

An Agent Based Model of Air Traffic Management

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ELSA

Empirically grounded agent based models for the future ATM scenario

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Two distinct spatio-temporal scales:

- **Strategic phase:** preparation of the flight plans by the air companies, allocation by the network manager.

⇒ time scale from the month to the hour. Spatial scale from the whole Europe to a sector.

- **Tactical phase:** real flight, controlled and modified by the air controller.

⇒ time scale from the hour to the minute, or even less. Spatial scale from an ACC to a sector.



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⇒ We split the strategic phase and the tactical phase in two separate “layers” with different agents, rules, etc.

STRATEGIC LAYER



Validation input for the strategic layer have been collected during interviews with people from the Alitalia Operation Center (OCC).

Preparing the flight plans

- Starts by collecting information like weather, aircraft performances, etc. between 2 and 6 hours before time departure.
- Minimization of the cost (mainly fuel and ATC fees) and safe execution based on these informations.
- no information on the other flights.
- Flight plan in ICAO format submitted through a dedicated system (SITA).
- The CFMU recalculates the flight plan using their own model and accept or reject the flight plan,
- The CFMU gives a reason for the rejection but no alternative routes.
- The company submits another flight plan.



Flight plans

Sequence of **sectors**, with time of departure.

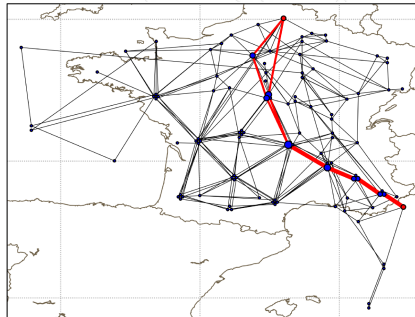
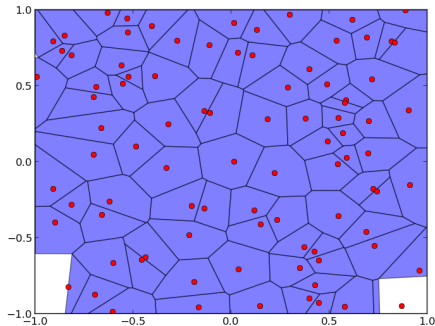


Flight plans

Sequence of **sectors**, with time of departure.

Network of sectors

- Can be generated (based on a Voronoi tessellation) or can be the real network (a single country for instance).
- Capacities are all equal to 5.
- Crossing times are taken either from a normal distribution or based on the geometrical distance between centroids of sectors.
- Crossing times are real numbers: model is a continuous time model.
- Unit of time is given by the average crossing time.



Left panel. An artificially generated tessellation of the airspace. Each elementary area represents a sector and neighbor areas are connected, forming a planar graph. Right panel. The real sector network of the French airspace.

- Defined by a cost function.
- chooses at random a couple origin/destination,
- finds best paths on the network,
- selects k couples (path, time of departure) based on minimal cost function,
- submits them to the NM.

$$c(\mathbf{p}, t) = \alpha|\mathbf{p}| + \beta(t - t^0)$$

Remarks

- Desired time t^0 is an input of the model. Presently, distribution is in a “wave” pattern.
- Can only be shifted ahead in time: $t > t^0$ of a quantity $\tau = 1$.
- $|\mathbf{p}|$ is the weighted length of the trajectory.



Network Manager (NM)

- Receives a flight plan from companies in random order;
- checks if all the sectors remain below capacity if the FP were accepted;
- approves or rejects the flight plan;
- if FP is accepted: allocates the flight plan (recompute all current sector loads);
- if FP is rejected: the company submits another flight plan with a higher cost.

