ONBOARD

Air Traffic Flow Management Under Uncertainty

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ONBOARD

DESCRIPTION OF THE PROJECT

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DESCRIPTION OF THE PROJECT

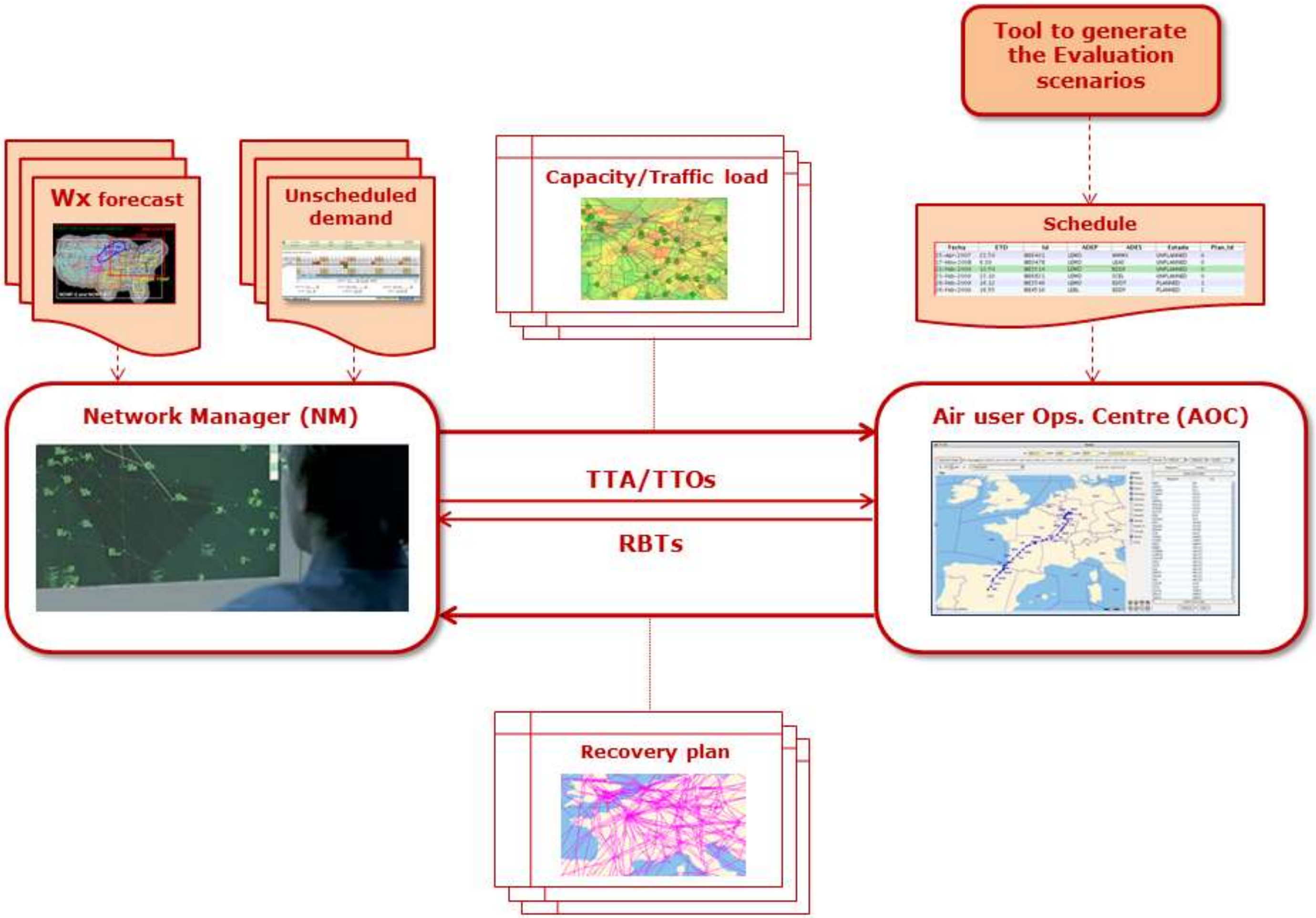
- Air Traffic Flow Management Uncertainties
  - Weather
  - Unscheduled Demand

- The goal of the ONBOARD project is to deal with those uncertainties.

- Two algorithms interacting each other have been developed, one acting as the Airlines Operation Centre and the other as the Network Manager.

More info at: http://www.onboard-sesar.eu/

DESCRIPTION OF THE PROJECT



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GLOBAL SYSTEM CONCEPT

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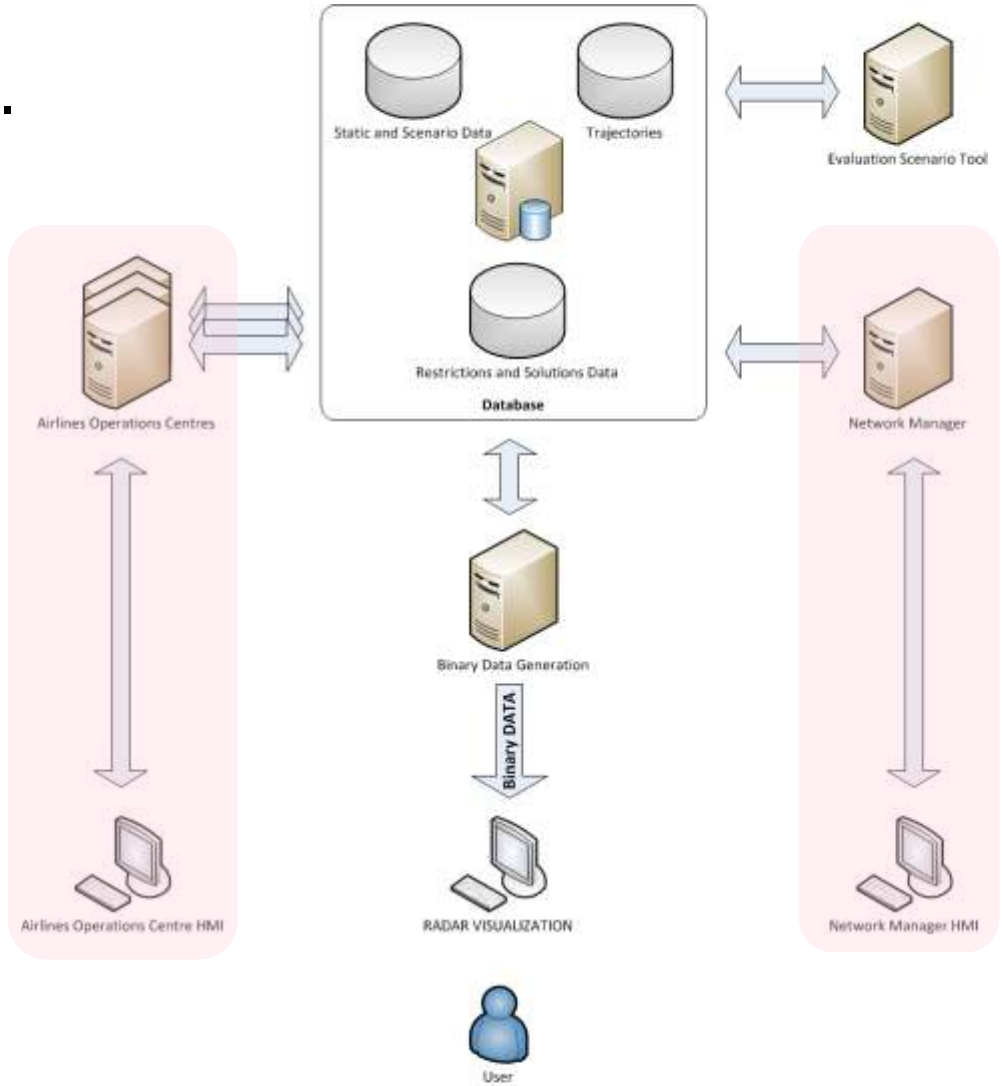
The architecture defined foresees the exchange of information through databases. This approach has several benefits.

