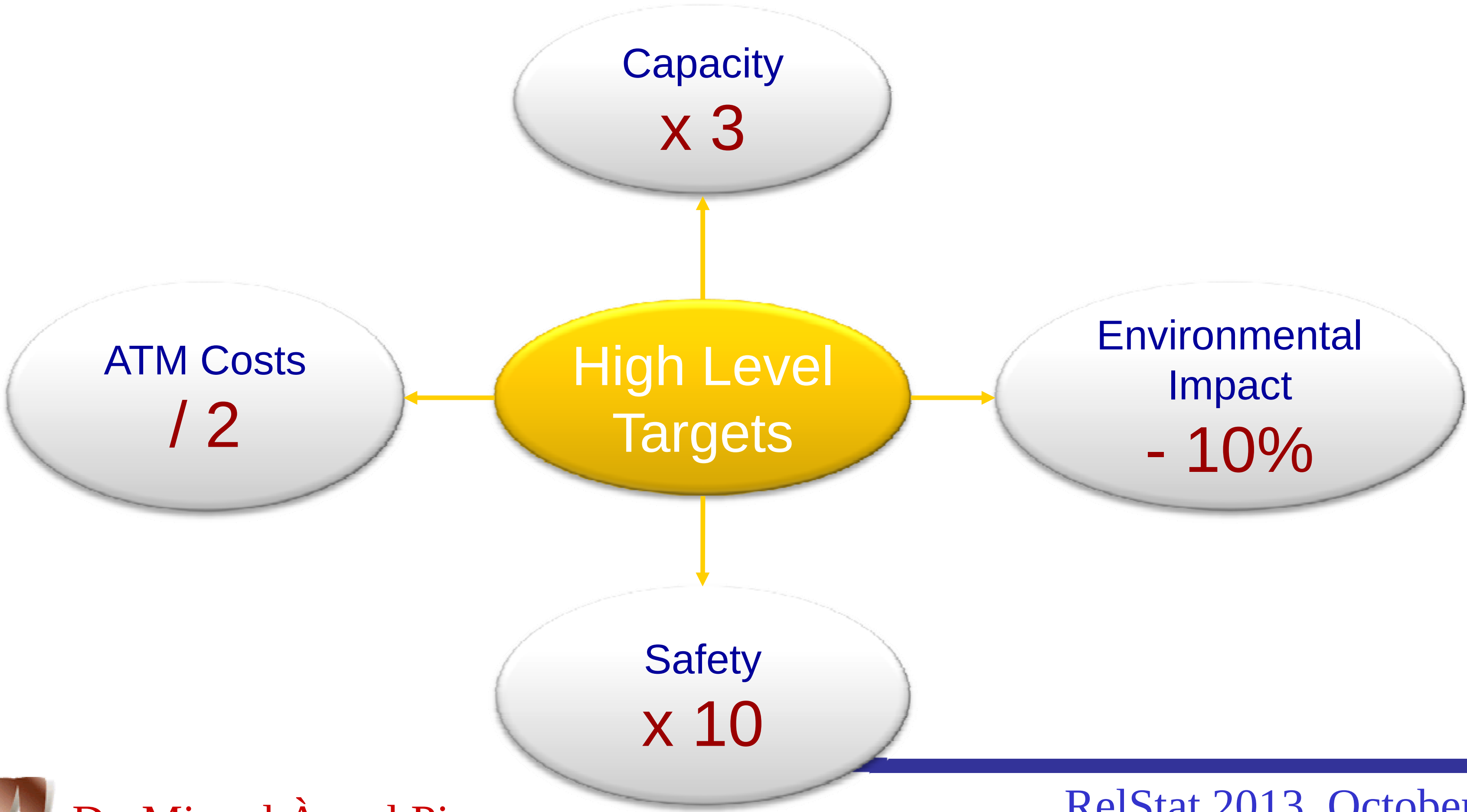
Airport Emergent Dynamics



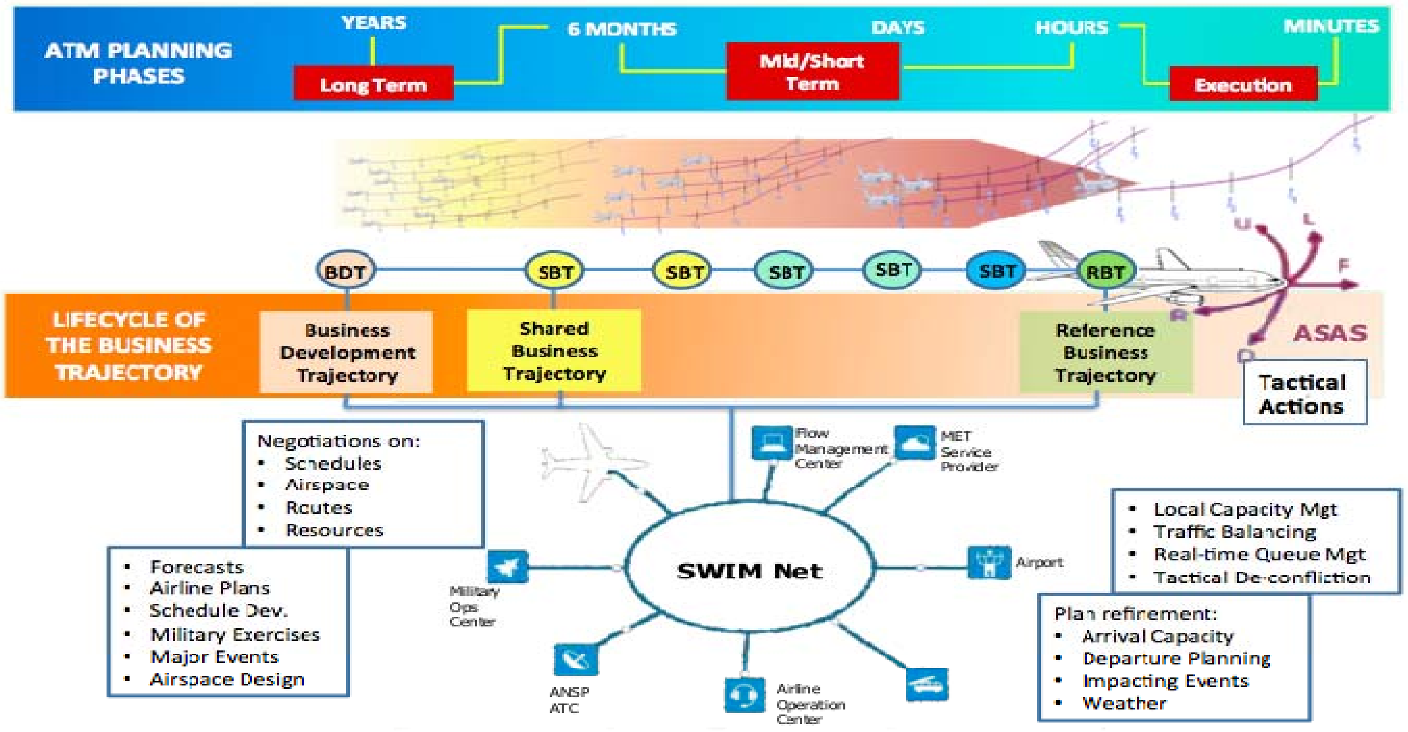


SESAR: ***S**ingle **E**uropean **S**ky **A**TM **R**&D*

4 Main Objectives: European Comission

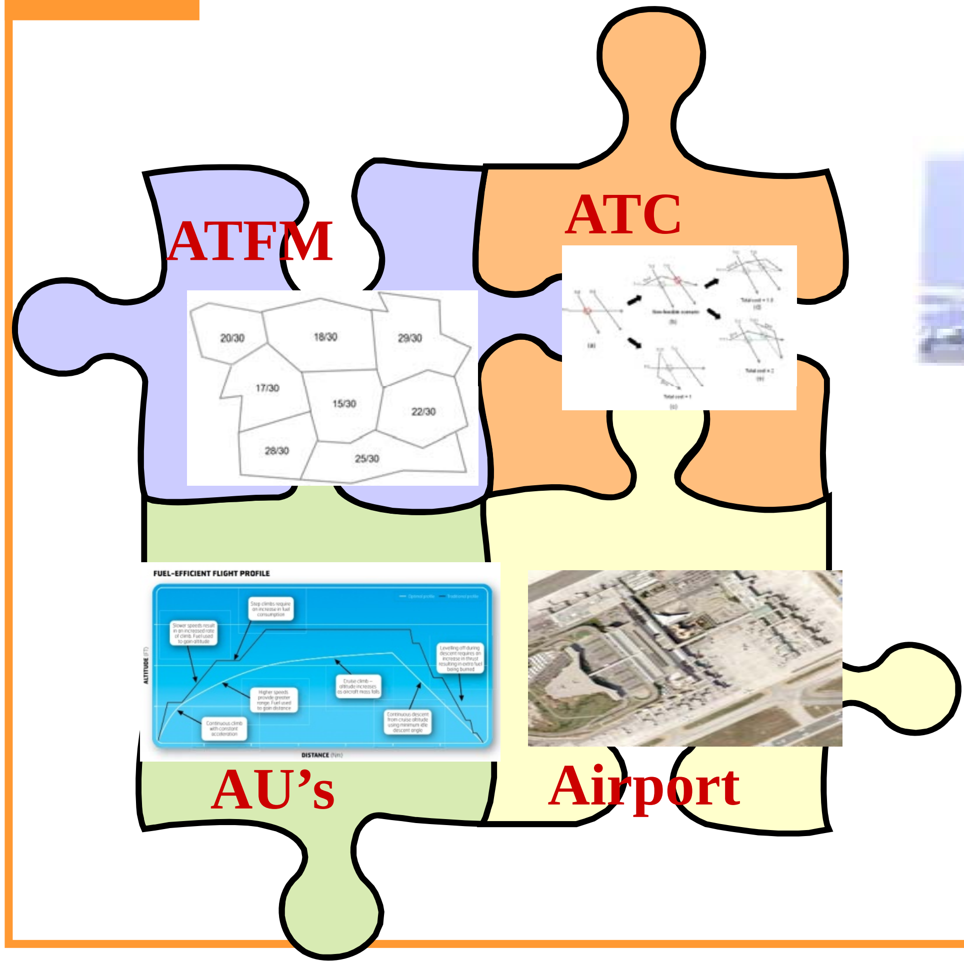


SESAR: *Single European Sky ATM R&D*

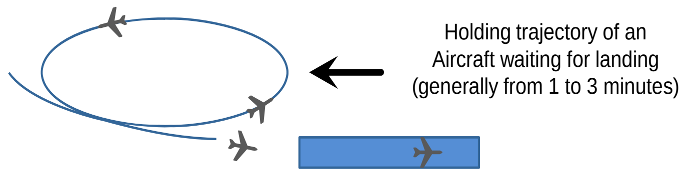


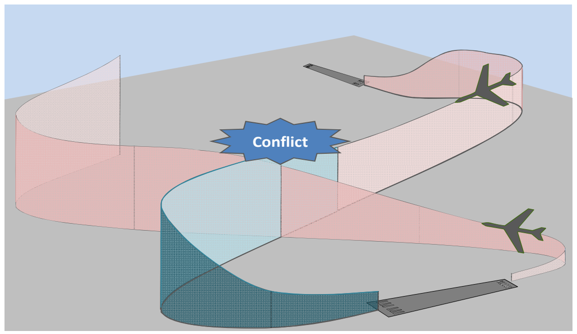
SWIM and **information sharing** are key enablers for the **CDM planning** in target ATM

CDM: Collaborative Decision Making



Coexistence of economic, technological, logistic and human behaviour aspects





CDM: Collaborative Decision Making

Events are propagated through the system, and can lead to poor KPI's due to idleness and over saturation in key critical resources.

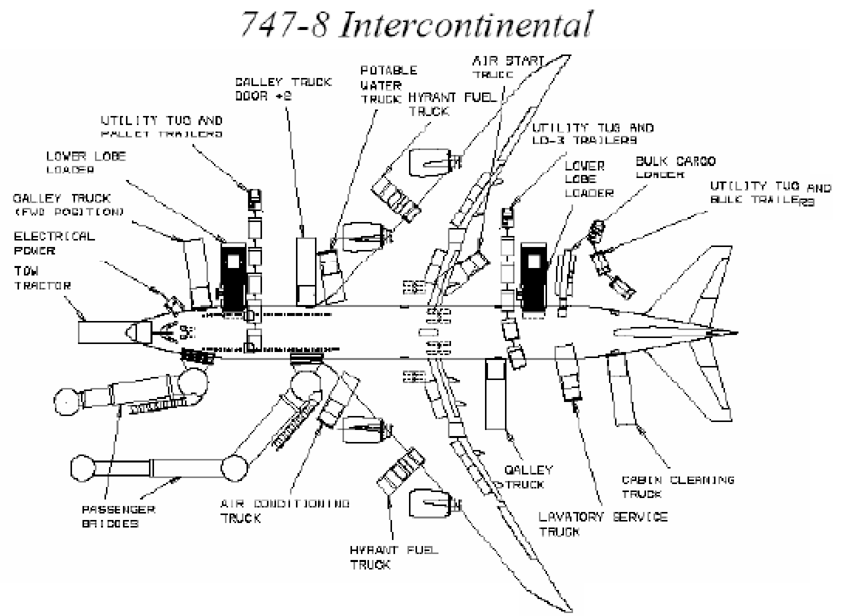
Why ATM is considered Complex?