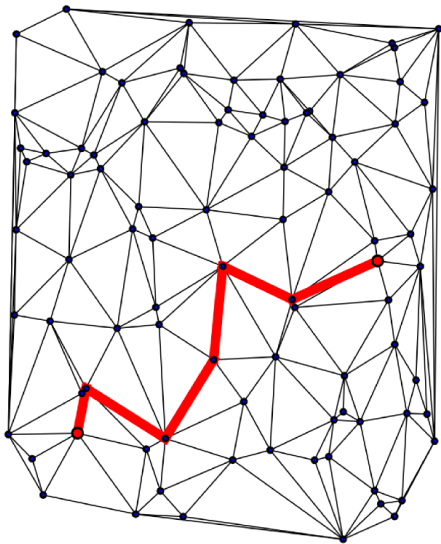


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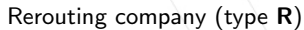
Remarks

- NM is a passive player
- No global optimization or counter-propositions.



Time shifting company (type S)

- $\alpha \gg \beta$,
- “Low-cost company”,
- wants shortest trajectories,
- shifts in time.

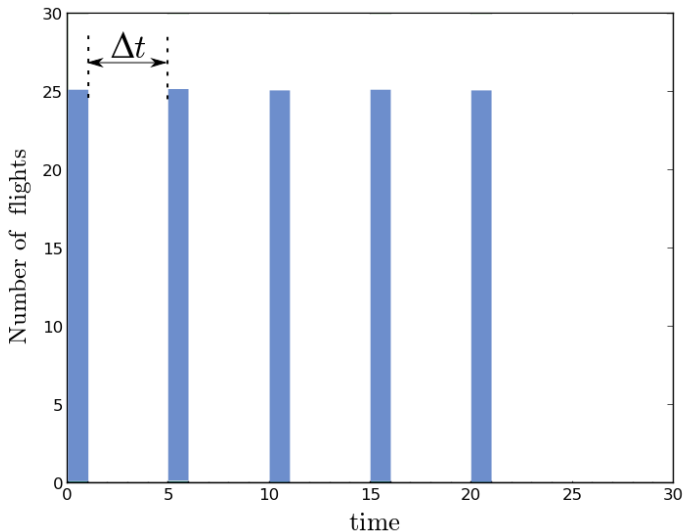


- $\alpha \ll \beta$,
- “Major airline company”,
- wants punctuality (because of waves),
- considers alternative routes.



Departure times pattern

Time window of 24 units of time.





Parameters

- Number of flight plans submitted (10);
- Time of shifting: 1;
- Duration of waves: 1.



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Metrics: satisfaction of a company and global satisfaction

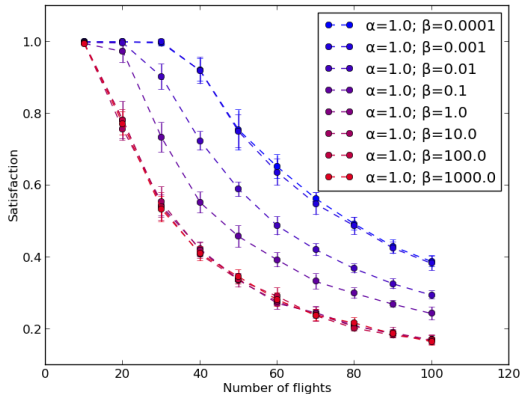
$$s_f = c(\mathbf{p}_{best})/c(\mathbf{p}_{accepted})$$

$$S = \frac{1}{N_f} \sum_f s_f$$



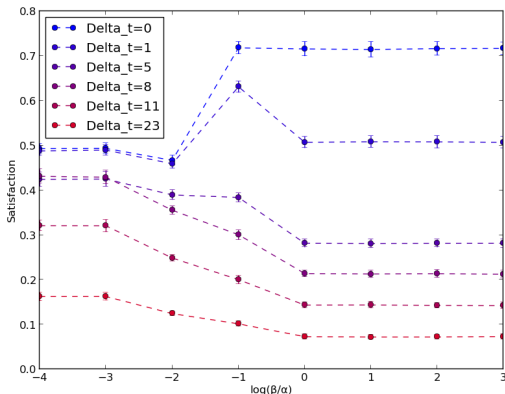
Pure populations: only one type of company

Total satisfaction against number of flights (well separated waves, i.e. large Δt)



