



Dedicated to innovation in aerospace



Optimisation and Prioritisation of Flows of Air Traffic through an ATM Network

SESAR Innovation Days, Braunschweig, November 2012

Hugo de Jonge and Ron Seljée, NLR
jongehw@nlr.nl

Overview

- **The ATM Network in Europe**
- **To enable Optimizing and Prioritizing ATFM by OPT-ATFM:**
 - Local context in space and time
 - How to apply enhanced ATFM
- **Model-based experiment:**
 - Scenario
 - Slot selection, using prioritization
 - Prioritization applied on 6 airport flows (5 disrupted)
 - Results
- **Conclusions**

Aim to develop prototype implementation of enhanced ATFM algorithm

- **Problems in the European ATM Network:**

- Systematic overload and congestion of small number of major airports
- Airports with unbalanced operational conditions, e.g. by weather
- Some airports suffering access restriction by lack of capacity of TMAs, e.g. London area
- Some ATS routes are critical due to En-route constraints, e.g. in the Core Area

- **EC statement:**

- *"...the use of transparent and efficient rules will provide a flexible and timely management of air traffic flows at European level and will optimize the use of air routes."*

- **Objective of this research:**

- To demonstrate benefits by regulating departure flows with enhanced ATFM algorithm
- Aim to apply ATFM with maximum throughput, best achievable efficiency and minimum impact on flight performance

The ATM Network and the Bottlenecks

Network defined by:

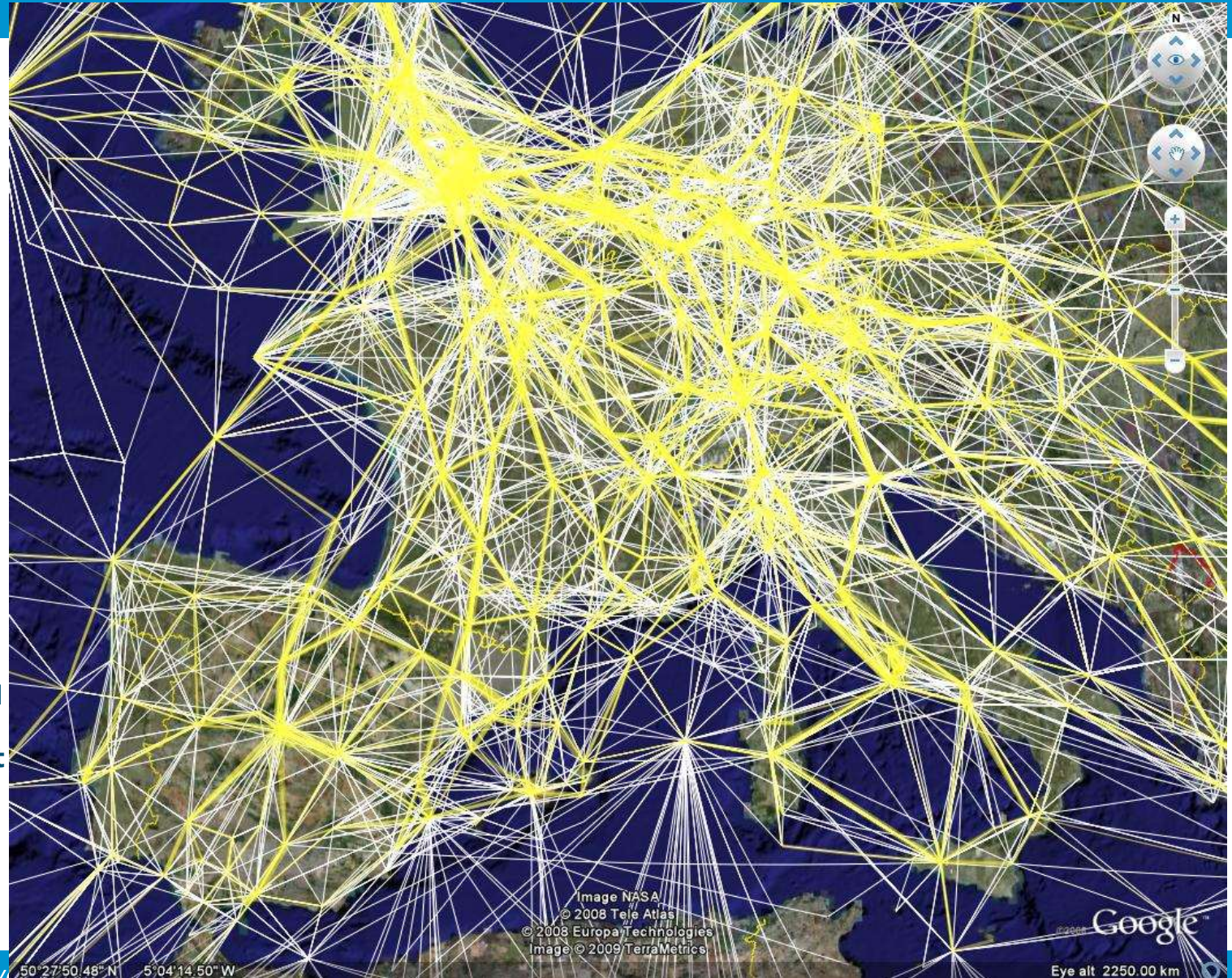
- non-optimal number of sectors
- non-optimal distribution of air traffic