- Independent development (AOC and NM) in terms of code and platform.
- Possibility of doing backups easily and run scenarios using stored backup data.



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AIRLINES OPERATIONS CENTRE

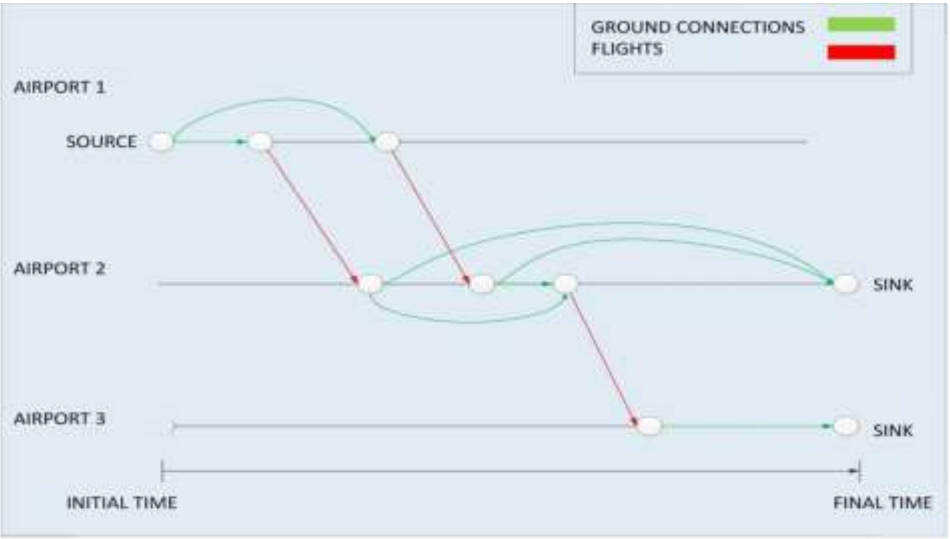
AOC MATHEMATICAL MODEL

- Objective: find the sequence of flights to be flown by each aircraft that minimizes the total cost and guarantees that all planned flights have been flown once and only once.

- Formulation:

$$\begin{gathered} Minimise \quad c^T x \\ Subject\ to: \ Ax = b \\ x \leq C \xrightarrow{C=1} x \in \{0,1\}^n \end{gathered}$$

- Model: Time-Line Network

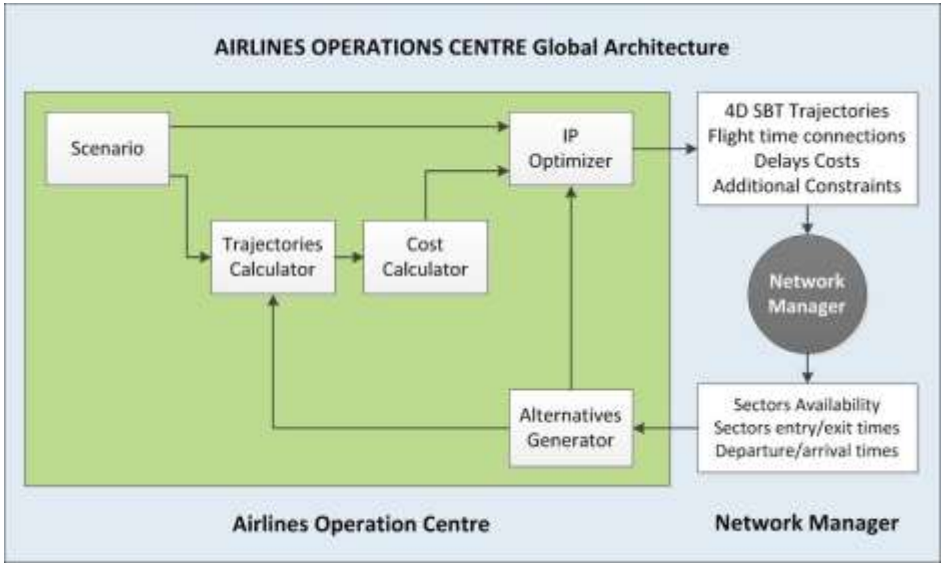


- Description
  - Nodes: represent location and time with associated flow.
  - Arcs: represent movement between two nodes with associated capacity and cost/profit.
  - Aircraft represent the commodities which are routed through the network with every arc.