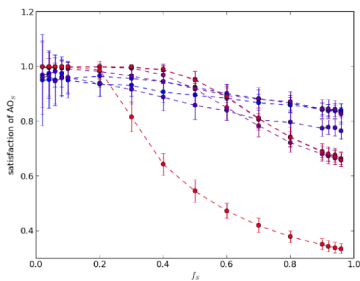
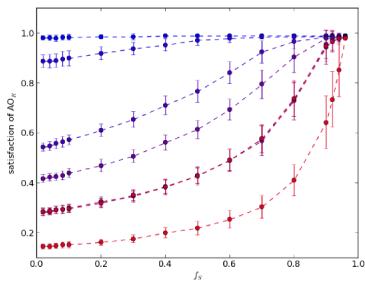
- Satisfaction of companies declines with the amount of traffic, due to regulation
- In this setting, time shifting companies are more satisfied than rerouting companies, however....

Total satisfaction against type of company (120 flights)



- When waves are well separated (large Δt) time shifting companies have a larger satisfaction
- When waves are close (small Δt) rerouting companies have a larger satisfaction.

Satisfaction of “Rerouting” (left) and “Shifting” (right) against fraction of “Shifting” Companies

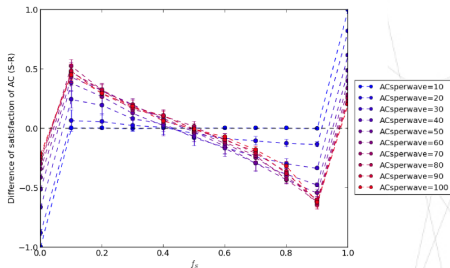
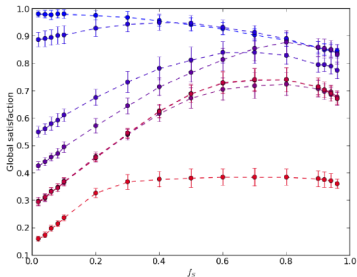


- For high values of Δt , it is always better to be alone (i.e. surrounded by companies of other time)
- For R companies, the uniform departing time case is always the best one
- For S companies, it is better for the flights to be gathered in waves (big Δt) for small fraction, whereas the uniform situation (small Δt) is better for high fraction.



Mixed populations: what is best for the whole system?

Total satisfaction (left) and difference of satisfaction against fraction of “Shifting” Companies (for $\Delta t = 1$)



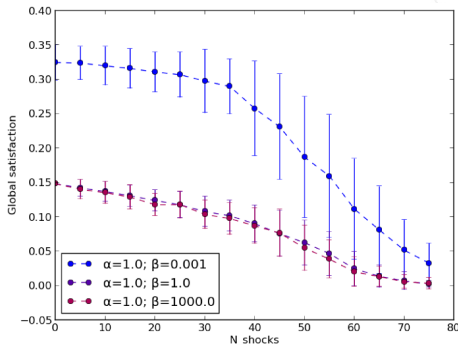
- For fixed Δt there is an optimal mixing of the two types of companies
- For a given Δt there is an stable equilibrium point (depending on the total traffic) which corresponds to the same satisfaction for the two types of companies



Shocks (pure population)

We model some “shocks” on the network by shutting down randomly a given number of sectors.

- We recompute all flight plans concerned by the shocks at **each** shock.



The S company is more resilient than the R, up to the certain threshold probably related to the percolation threshold. A consequence is that company S is increasing its advantage on R.



Aim

- The model allows to understand the main issues which arise from the existence of different strategies for the choice of flight plans.



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Conclusions

- Dominant strategies depend on the departing times pattern;
- Dominant strategies depend on the fraction of populations;
- Global satisfaction of the system does not always depend on the fraction of population;
- Some companies are more resilient (to this kind of shocks) than others;
- From an evolutionary point of view, there is one stable point with mixed populations. The point depends on the time pattern, but not on the number of flights.

