

An Air Traffic Control Model Based Local Optimization over the Airways Network

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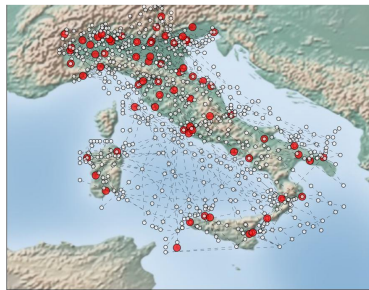


Analysis of Aircraft Radar Tracks

- ▶ Data about flight plans (before ATC) and radar updated tracks (after ATC) in Europe (DDR data.)
- ▶ Time resolution ~ 2 min: conflicts cannot be spotted!
- ▶ Sectors structure.
- ▶ Safety Dataset: data about Short-Term Conflict Alerts (STCAs) [1]

[1] Lillo, Fabrizio, et al. "Coupling and Complexity of Interaction of STCA Networks." *EUROCONTROL 8th Innovative Research Workshop Exhibition*. 2009.

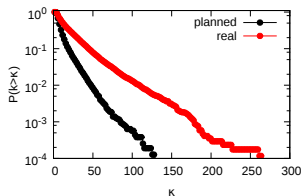
Navigation Point Networks



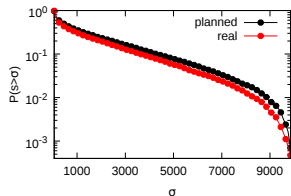
Planned Follows the airways structure.

Real Topological changes due to ATC.

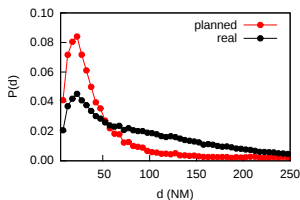
Navigation Point Networks



Degree



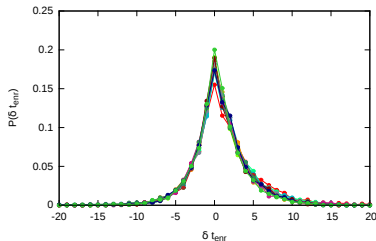
Strength



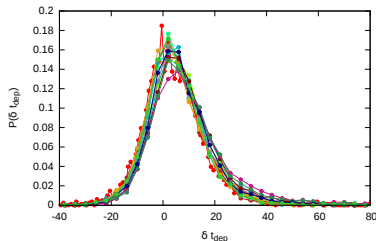
Links' Length

- Creation of longer links, the traffic over the network becomes more homogeneous

Delays



En-route Delay

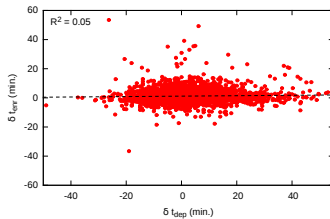
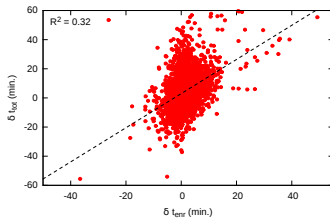
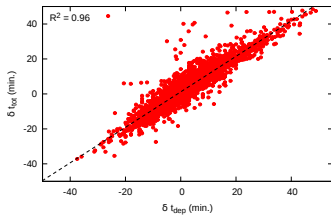


Departure Delay

$$\triangleright \delta t_{tot} = \delta t_{dep} + \delta t_{enr}$$

- Delays of aircraft crossing the Italian Airspace in June 2011.