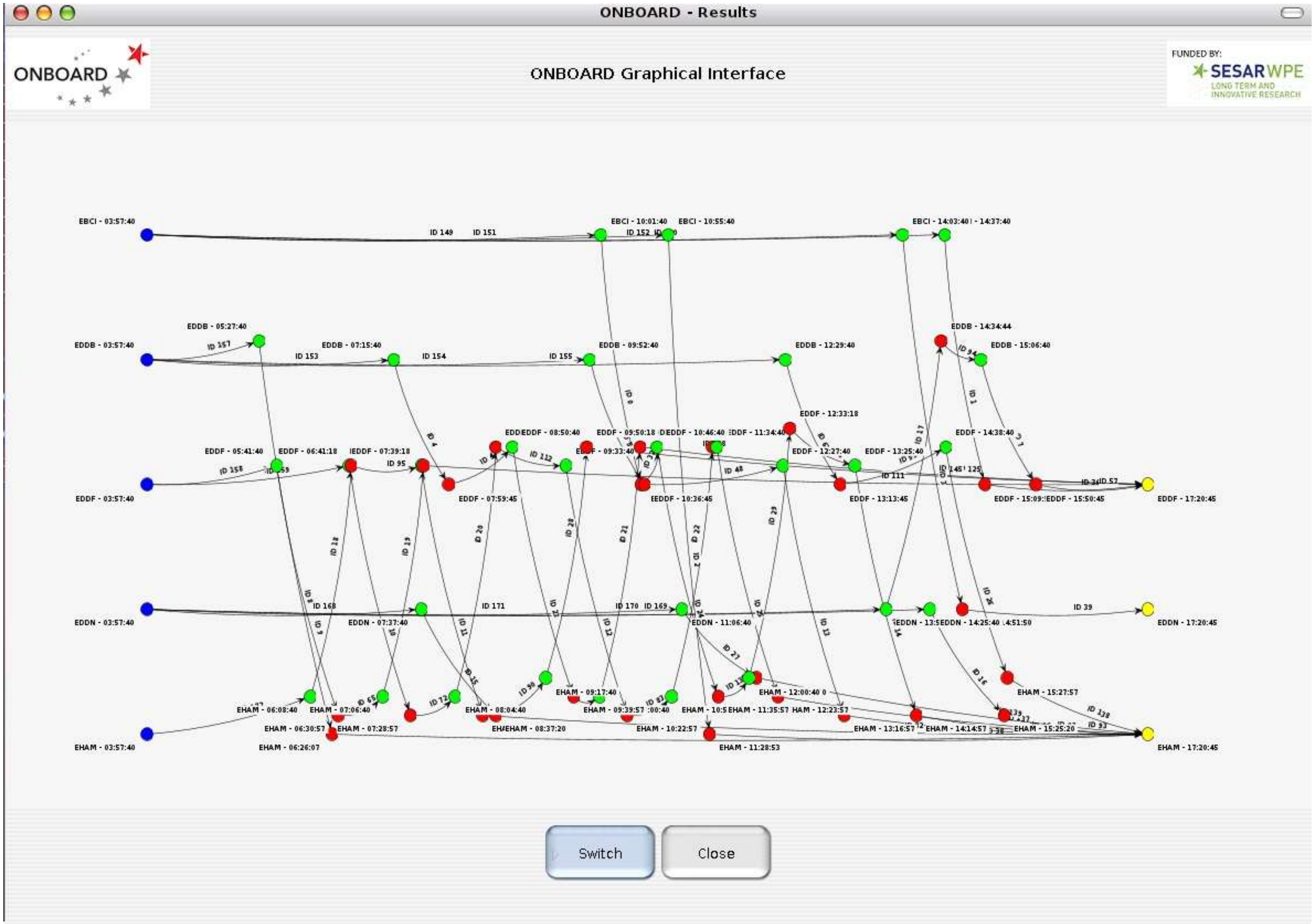
AOC ARCHITECTURE

The Airlines Operations Centre is in charge of the following functionalities:

- Keep or cancel the flight legs on ground
- Change the assignment of aircraft tails to flight legs on ground
- Change the departure time of each flight leg on ground
- Re-time a SBT on ground
  (e.g. changing the CI or speed profile)



AOC MATHEMATICAL MODEL



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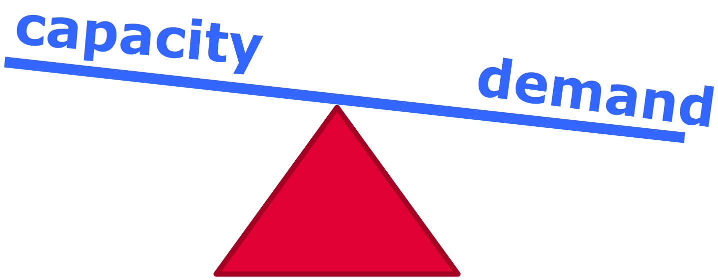
NETWORK MANAGER