Problems:

- Specific sector nodes with overload problems
- Very thick and very thin traffic flows
- Airports nodes very small, very large and sometimes very congested

Conclusion:

- Network is super critical
- Solving bottlenecks to make Network robust
- More robust network by aggregation



Enhanced ATFM in adherence to SESAR

- **ATFM today:**

- ICAO flightplans, possibly updated
- Assign overloaded nodes to be regulated
- FC-FS: Assign departure slots on overloads by first arrival at the overloaded node (sector)

- **Options for Optimization and Prioritization:**

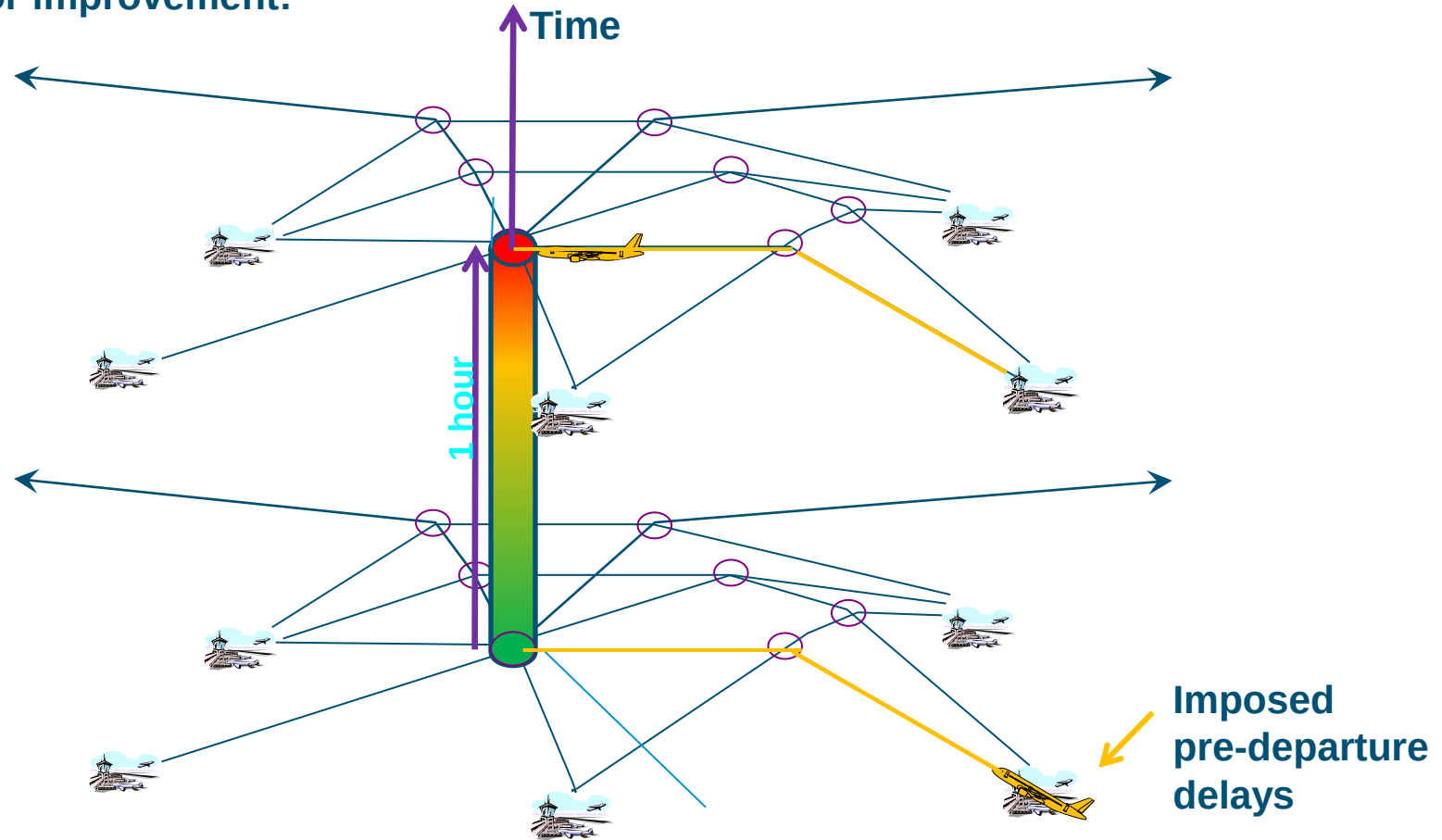
- Economic value prevails over FC-FS principle
- 4D RBTs, up-to-date by SWIM (SESAR)
- Apply optimization towards minimized imposed delays
- Impose pre-departure delay, whilst being able to assess impact on other flight operations
- Apply optimization towards the economic value of flight by prioritization