TACTICAL LAYER



Agents of Tactical layer

- One type of agents in this layer of the model is given by **AIRCRAFT/PILOTS**
 - **At this stage**, flights cross the selected sector within a certain time-span as recorded in our database reporting DDR and NEVAC real data
 - Flights can overlap in different segments, can enter the sector in any part of its boundaries and can cross to each other
- For the sake of simplicity, we do not model the take-off and the landing phases of the flight-plans. Our focus is on the “en-route” flights trajectories.
- Another type of agents in the model is given by the **CONTROLLERS**.
 - Controllers give instructions to flights whenever a problem occurs.
- **In the present version of the model:**
 - *Aircraft/Pilots can not reply to controllers*
 - *Aircraft/Pilots do not directly interact with each other.*

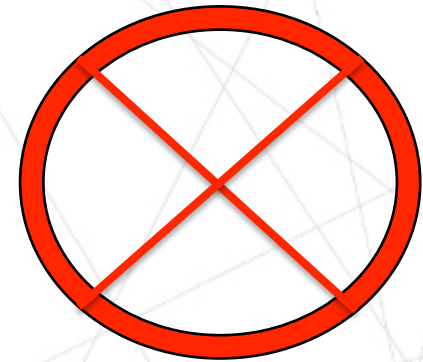


Aim of the model

We check whether there are critical regions:

**Either because flights are crossing a “shocked” area
EXTENDED CRITICAL REGION**

**Either because flights are colliding
POINT-like CRITICAL REGION**



We then apply a 3-step algorithm to avoid the critical region:

RE-ROUTING

FLIGHT-LEVEL CHANGE

VELOCITY CHANGE (not shown here)

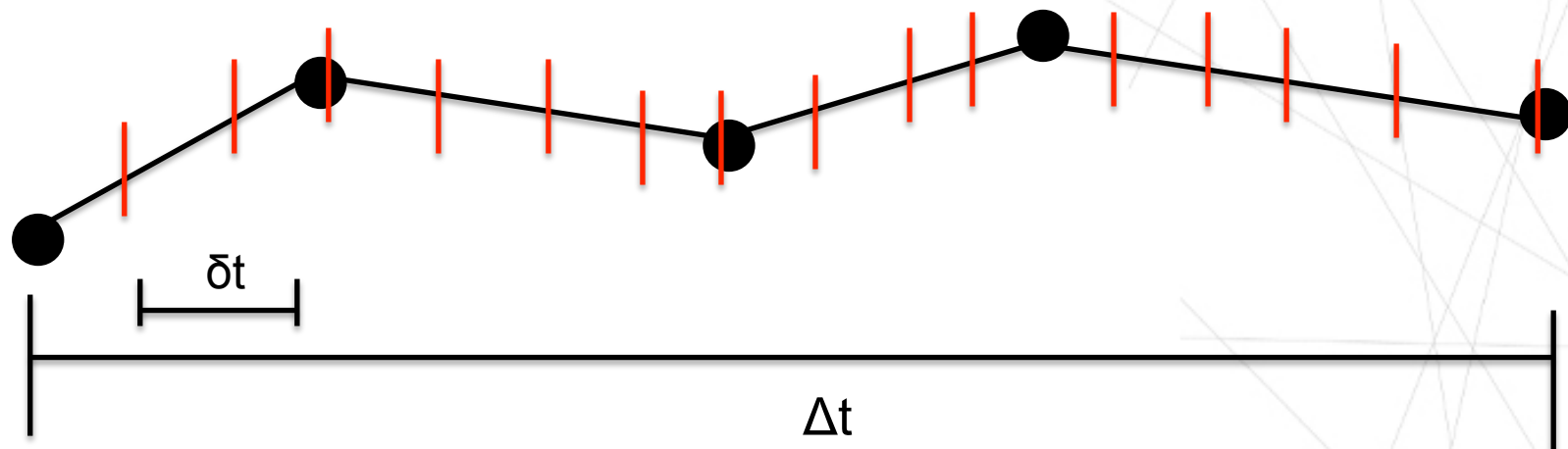
in order to solve the conflicts



FLIGHT-LIST MODULE

At this stage flight trajectories M1 have been taken from the ELSA database.