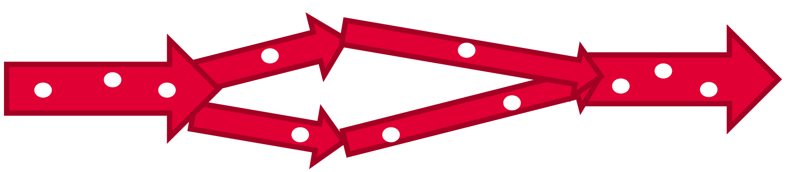
NETWORK MANAGER

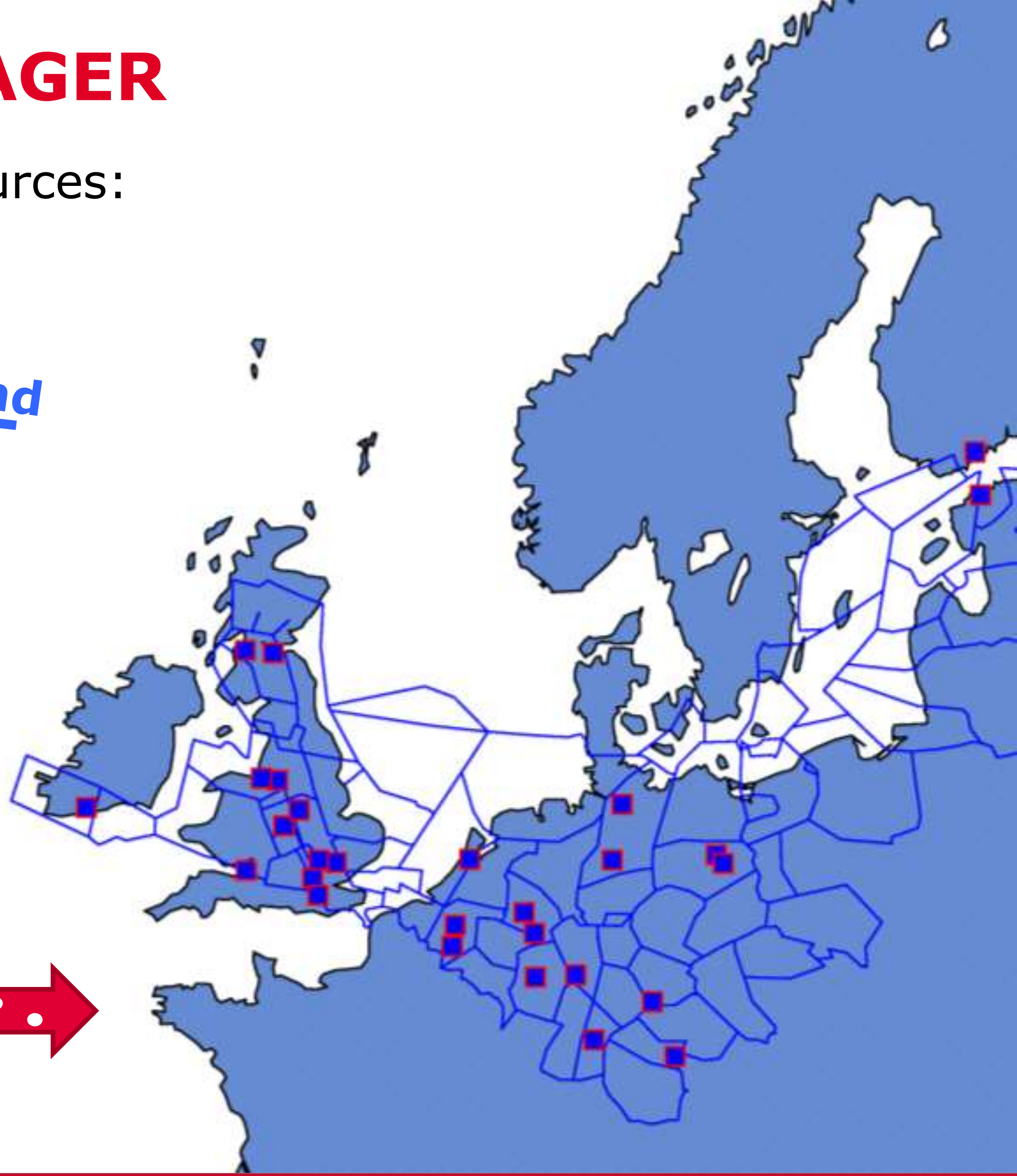
Allocating Airspace Resources:



Flow Based Models:

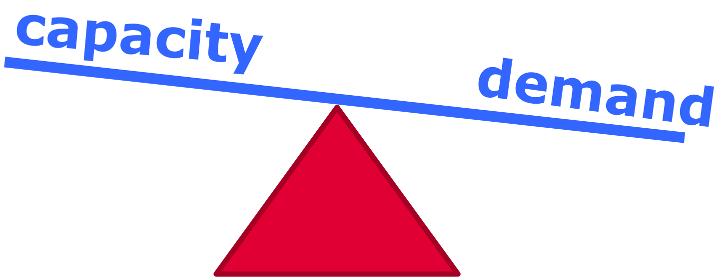
Aggregate Flights within the optimizer mean only particle **flow rates** are known.





NETWORK MANAGER

Allocating Airspace Resources:

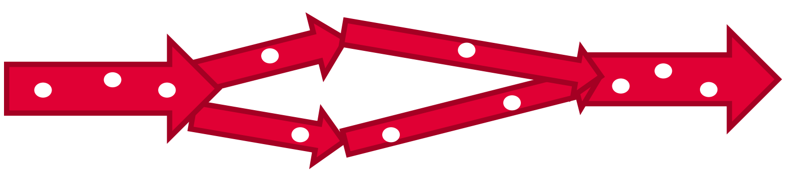


BIG QUESTION:
How do we include uncertainty in this problem?

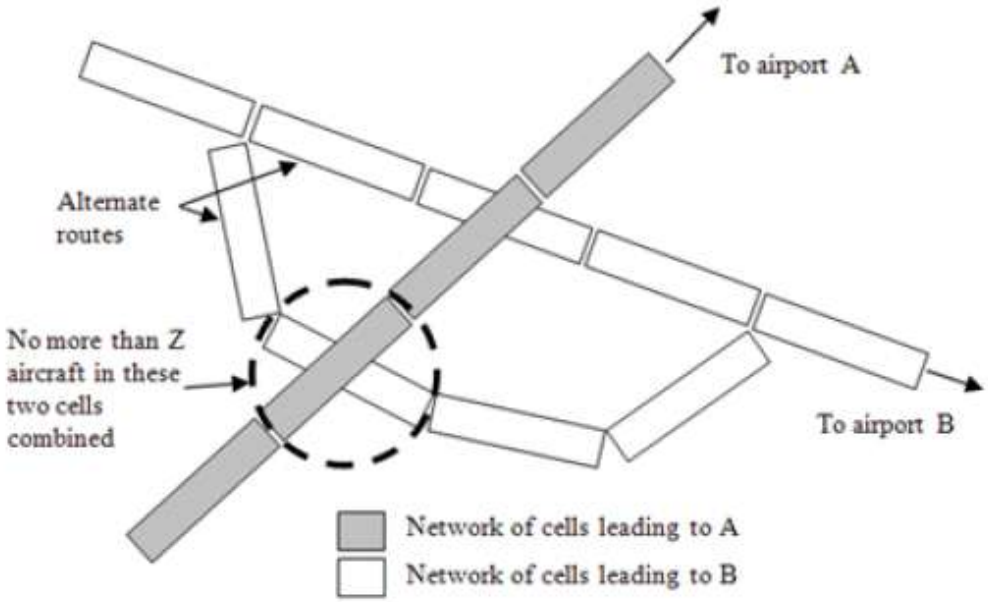
WHAT'S NEW:
Previously: chance constraints
Now: disturbance feedback

Flow Based Models:

Aggregate Flights within the optimizer mean only particle **flow rates** are known.