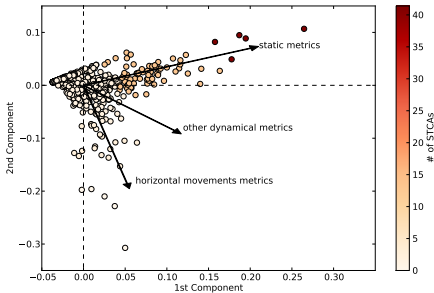
Delays: Correlations



Dynamical Metrics and STCAs

- ▶ Short-Term Conflict Alert (STCA) $\rightarrow n_{STCA}$ & $P_n(STCA)$
- ▶ Dynamical Metrics [2]:
 - ▶ Horizontal Movements (*Frac*, *Fork*...)
 - ▶ Vertical Movements (*Alt*)
 - ▶ Generated Delays (*Positive Delays* and *Negative Delays*)

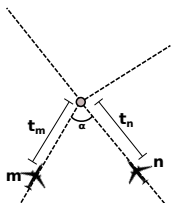
[2] Vitali, S. et al. *Statistical regularities in atm: network properties, trajectory deviations and delays.*



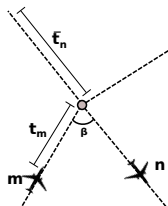
- ▶ Vertical Deviations used in critical and highly trafficked nodes.
- ▶ Horizontal Deviations used in non-critical and low-trafficked nodes.

Air Traffic Model: Conflict Detection

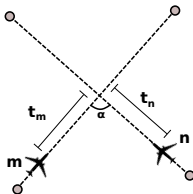
a)



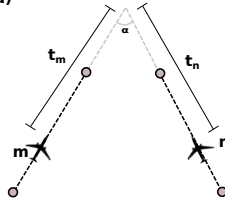
B)



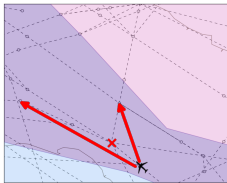
c)



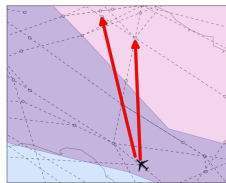
d)



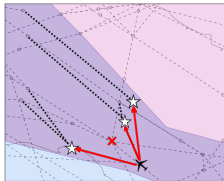
Air Traffic Model: Conflict Resolution



IN



OUT



Vectoring

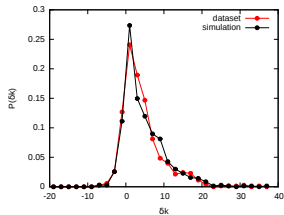
Model Validation

- ▶ Simulation of full day schedules in a chosen airspace (Estonian, Greek and Italian)
- ▶ Data inferred management protocol:
 - ▶ Vertical Deviations allowed
 - ▶ IN-OUT protocol
 - ▶ *Direct Assignment*
 - ▶ *Sectors Capacity Constraints*
- ▶ External disturbances: penalty delay generating areas

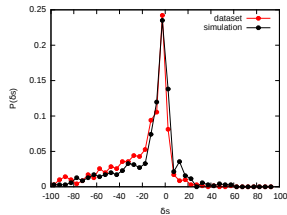
Coarse Grained Validation

- ▶ Measure of Network Metrics Variations on the Airways Network due to ATC
- ▶ Degree k of a node: the number of other nodes that are linked to the considered one.
- ▶ Strength s of a node: the sum of the weights of all the links connected to the considered node (Traffic Load)
- ▶ Betweenness Centrality b of a node: this metric measures the “importance” of a node in the network.

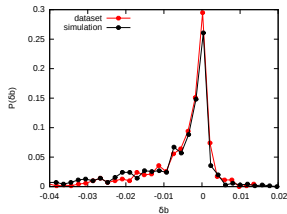
Coarse Grained Validation



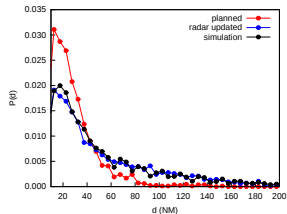
Degree



Strenght



Betweenness

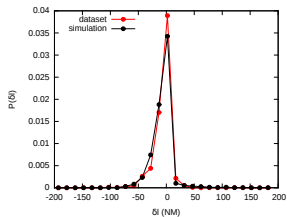


Links' Length

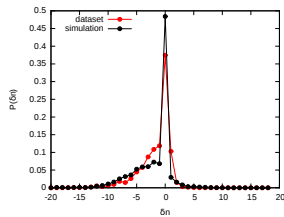
Microscopic Validation

- ▶ Measure single trajectory variations from flight plans to real trajectories.
- ▶ δl : variation in length.
- ▶ δn : variation in the number of crossed navigation points.
- ▶ δt_{enr} : en-route delay.