- The management of the trajectory is done within a $\Delta t = 240$ secs time horizon (controller's look.ahead)
- The flights are sampled every $\delta t = 1/3 \Delta t$ secs (by linearly interpolating if necessary)





SHOCKS MODULE

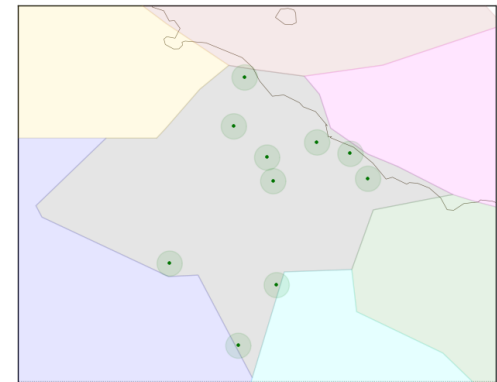
model exogenous shocks INSIDE the sector

A random number of INTERNAL navigation points is hit by a shock
We construct around these points an area that can not be crossed by any flight in the current time-period. This area is defined as a circular area of a certain radius (e.g. 10 Km).

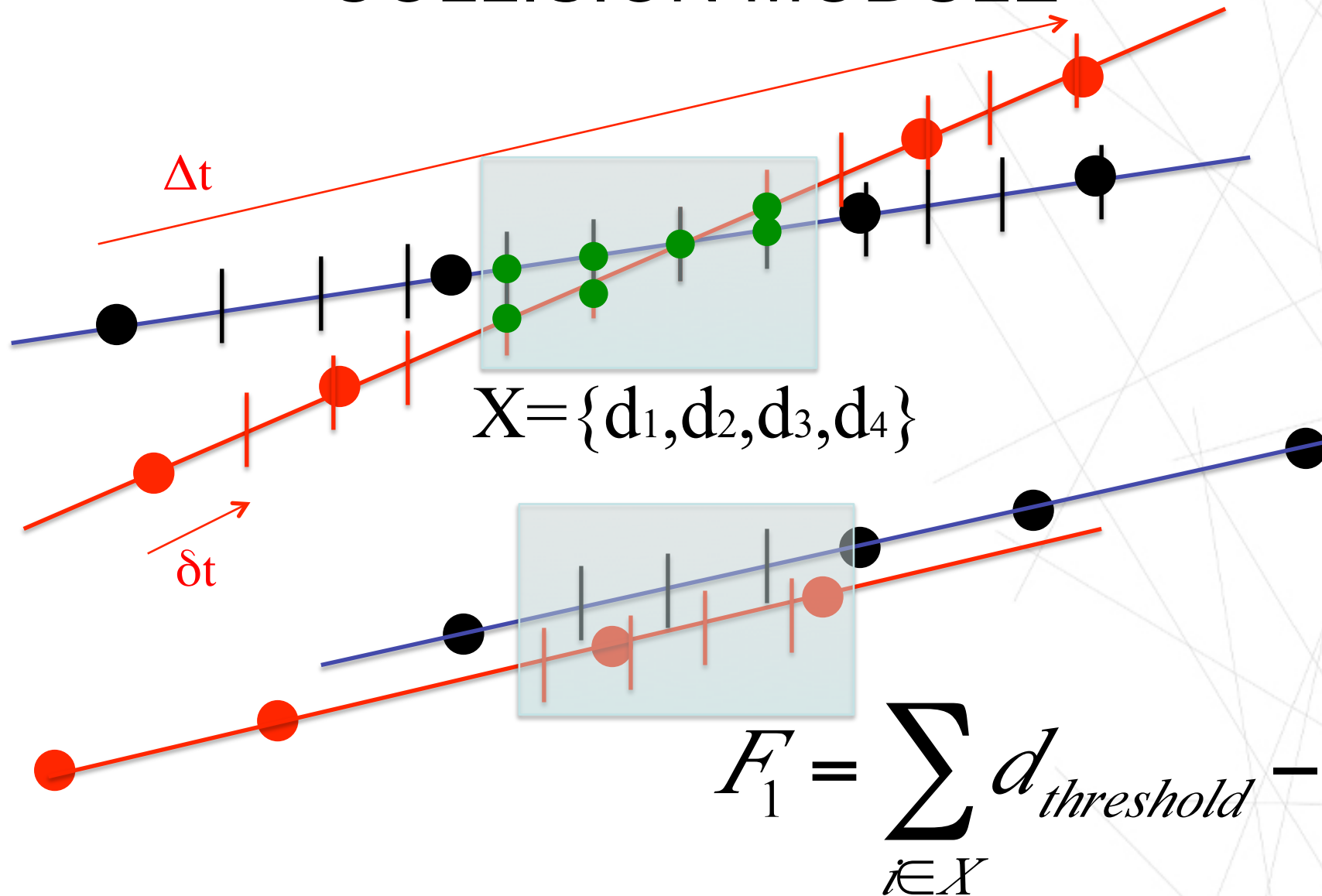
At the moment all shocked area are totally included in the sector.