BASE ATFM MODEL



- Prevents dispersion problems
- Aids Disaggregation

Cells:

Paths are ***grouped by destination*** and split into a series of ***cells*** which each represent a sector in the shared flight path. Control actions are represented as binaries:

$$u^i(k) = \text{no. aircraft held back at cell } i \text{ in time period } k$$

$$u^{i,j}(k) = \text{no. aircraft moving, cell } i \to j \text{ in time period } k$$

FLOW BASED

Objective:

Minimize weighted sum of **Airborne Delay + Ground Delay**

$$\min \sum_{k \in \mathcal{T}} \left(\sum_{s \in \mathcal{S}} \sum_{i \in \mathcal{B}(s)} c_a u^i(k) + \sum_{a \in \mathcal{A}} \sum_{i \in \mathcal{B}(a)} c_g u^i(k) \right)$$

Capacity Constraints:

Predicted capacity over time (DETERMINISTIC)

$$\sum_{i \in \mathcal{B}(s)} \underbrace{\left(u^i(k) + \sum_{j \in \mathcal{L}_i} u^{i,j}(k) \right)}_{x^i(k)} \leq C_s(k)$$

$$\forall s, k \in \mathcal{T} : k > 1$$

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Predicted capacity over time (DETERMINISTIC)

BIG DEAL:
Uncertainty in this Capacity due to Weather

WHY FEEDBACK FOR UNCERTAINTY?

Nominal Plans

- Single plan
- Plan for most likely scenario

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Feedback Plans
- Multiple plans
- Robust to all possible scenarios
- Represented by feedback

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Feedback Plans
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- Represented by feedback

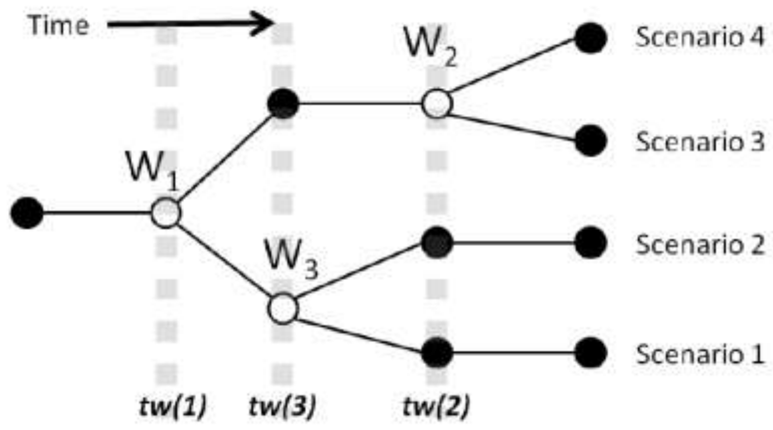
Disturbance Feedback Formulation:

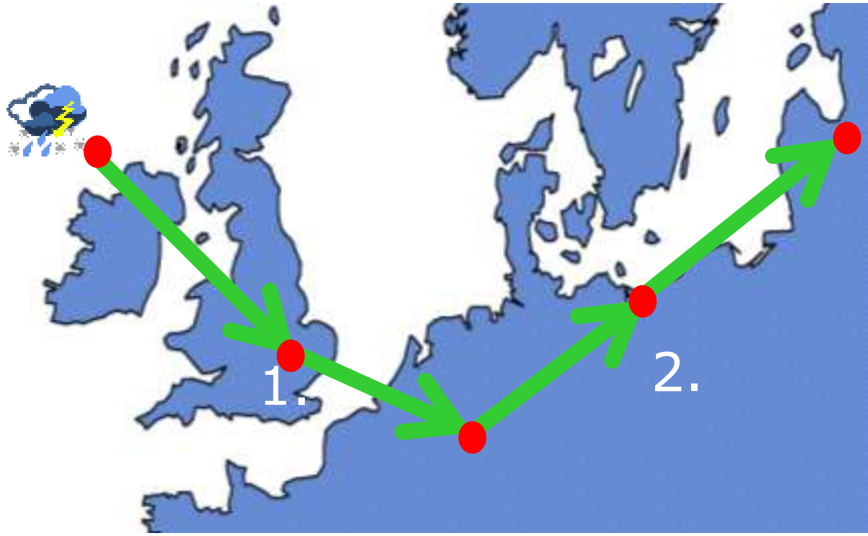
Express the **control variables** as functions of the **disturbance** seen:

Control Action = Baseline Control Action + Feedback Term * Disturbance Signal

- Use this to enable us to react to differing weather capacity scenarios

DISTURBANCE SIGNAL: SCENARIO TREE

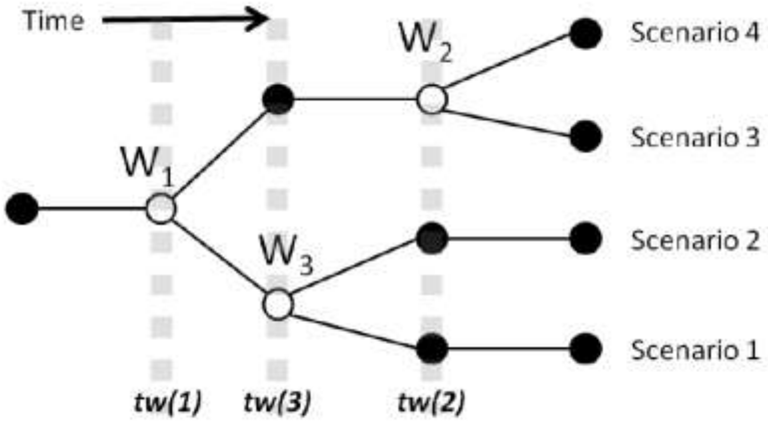




DISTURBANCE SIGNAL: SCENARIO TREE

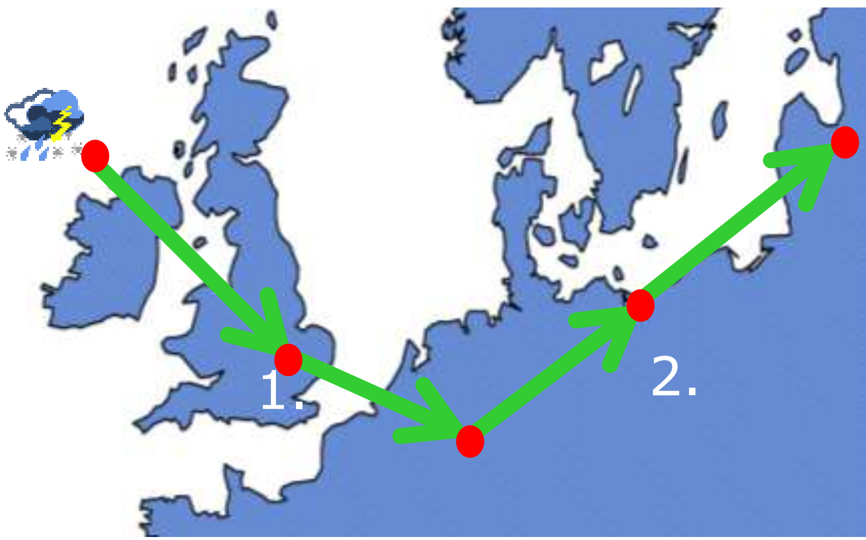
W's are the binary ***branching points***, so each scenario is represented by a individual set of W's.