Complexity becomes apparent to humans each time we are asked to take a decision in a context that it is not possible to predict all the consequences of a certain action.

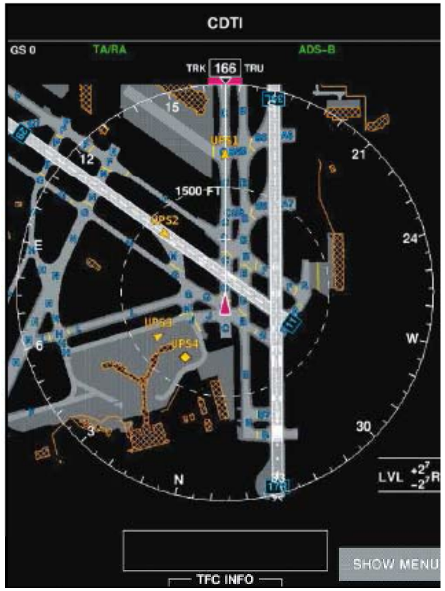
Cause – effect relationship should be properly formalized and analyzed to improve logistic systems performance.

CDM: Collaborative Decision Making

The Rule of Seven Rs: Logistics is ensuring the availability of the ***right product***, in the ***right quantity*** and ***right condition***, at the ***right place***, at the ***right time***, for the ***right customer***, at the ***right cost***.



Decision Support Systems

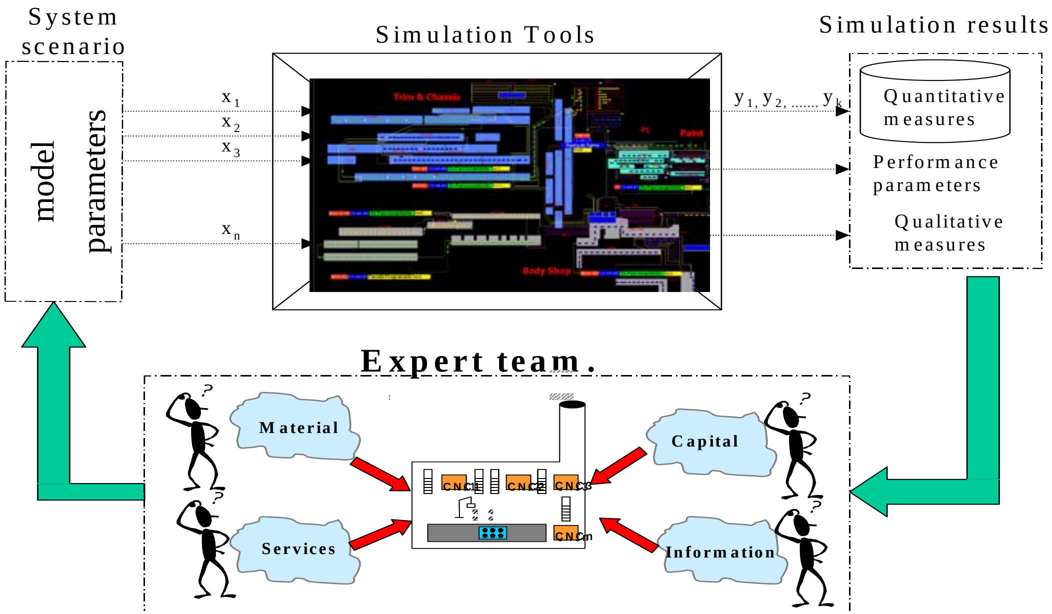


- Optimisation
  - Poor model
  - Optimal (real?)
- Simulation
  - Good model
  - Poor results

Scheduling policy

How to tackle Flexibility?