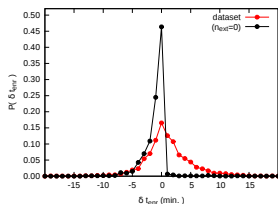
Validation: Trajectories Statistics



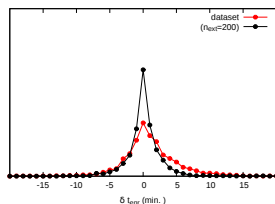
δl



δn



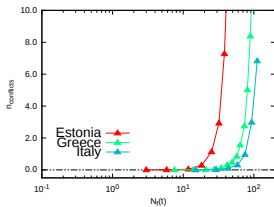
δt_{enr} (no ext. dist.)



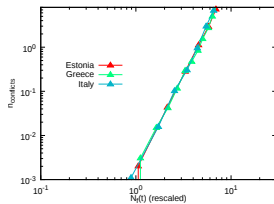
δt_{enr} (with ext. dist.)

High-Traffic Simulations

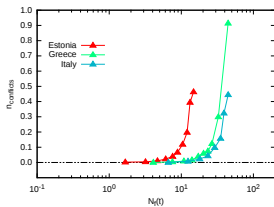
- ▶ Simplified conflict resolution protocols: IN-OUT, OUT-IN, Vectoring-OUT, IN-OUT(Vertical Deviations).
- ▶ Realistic protocol used in validation.
- ▶ Random schedule of N aircraft departing in a time frame of 2 h
- ▶ Simulation is over when every aircraft arrives at destination.



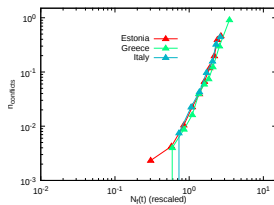
IN-OUT



IN-OUT(scaling)



Vectoring-OUT



Vectoring-OUT(scaling)

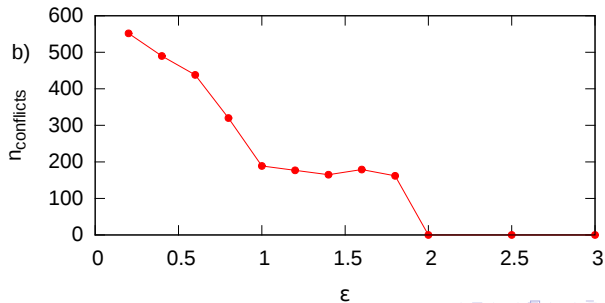
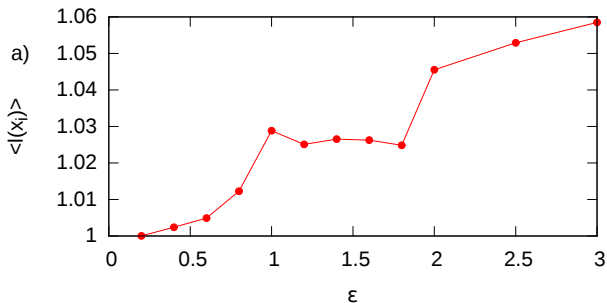
Efficiency of Global Optimum Planning

- ▶ The model is suited to test new trajectory planning and airspace structures.
- ▶ Built a new solution for the planned trajectories and use the model to compare them with the current ones.
- ▶ Local Optimization (ATC) → Global Optimization