We can control whether they **overlap** or not.

Shocks are random i.i.d. or spatially/temporally Distributed.



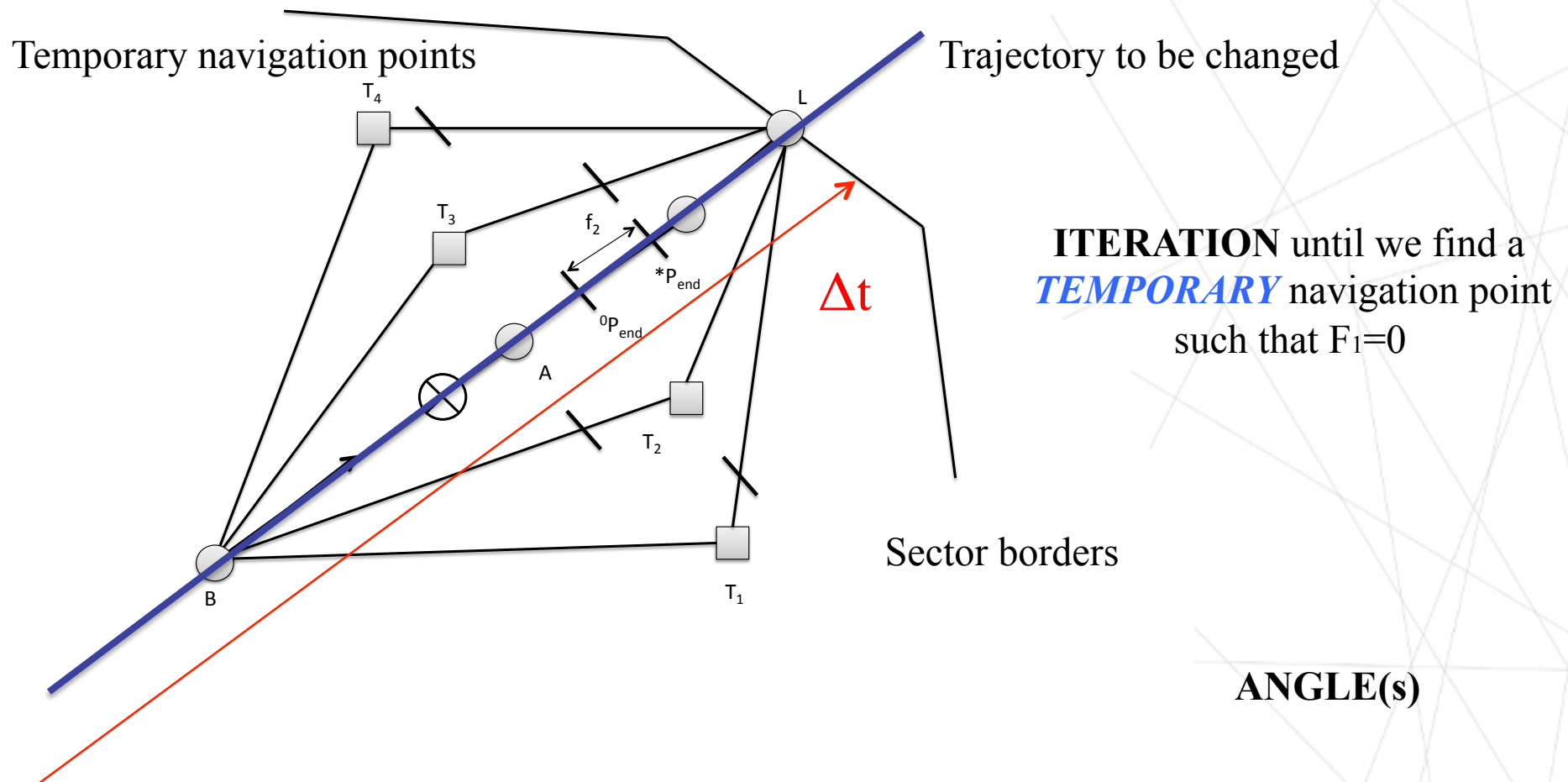
COLLISION MODULE





DE-CONFLICTING MODULE