Simulation Approach

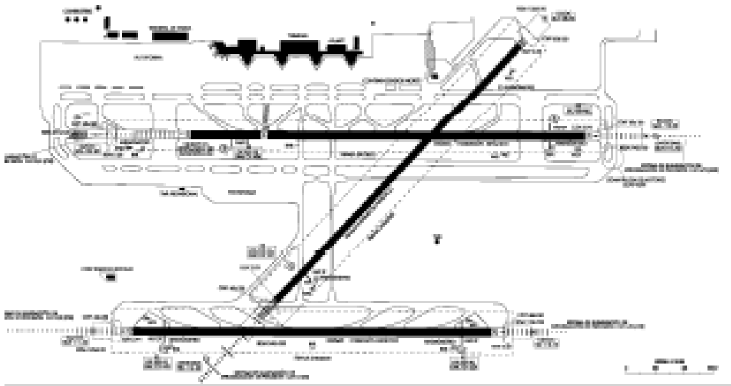


Simulation limitation arises out of an inability to evaluate more than a fraction of the immense range of options available

Managing System Complexity

How to tackle complexity?

- Keep it simpler and add complexity later
- Reduce the scope of the model
- Reduce the level of detail using hierarchy



It is enough a fiability around the 99.9%?

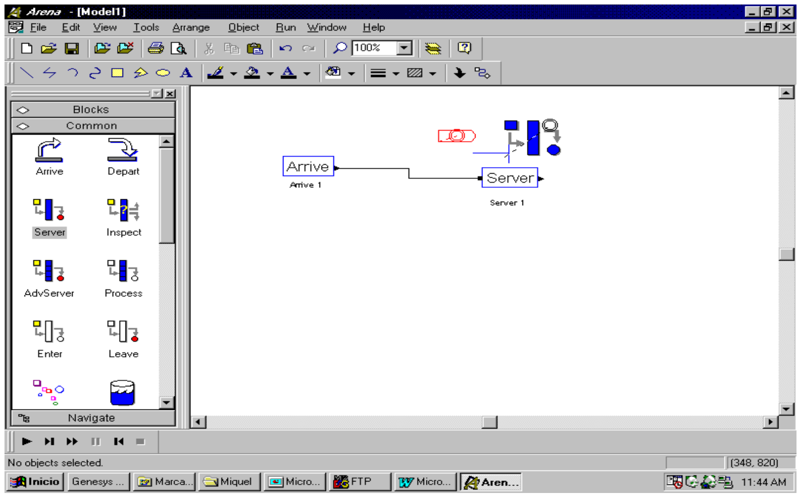
- More than 4 accidents per day in the main airports
- 20.000 objects lost per day in a mail service
- 5.000 wrong surgical operations per week

Managing System Complexity

Workflow Modeling Methods

When a process is understood to be a specific ordering of work activities, with a beginning, an end, and clearly identified inputs and outputs, then models can be easely formalized by mapping elements in the real world into modeling components.

Present simulation languages provide the modeler with powerful tools that greatly facilitate building models.



Petri Net Formalism

Modeling Goal:

Specify the sequence of activities that a certain event can activate/propagate/freeze.

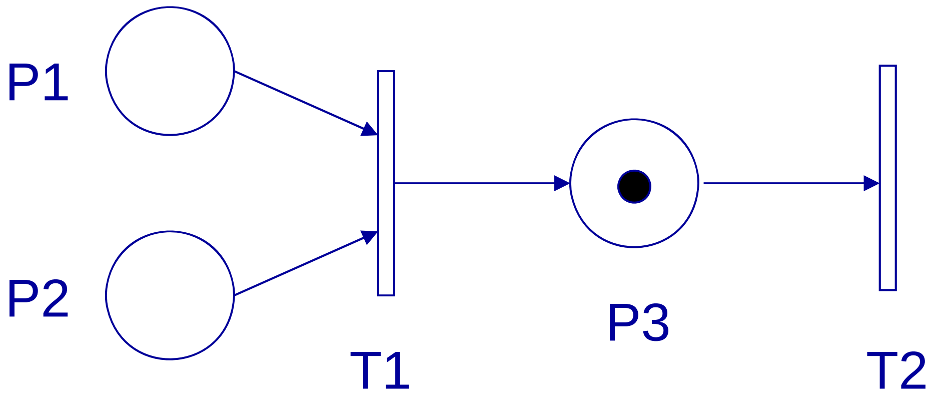
Methodology:

- Describe modularly each subsystem
- Describe the **set of logical relationships that determine the interaction between subsystem components**.
- Set up the whole simulation model by coupling shared elements together with their interactions.

Petri Net Formalism

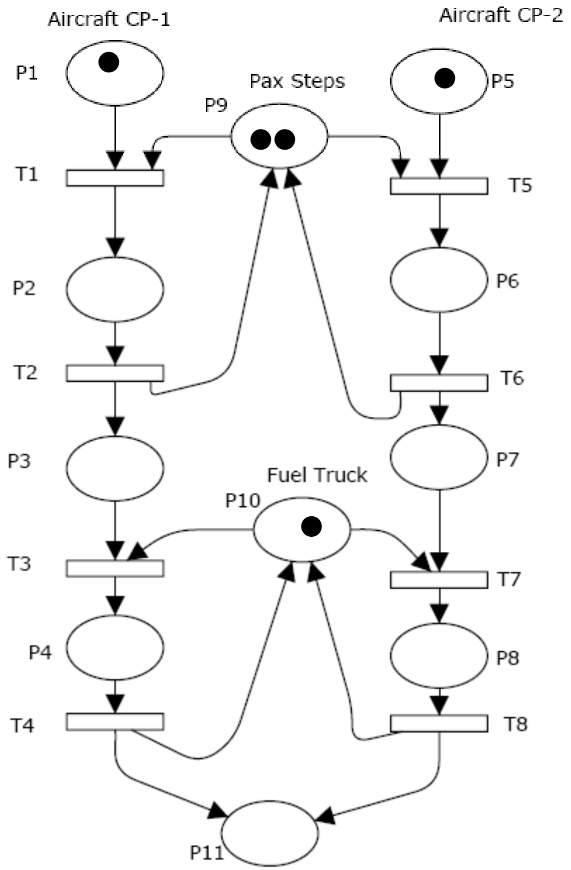
Petri net definition: PN = (P,T,I,O,Mo)