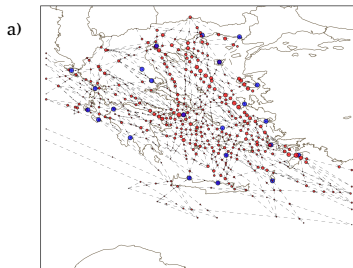
Extremal Optimization Algorithm

- ▶ Based on the Self-Organized Criticality Phenomenon (SOC): optimization via avalanche dynamics.
- ▶ $C(\gamma) = \sum_i \gamma_i$.
- ▶ $x_i = \{(n_{start}, t_{start}), (n_1, t_1), \dots, (n_{stop}, t_{stop})\}$
- ▶ $\gamma_i = l(x_i) + \frac{\epsilon}{2} \sum_{j=1, j \neq i}^N m(x_i, x_j)$ (Fitness of the i^{th} trajectory)
- ▶ Parameter ϵ allows to modulate between straight and conflict-free flight plans.
- ▶ Sectors Capacity constraints are enforced.

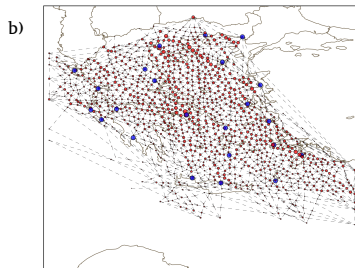
Suboptimal Flight Plans



Suboptimal Flight Plans



Current



Sub-Optimal

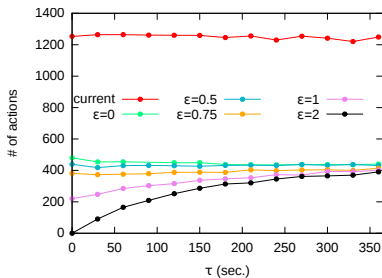
Efficiency Against Perturbations

- ▶ External disturbances have not been included in the optimization process
- ▶ How these solutions behave under their influence?
- ▶ What are the differences with respect to the current situation?
- ▶ Departure Delays: from a uniform distribution in $[-\tau, \tau]$
- ▶ External disturbances: penalty delay generating areas

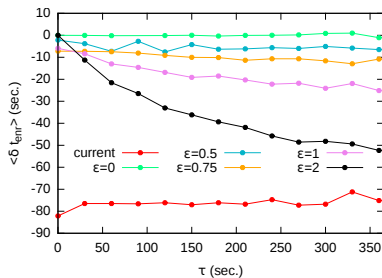
Efficiency Against Perturbations

- ▶ Every aircraft flies according to a flight plan obtained with the EO algorithm for various values of ϵ .
- ▶ The structure of the sectors is unvaried with respect to the current situation. After every redirection an aircraft is sent directly to its destination following a straight line.
- ▶ Directs in order to speed up the traffic are not considered.
- ▶ Controllers solve conflicts using the IN-OUT protocol.
- ▶ Capacity constraints are enforced.
- ▶ Efficiency: Number of Action Performed by the ATCs

Departure Delays

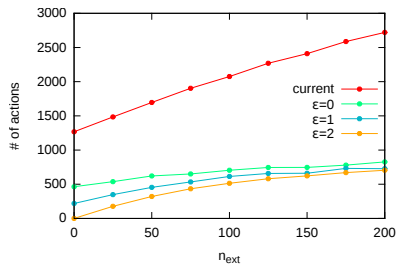


of actions

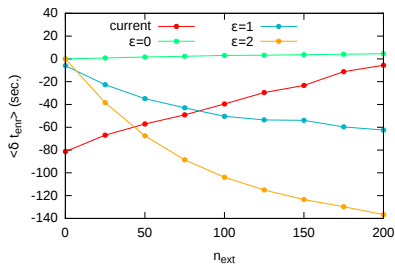


En-Route Delay

Perturbed Areas



of actions



En-Route Delay

Conclusions

- ▶ Developed a model of ATC using historical data
- ▶ The action of the ATC is modeled as a local optimization over the network of the Airways.
- ▶ Used the Extremal Optimization Algorithm to build sub-optimal flight plans.
- ▶ Their efficiency have been compared to the current flight plans.