We define associated ***capacity reductions*** for each scenario, e. These then count towards the sector capacity. i.e. they are appended to this side of the previous capacity equation.



$$\sum_{i\in\mathcal{B}(s)} \underbrace{\left(u^i(k) + \sum_{j\in\mathcal{L}_i} u^{i,j}(k)\right)}_{x^i(k)} \le c_s(k) - q(e,s,k)$$

$$\forall s, k \in \mathcal{T} : k > 1$$



FEEDBACK REFORMULATION

Control Variables:

$$u^i(k) = v^i(k) + \sum_{n:tw(n)<k}^{Nw} M_n^i(k) W_n(c)$$

Objectives:

$$\min \epsilon_1 \sum_{k\in\mathcal{T}} \left(\sum_{s\in\mathcal{S}} \sum_{i\in\mathcal{B}(s)} c_{td} v^i(k) + \sum_{a\in\mathcal{A}} \sum_{i\in\mathcal{B}(a)} c_g v^i(k) \right)$$

$$+\epsilon_2 \sum_{w\in\mathcal{W}} \sum_{k\in\mathcal{T}} \left(\sum_{s\in\mathcal{S}} \sum_{i\in\mathcal{B}(s)} c_{td} u^i(k) + \sum_{a\in\mathcal{A}} \sum_{i\in\mathcal{B}(a)} c_g u^i(k) \right)$$

Delay Cost of **nominal** (disturbance-free) plan

Delay Cost of **disturbance recovery plans**

$\epsilon_2 << \epsilon_1$

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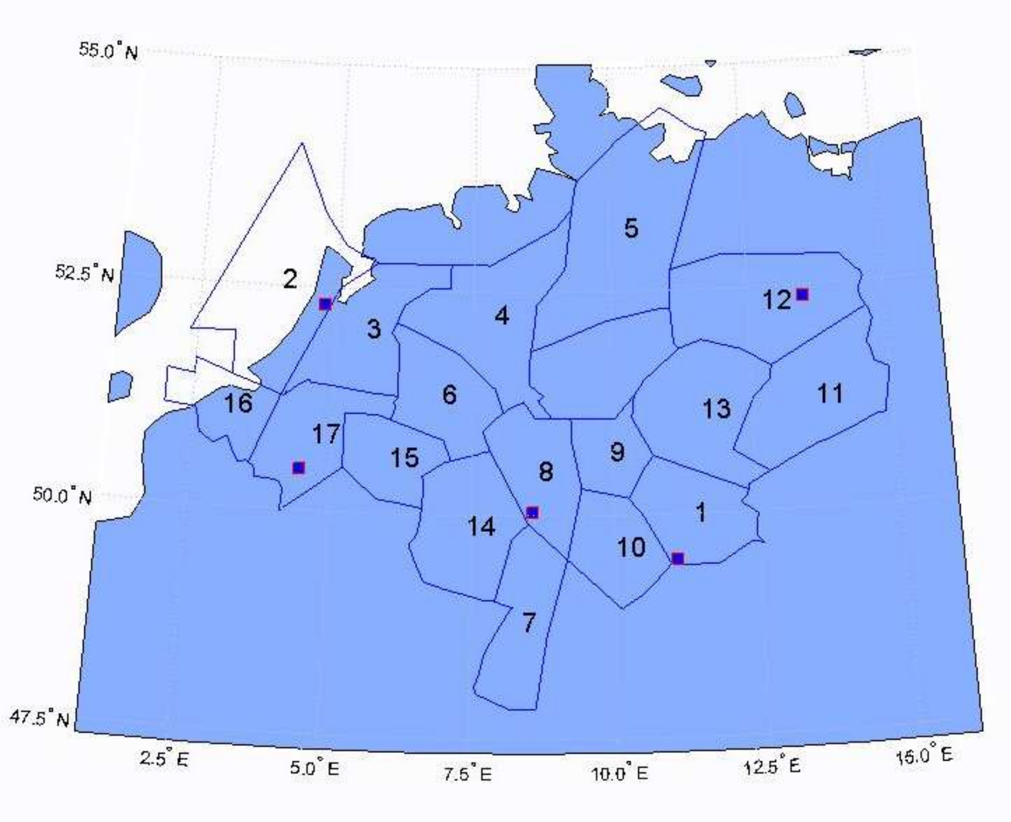
RESULTS

RESULTS: PROBLEM TEST CASE

- **30** flights
- **5** airports, **17** sectors
- Flights between **06:00**h and **16:00**h
- **5**-aircraft capacity limit
- **5**-minute time windows



- Capacity Reduction Scenarios
  - **4** storms, one subject to some speed uncertainty
  - Storms reduce capacities to **1 aircraft per 5-minute** time window.