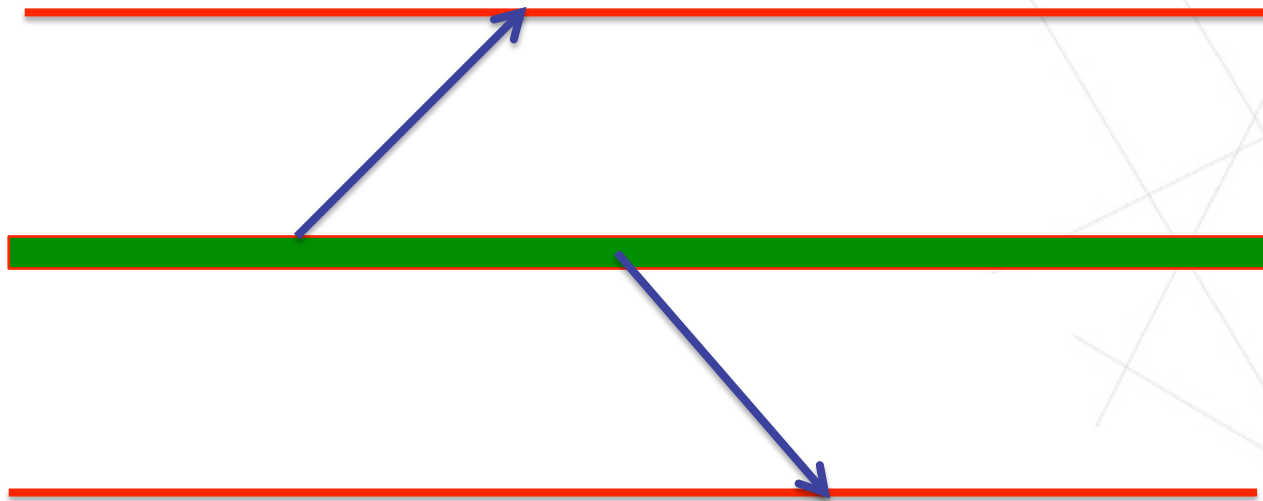
STEP 1: RE-ROUTING 1





DE-CONFLICTING MODULE

STEP 2: CHANGE of FLIGHT LEVEL



We choose the FL where F_i , summed for all flights in that level, is the **smallest**.