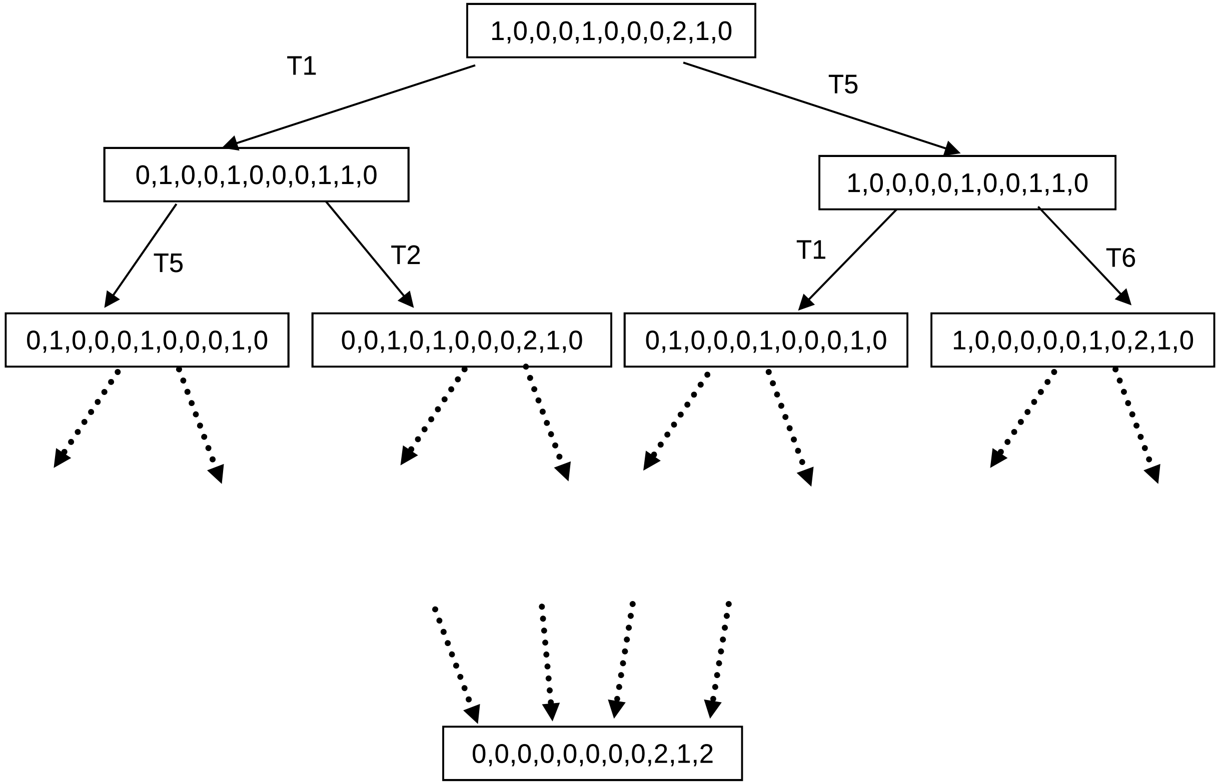
- P = $\{p_1,p_2...,p_n\}$, a set of *places*,
- T = $\{t_1,t_2,...,t_n\}$, a set of *transitions*;
- I : $(PxT)\rightarrow N$, directs *arcs* from places to transitions;
- O : $(PxT)\rightarrow N$, directs *arcs* from transitions to places;
- Mo = $\{\#P_1,\#P_2,...,\#P_n\}$, an initial marking.



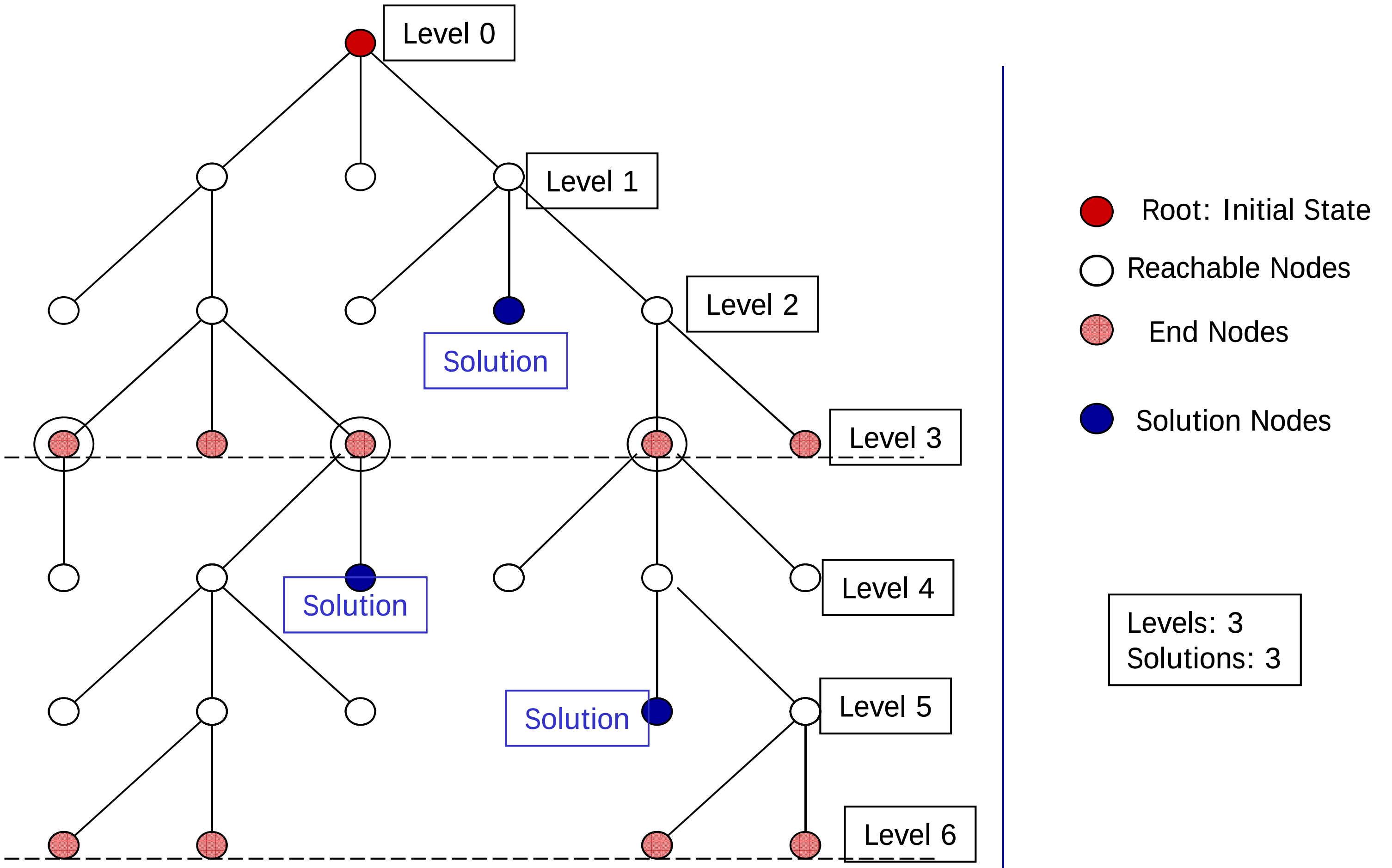
Mo = [0,0,1]