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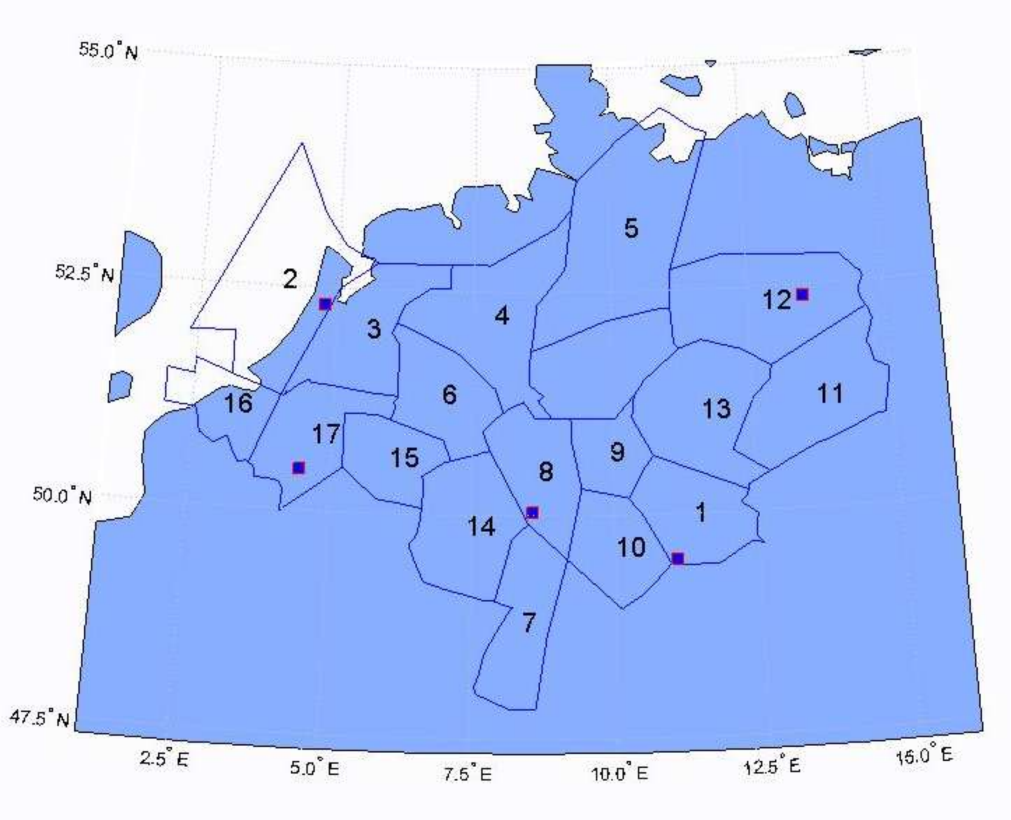


- Capacity Reduction Scenarios
  - **4** storms, one subject to some speed uncertainty
  - Storms reduce capacities to **1 aircraft per 5-minute** time window.

CURRENT SCOPE:
200 flight problem in less than 2 minutes

TEST CASE RESULTS: INTERACTION

- **Iterative Process:**
  - **START:** AOC shares an ideal plan
  - **ITERATION 1:** NM introduces additional delays to meet capacity restrictions

Flight Id	Resource Id	OTA (mins)	TTA (mins)
16852	EDUUFULL	503.6	513.6
	EDUUFFMML	512.0	522.0
	EDYYMNHI	514.7	524.7
	EDYYFLELO	534.4	544.4
	EDYYZEELO	548.6	558.6
	EHAM	550.7	560.7
1227	EDYYMNHI	564.9	574.9
	EDYYFLELO	582.1	592.2
	EDYYZEELO	596.2	606.2
	EHAM	598.3	608.3
2223	EDYYFLELO	635.9	645.9
	EDYYRHHI	643.6	653.7
	EDUUNTMML	656.2	666.2
	EDUUFFMML	660.8	670.7
	EDUUSLNH	663.3	673.3
	EDDF	666.6	676.6
2224	EDUUFFMML	718.7	743.7
	EDUUSLNH	721.3	746.3
	EDDF	724.6	749.6
1229	EDYYMNHI	680.9	690.9
	EDYYFLELO	698.1	708.2
	EDYYZEELO	712.2	722.2
	EHAM	714.3	724.3
16854	EDUUFULL	911.6	916.6
	EDUUFFMML	920.1	925.1
	EDYYMNHI	922.7	927.7
	EDYYFLELO	942.4	962.4
	EDYYZEELO	956.6	976.6
	EHAM	958.7	978.7
1233	EDYYMNHI	912.9	917.9
	EDYYFLELO	930.1	945.2
	EDYYZEELO	944.2	959.2
	EHAM	946.3	961.3

  - **ITERATION 2:** AOC re-adapts its ideal plan considering NM output

Flight Id	Alternative
16852	On Ground Delay (600)
1227	On Ground Delay (600)
2223	Modified Trajectory (0.95)
2224	On Ground Delay (1500)
1229	Modified Trajectory (0.95)
16854	On Ground Delay (300)
1233	Modified Trajectory (0.95)

  - **ITERATION 2:** NM suggests new delays to meet capacity restrictions

Flight Id	Resource Id	OTA (mins)	TTA (mins)
2223	EDYYFLELO	635.9	640.9
	EDYYRHHI	643.8	648.8
	EDUUNTMML	656.9	666.9
	EDUUFFMML	661.5	671.5
	EDUUSLNH	664.3	674.3
	EDDF	667.6	677.6
16854	EDUUFULL	916.6	921.6
	EDUUFFMML	925.0	945.0
	EDYYMNHI	927.7	947.7
	EDYYFLELO	947.4	967.4
	EDYYZEELO	961.6	981.6
	EHAM	963.7	983.7
1233	EDYYMNHI	913.4	923.4
	EDYYFLELO	931.7	946.7
	EDYYZEELO	946.1	961.1
	EHAM	948.2	963.2

- Iterative process continues until convergence is reached i.e. AOC plan meets all capacity restrictions.

RESULTS: BENEFITS OF FEEDBACK

	Scenario	No. Sector Capacity Breaches	Ground Delay
AOC Ideal Plan Solve Time: 4.6 s	c_1	13	0
	c_2	13	0
	c_3	13	0
	c_4	15	0
Nominal Solve Time: 4.9 s	c_1	0	18
	c_2	0	18
	c_3	0	18
	c_4	2	18
Robust Solve Time: 14.5 s	c_1	0	20
	c_2	0	20
	c_3	0	20
	c_4	0	20
Disturbance Feedback Solve Time: 130.3 s	c_1	0	18
	c_2	0	18
	c_3	0	18
	c_4	0	20