SIMULATIONS (no velocity change)

172 aircraft/day - 5000 iterations

RE-ROUTING – duration= Δt

no overlap

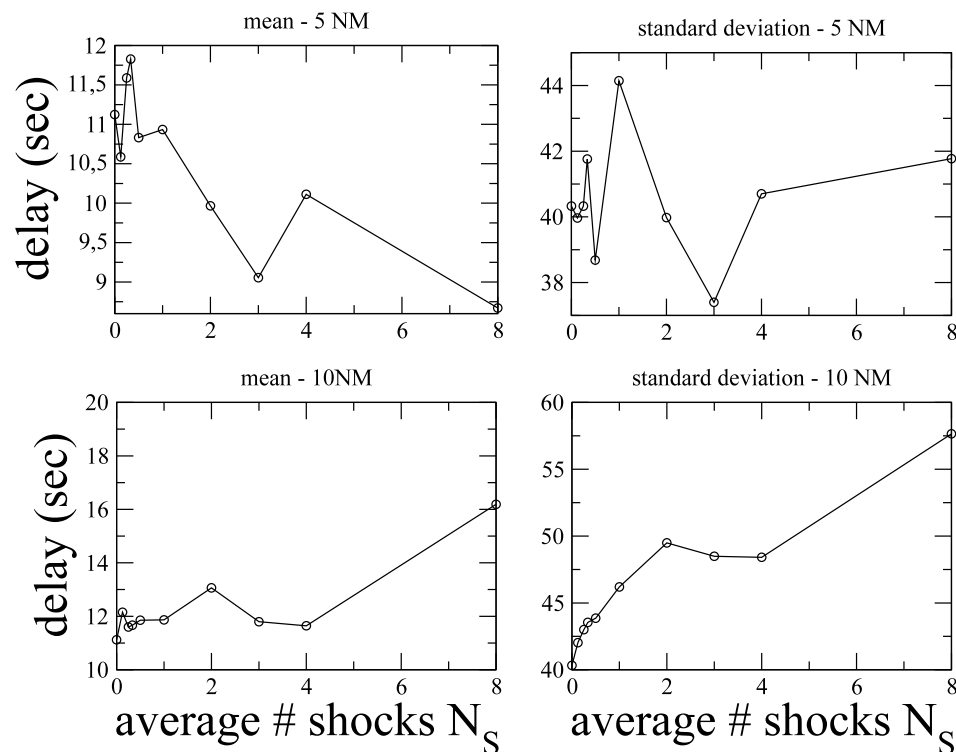


TABLE II
PERCENTAGE OF AIRCRAFT THAT ARE RE-ROUTED OR CHANGE THEIR FLIGHT LEVEL. THESE SIMULATIONS ARE PERFORMED ASSUMING THAT THE SHOCKED AREAS IS INVERSELY PROPORTIONAL TO N_S AND SUCH THAT WHEN $N_S = 1$ THE RADIUS IS 5 NM.

N_S	re-routed	flight level changes
0	0.159343	0.0977733
$\frac{1}{8}$	0.218005	0.166307
$\frac{1}{4}$	0.166115	0.187858
$\frac{1}{2}$	0.171248	0.191772
1	0.177301	0.199638
2	0.189807	0.216972
3	0.210333	0.241837
4	0.222334	0.258345
8	0.227505	0.267824
8	0.274455	0.326434

100% of M1 flight plans are delayed (+/- 900 sec) by hand to simulate interaction with other sectors



CONCLUSIONS

In the case when the occupied surface is **constant**:

We observe a general decrease of the average delay. This is due to the fact that shocks are smaller therefore the algorithm easily find “smaller” re-routings with respect to the case when we have less and larger shocks.

In the case when the occupied surface is **variable**:

Simulation results are less clear. We do not have a clear-cut interpretation of the results. The **size** of the perturbation seems to be **critical**.

We are working of the calibration/validation of the model, trying to see whether the model is capable of reproducing the average delay observed in this sector which is about 70 seconds (all scheduled flights above 240 FL, no military, no helicopters, flight time > 10 minutes).

- Strategic layer
 - ▶ Build the flight plans from the network of navigation points (as in reality)
 - ▶ Calibrate on real traffic data
 - ▶ Test alternative policies of the network manager
- Tactical layer
 - ▶ Multi sector scenario and propagation of distress
 - ▶ Calibrate on real traffic data
 - ▶ Test alternative air traffic control practices
- Integrated model
 - ▶ Integrate the strategic and tactical layer: the first feeds the second
 - ▶ Calibration and validation with real traffic data

For more details see the poster of Christian Bongiorno