Petri Net Formalism



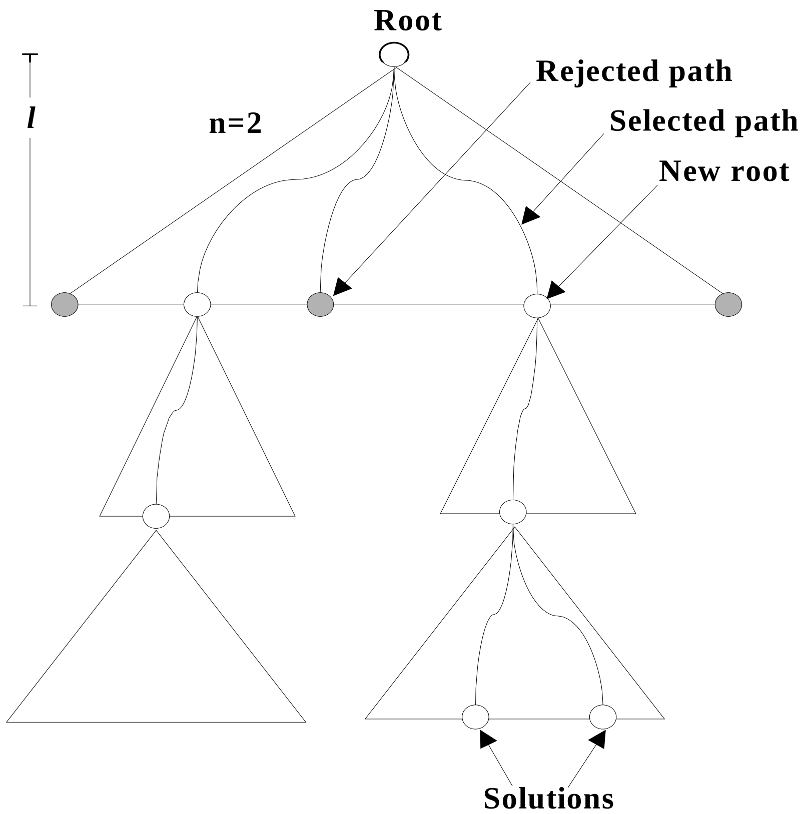


Petri Net Formalism

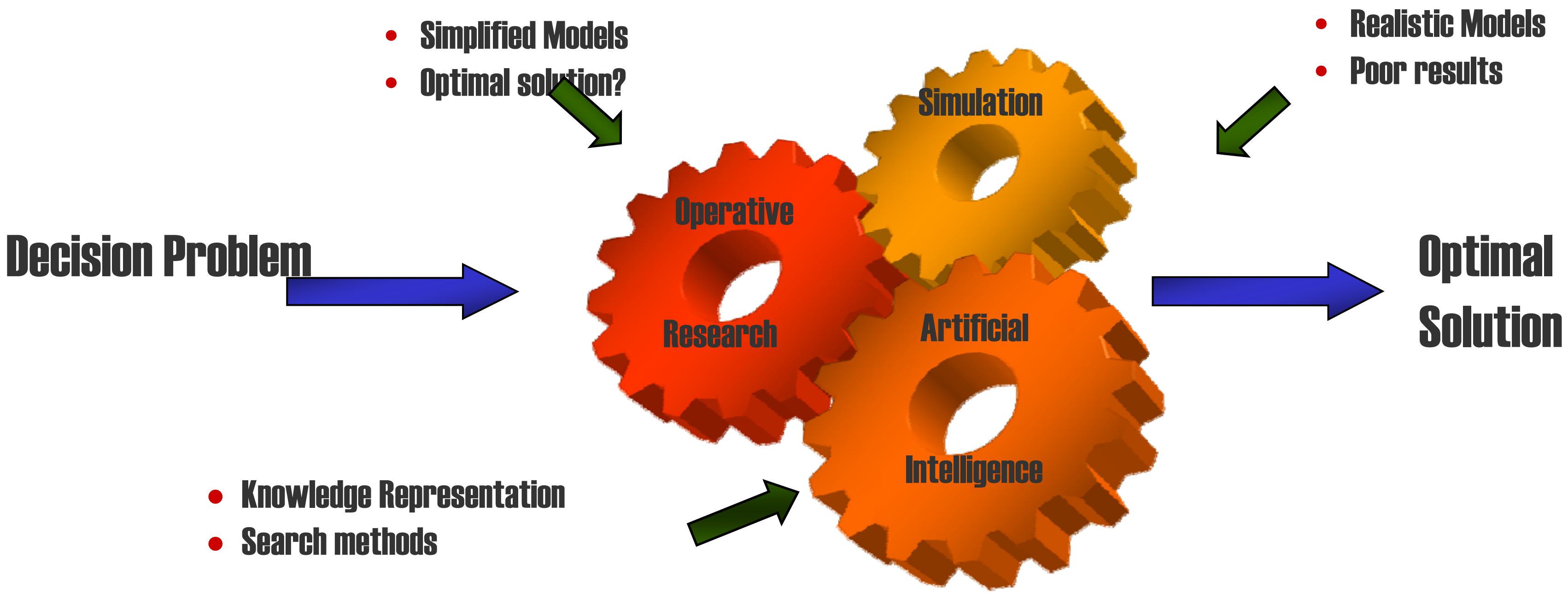


Petri Net Formalism

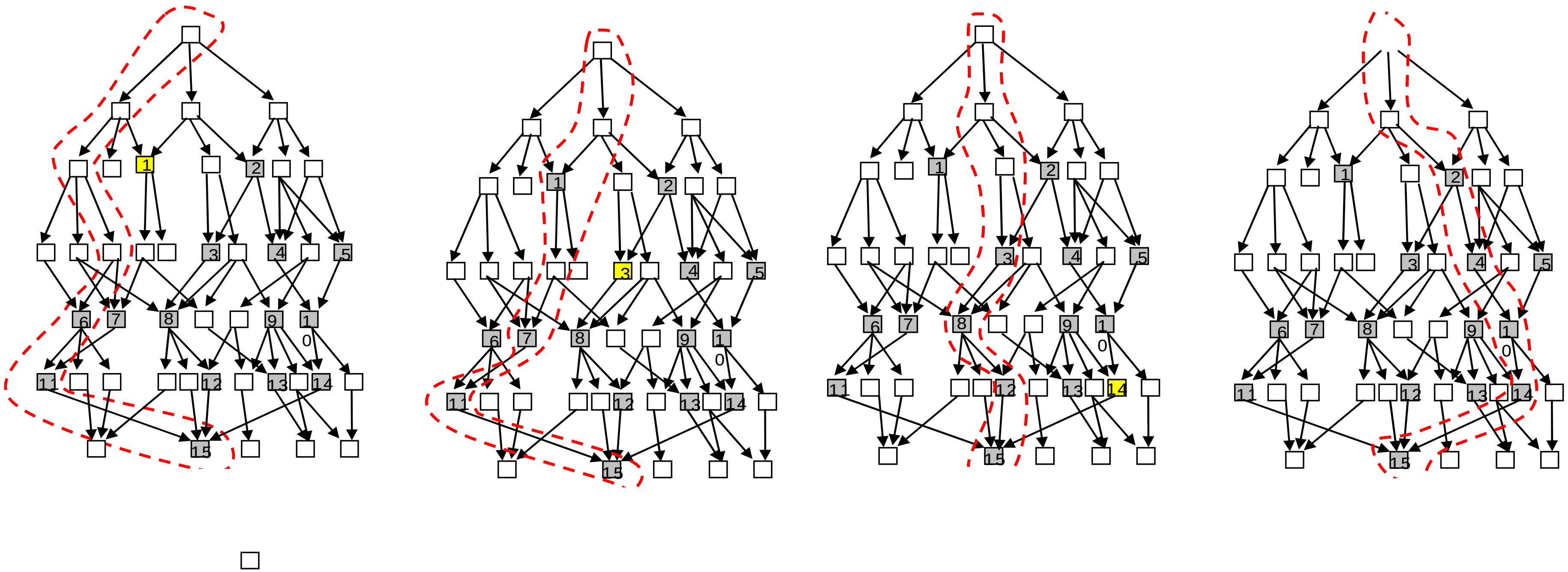
A tool to determine the optimal plan



Managing System Complexity

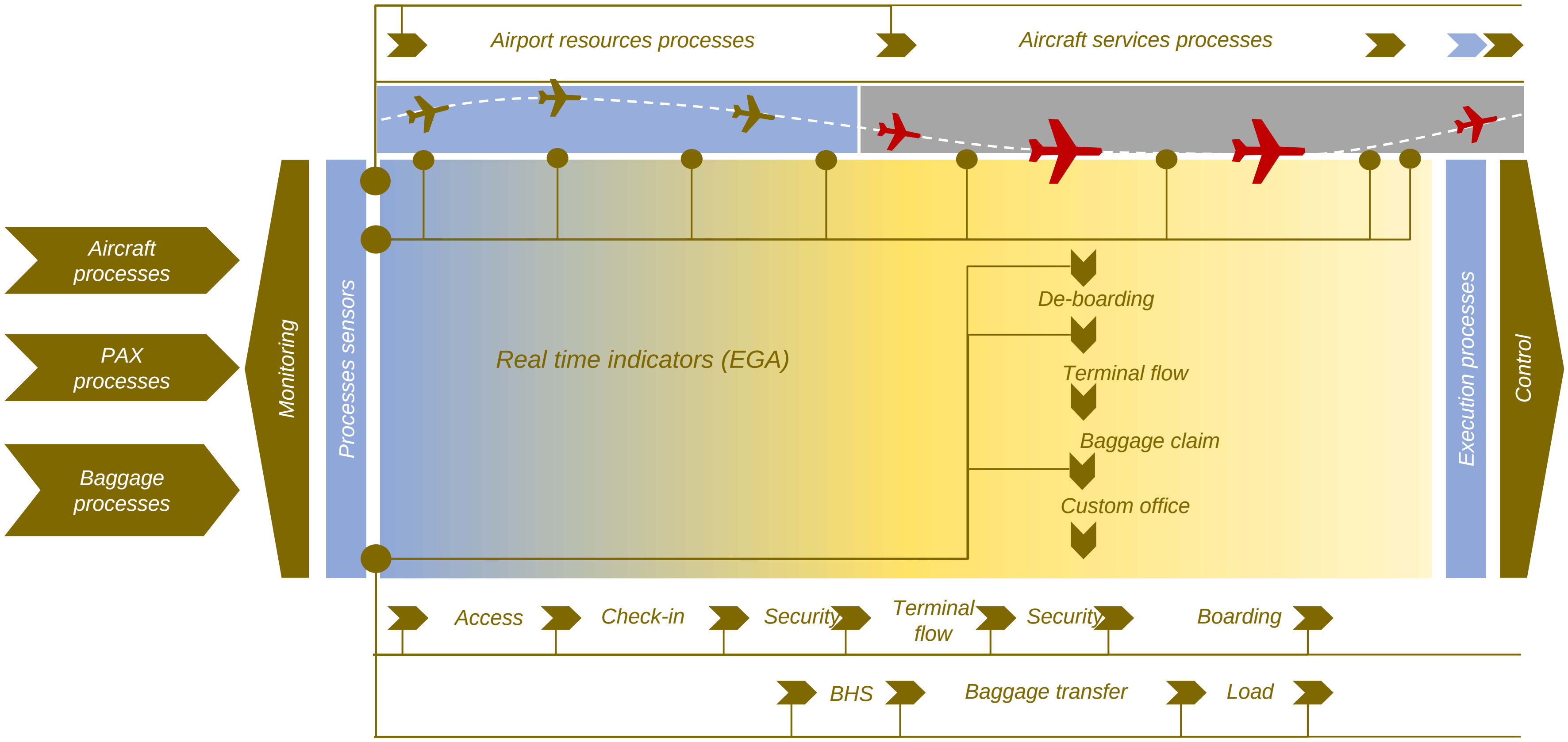


Futher Research

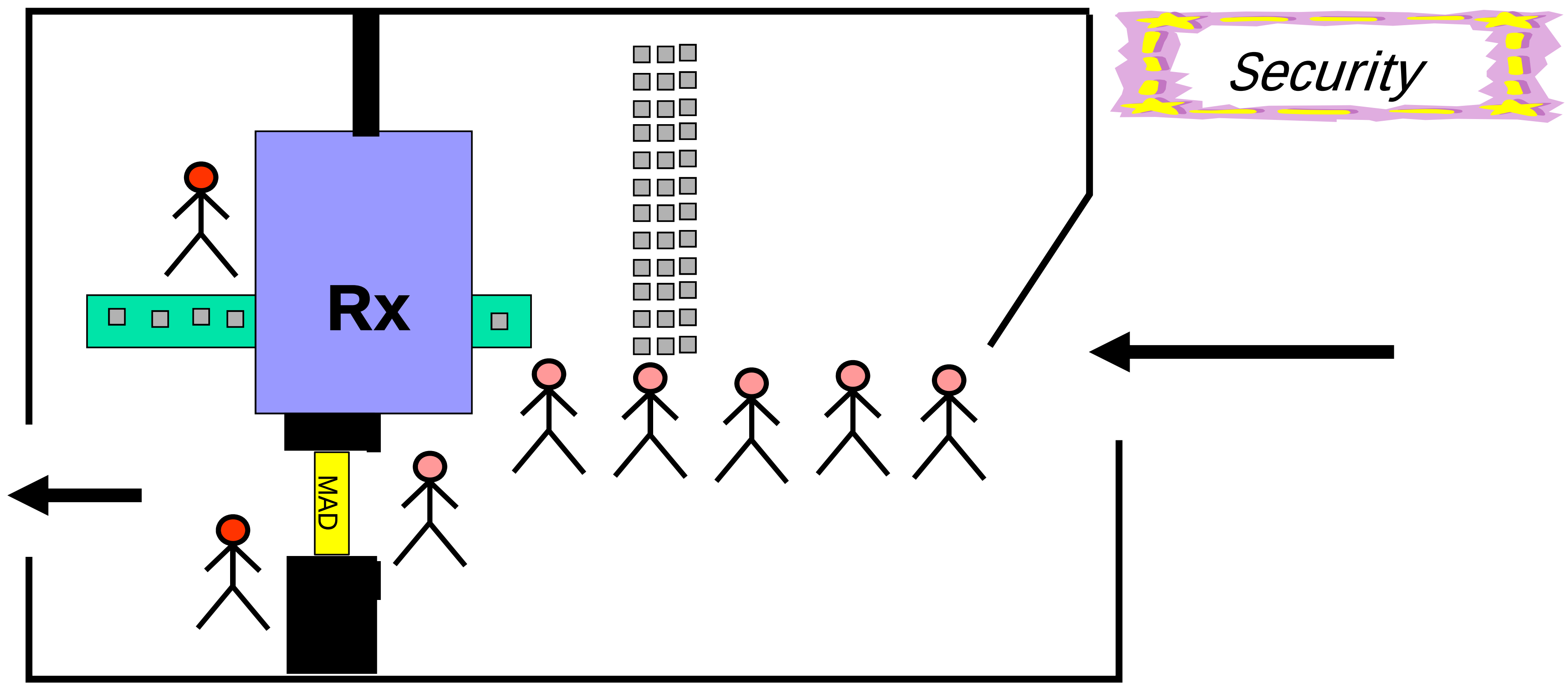


Colours

Coloured Petri Net Formalism