RESULTS: BENEFITS OF FEEDBACK

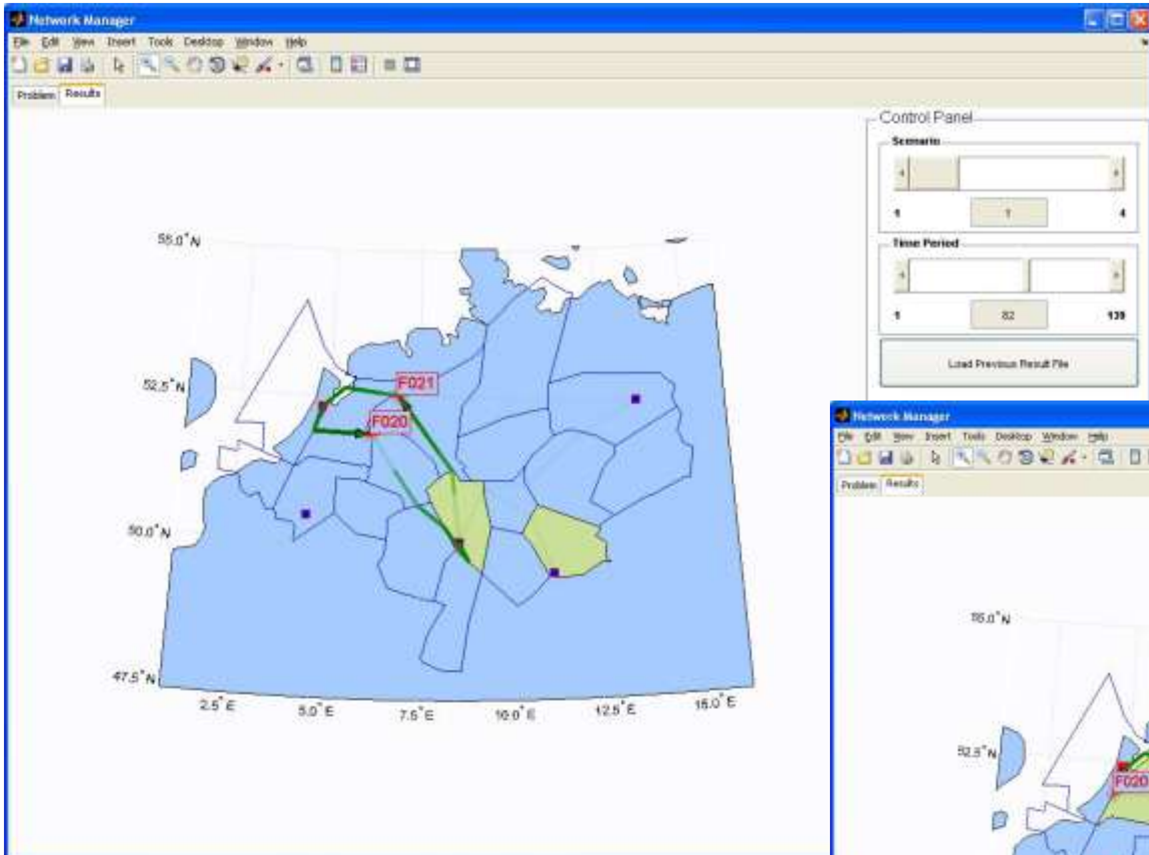
		No. Sector	…elay
AOC			
Solve…			
Nomi…			
Solve…			
Robu…	c_3	0	20
Solve Time: 14.5 s	c_4	0	20
Disturbance Feedback	c_1	0	18
	c_2	0	18
	c_3	0	18
Solve Time: 130.3 s	c_4	0	20

Disturbance Feedback solve times *now* on the order of several **seconds**:

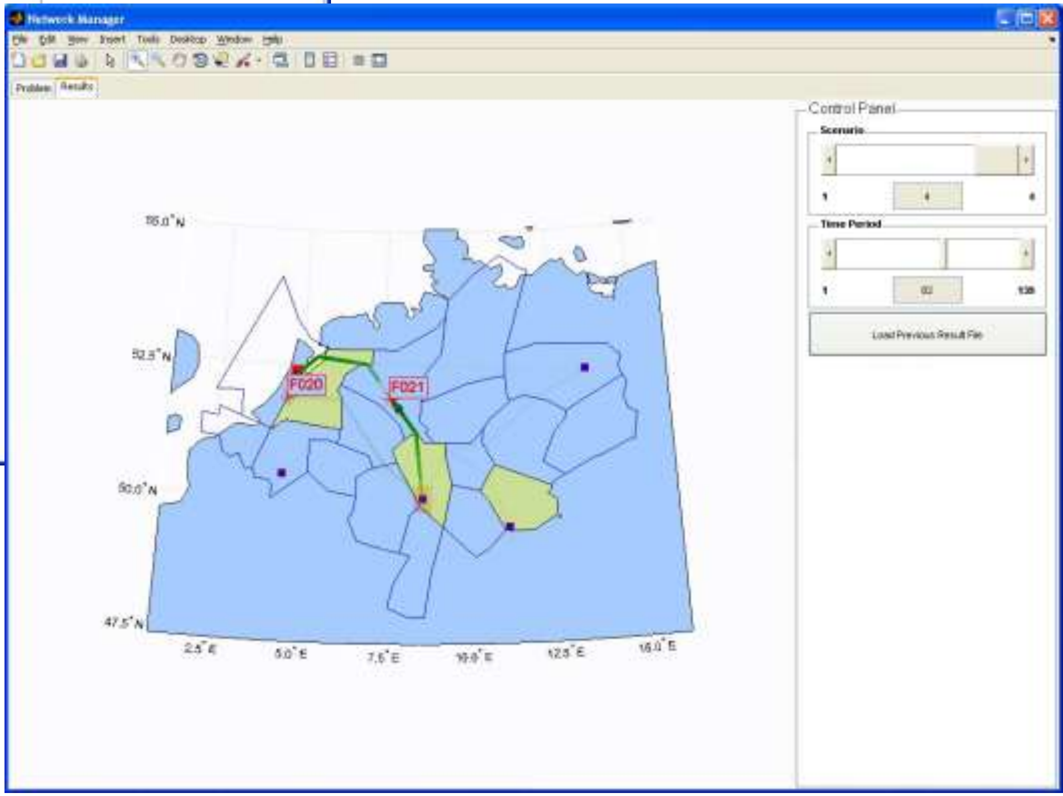
- Due to reduced number of control variables in time.

200 Flight problems now possible

RESULTS: DISTURBANCE FEEDBACK



Scenario 1



Scenario 4

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FURTHER WORK

FURTHER WORK

- Incorporate **unscheduled demand**.
- Increase the **problem size**.
  - The main goal is to handle up to several hundred flights in one iteration. Meaning that thousands of flights can be considered during one day.
- Conduct a **series of tests** in order to demonstrate the benefits of this approach.

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CONCLUSION

CONCLUSION

- The **integrated AOC / NM** has been presented.
- The **benefits of a disturbance feedback** approach over a single robust plan have been demonstrated.
- The system is ready to run **realistic size problems** in a rolling window fashion.
- A **testing platform** based on databases has been set up between University of Bristol and GMV in order to conduct the testing phase.

Thank you

ONBOARD Team

http://www.onboard-sesar.eu

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