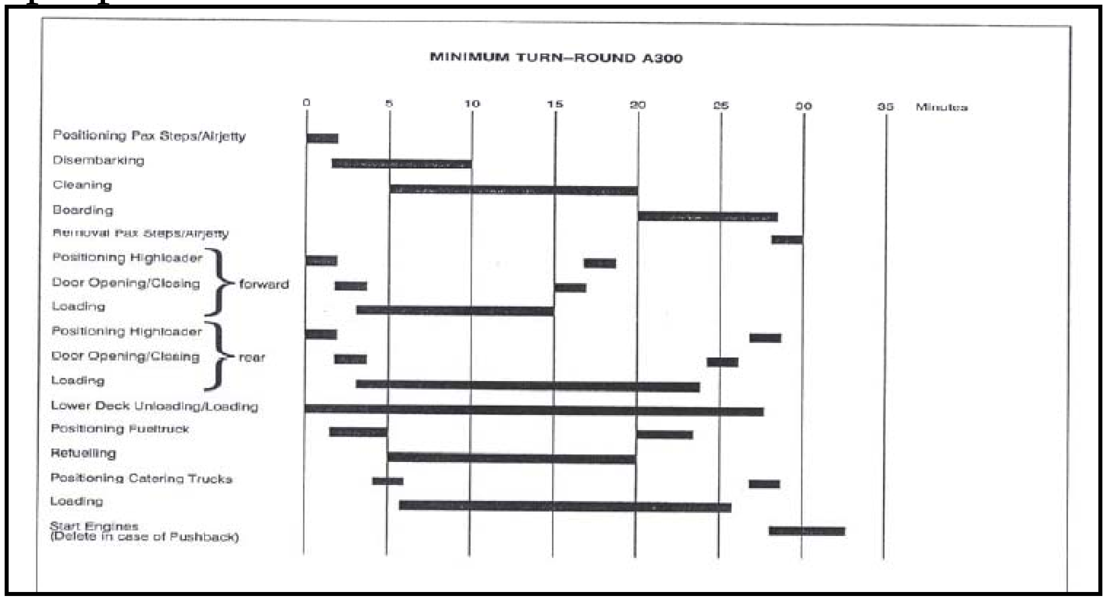
Practical Applications using Petri Net Formalism



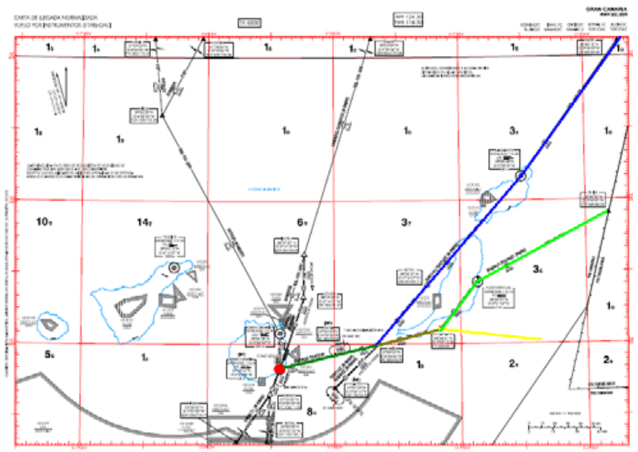
Practical Applications using Petri Net Formalism

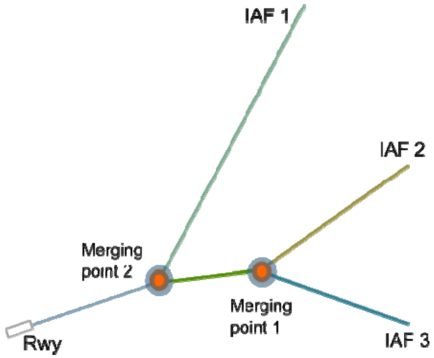
Petri Nets modeling features

- Allow description of a system at different abstraction levels.
- Easy use due to graphics visualization.
- Allow checking for undesirable properties such as deadlock.



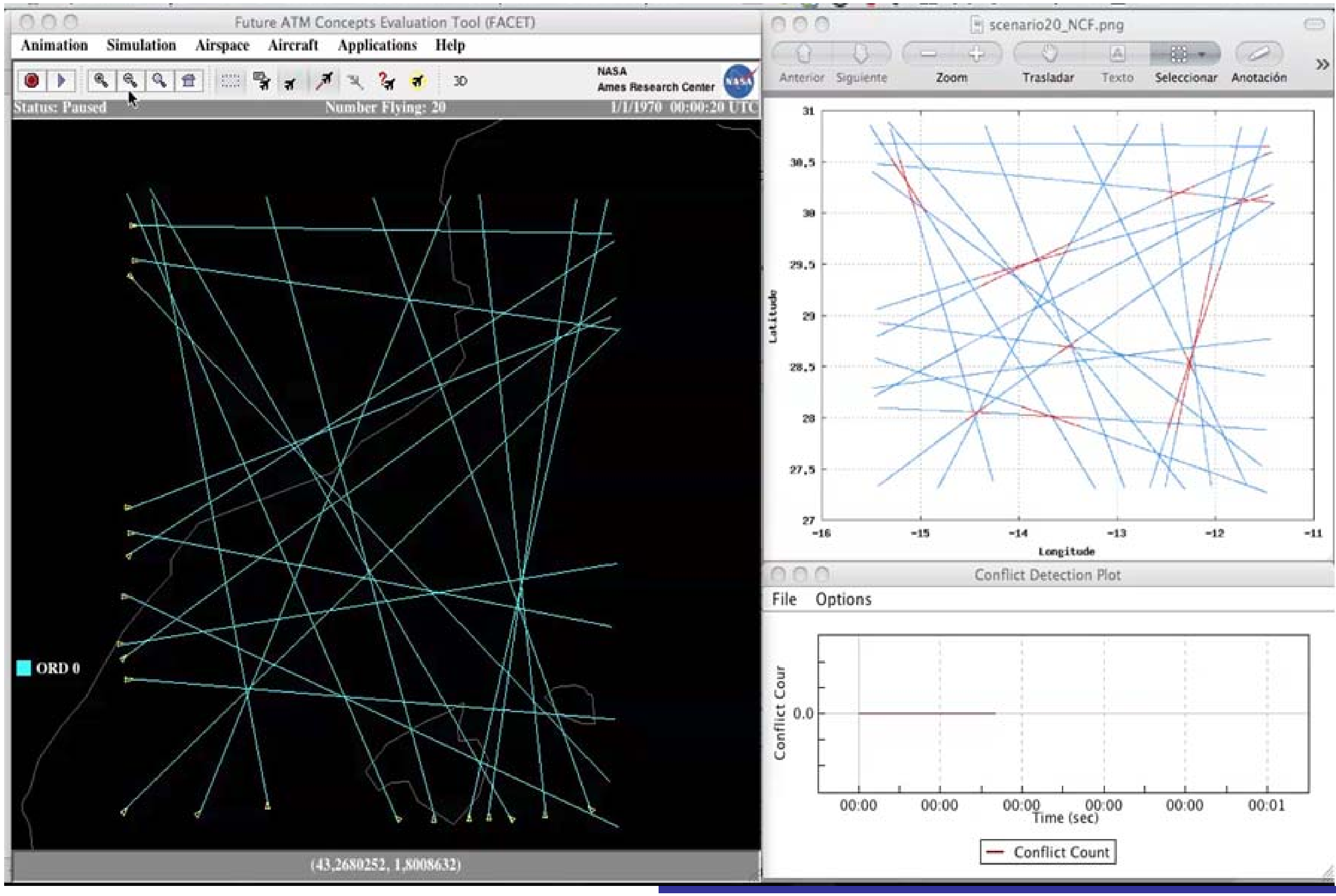
Practical Applications using Petri Net Formalism



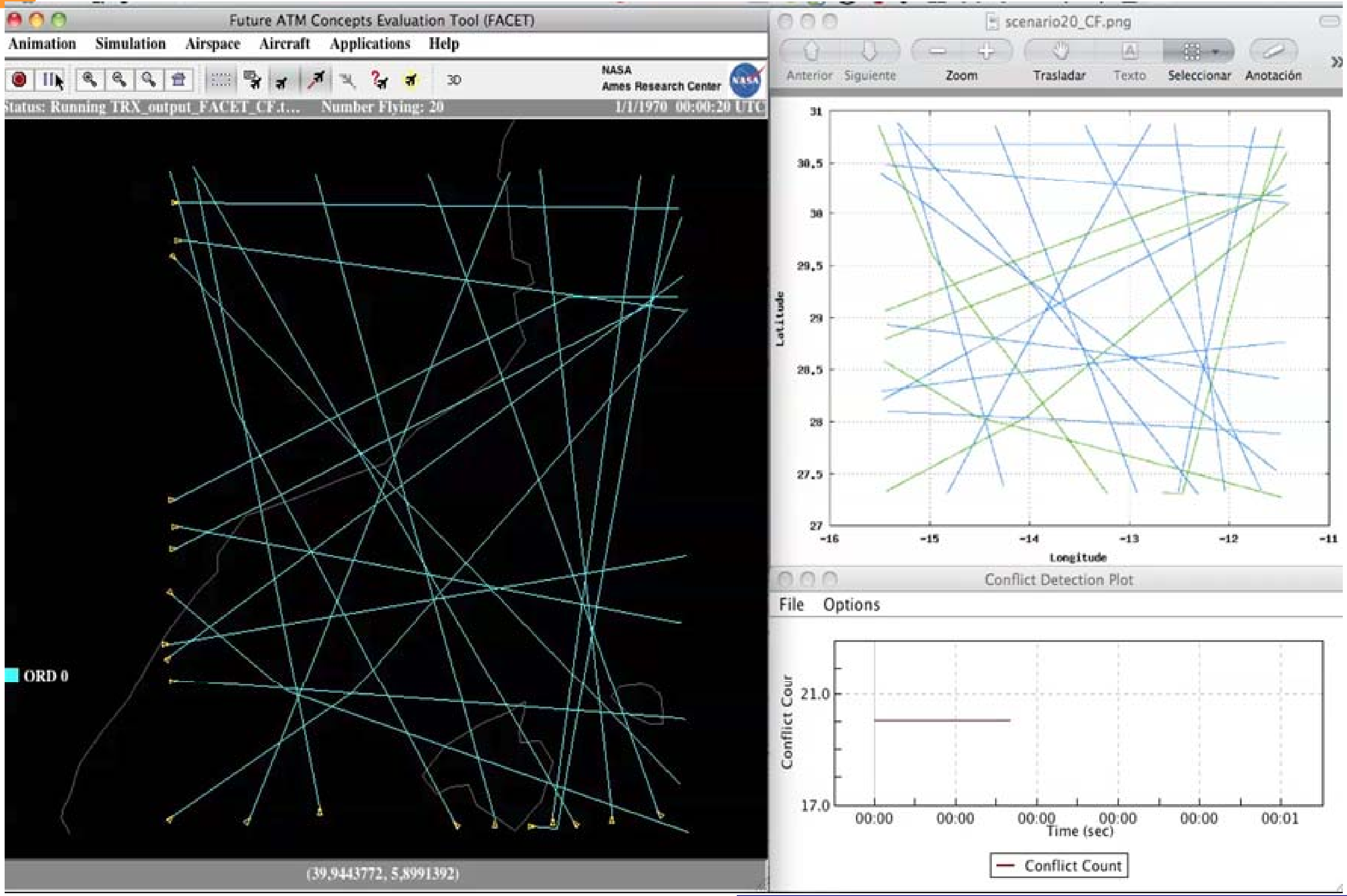


Waypoint	Latitude		Longitude		FL	Distance (NM)	IAS (Kts)	TAS (Kts)	Abas.tiem (HHMM)	Rel.time (min)
RUSIK	28°	54.4'	-12°	49.0'	300	0	300	466	1621	0
WPT66	27°	57.9'	-13°	25.4'	300	64	300	466	1629	8
CANIS	28°	00.0'	-14°	38.9'	214	64	300	409	1638	17
ENETA	27°	55.0'	-14°	59.6'	136	19	300	364	1641	20

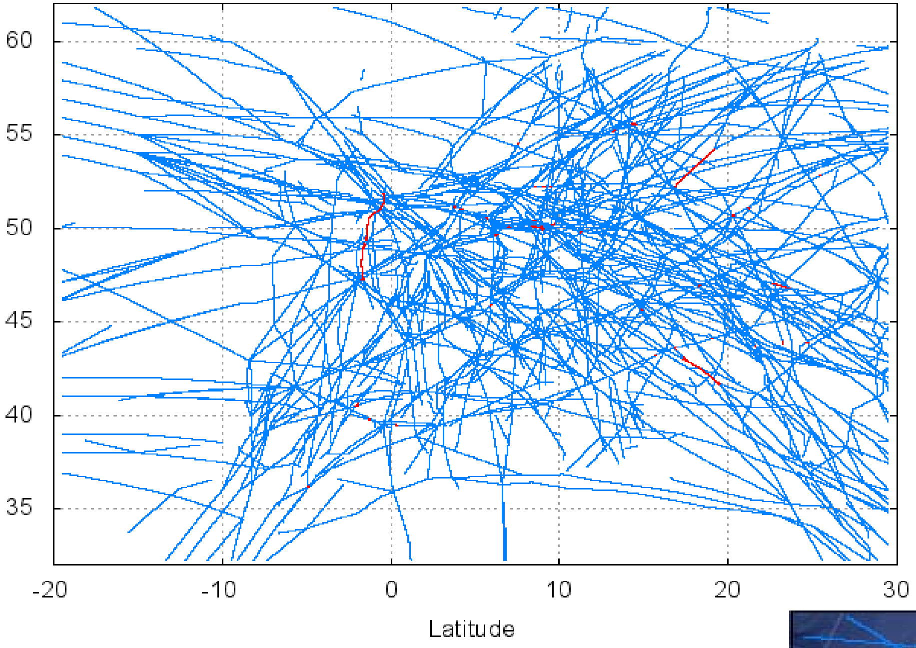
Practical Applications using Petri Net Formalism



Practical Applications using Petri Net Formalism



How to improve TMA operations



1200 trajectories over Europe

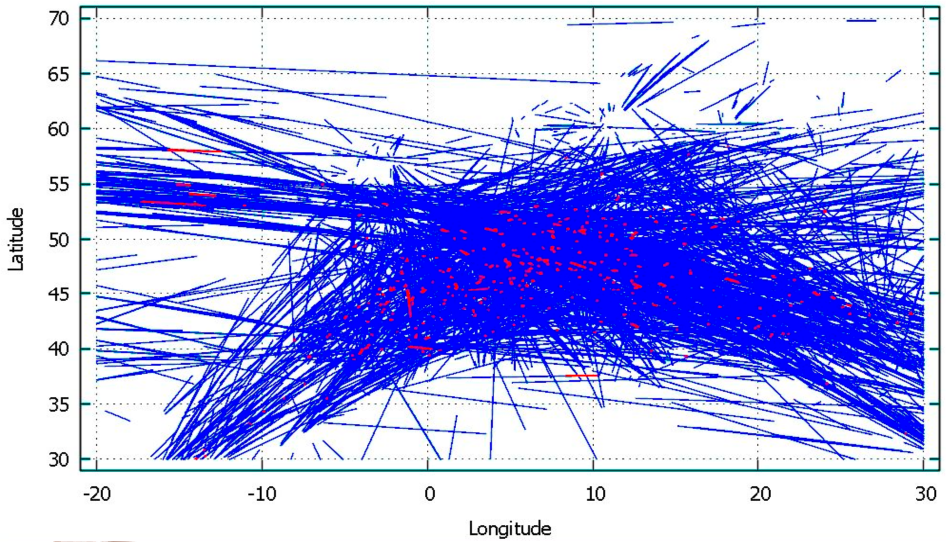
Optimization through Simulation: How to improve TMA operations

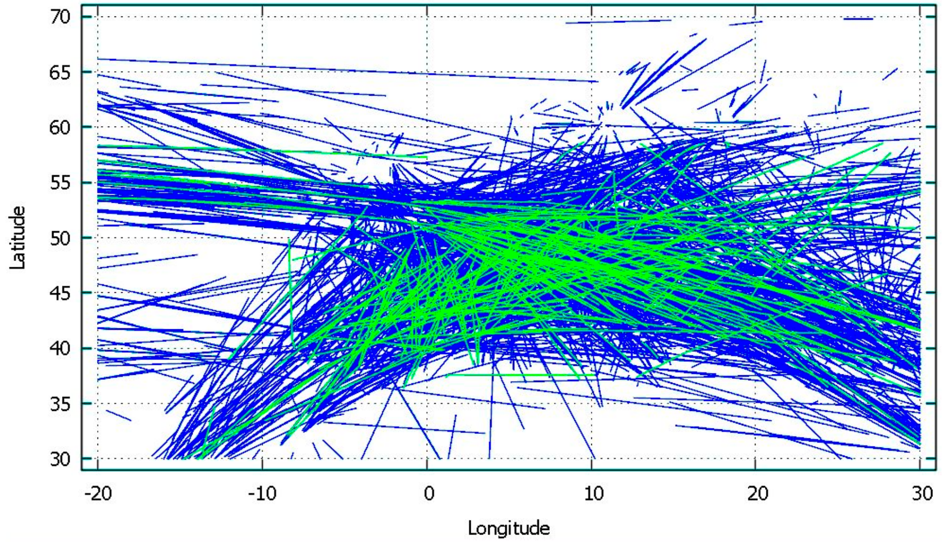
Results with 7NM and 10NM in CR (5NM in CD):

	7NM	10NM
Nominal trajectories	4010	4010
Resolution trials generated	752	723
Total trajectories after RTG	4762	4733
Nominal conflicts	211	211
2on and 3rd order conflicts	743	629
Total conflicts after RTG	954	842
HAC manoeuvres in solution	190	180
FL Changes in solution	3	6
Total modified trajectories	193	186

CD&R runtime:

Module	Runtime
CD	8 sec.
RTG+CD	41 sec.
Clustering	9 sec.
ICS	20 sec.
Total	**78 sec.**





Conclusions

The use of a formalism to specify all the events that affect the system performance has been introduced as an indispensable task to be made previously to optimize a cost function.

PN are a very suitable formalism to model and visualize patterns of behaviour comprising: concurrency, synchronization and resource sharing

The proposed approach allows the integration of OR (optimization algorithms), Heuristics (search methods), and Simulation (evaluation methods) methods which are essential to deal with quasi-optimal solutions in complex problems.

Conclusions

System Complexity should not be seen as a property inherent to the system, instead it should be seen as a lack of a methodology and tools that would allow the engineer to specify and formalize the knowledge we got about a system.

Miquel Angel Piera
MiquelAngel.Piera@uab.cat

Systems Engineering Group
Dept. of Telecomunication
Universitat Autonòma de Barcelona
Barcelona (Spain)