- **Alternative solutions:**

- **MILP** and find optimum against minimizing cost-function
- Use **Petri-Nets** and select a local context in space and time

Optimising and Prioritising ATFM in Local context of space and time

Proposed solution for improvement:

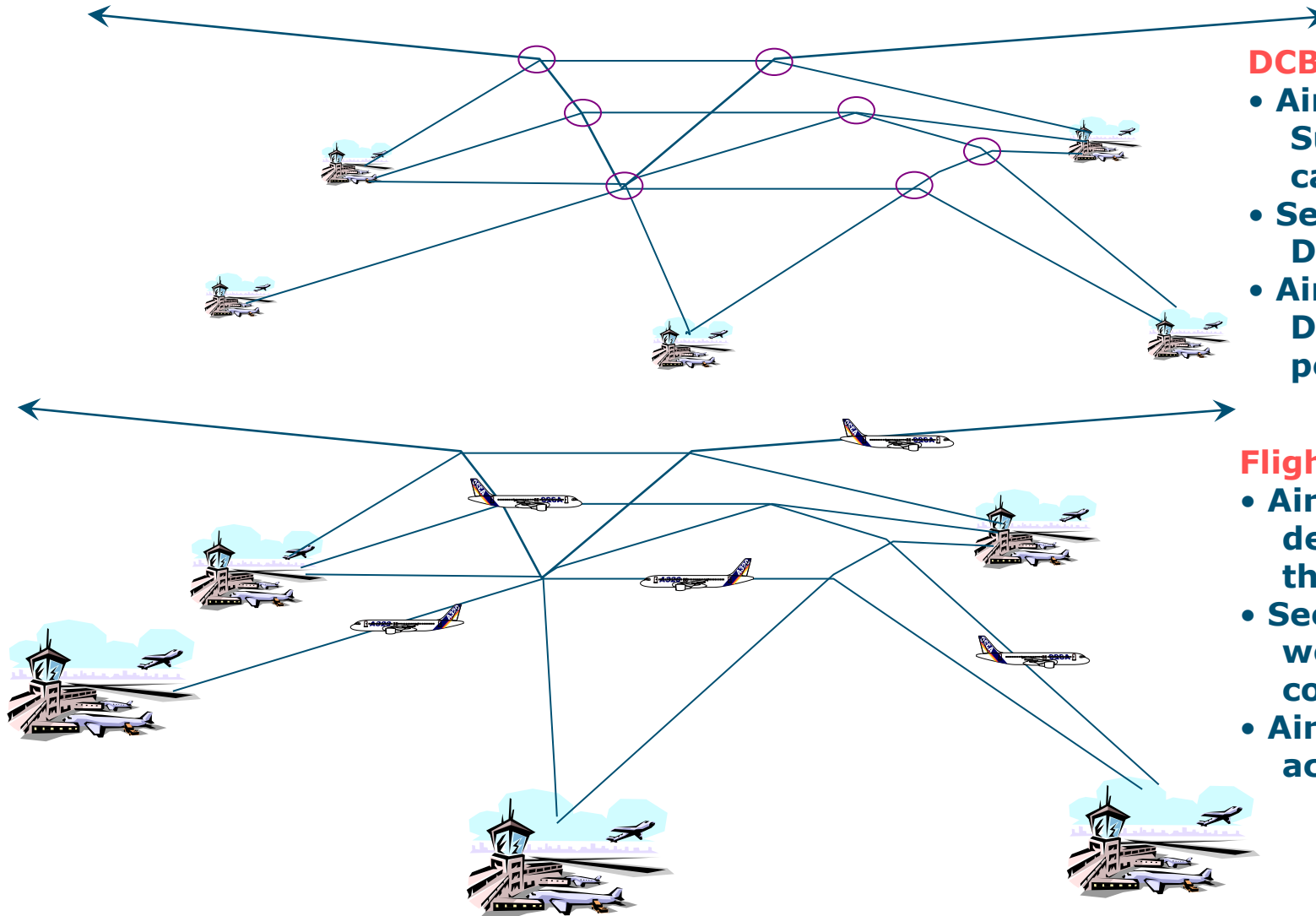


Weighted minimisation
of imposed delays over 1 sector during 1 hour

Demand and Capacity Balancing (DCB) Solution Strategy

- **Full ATM network, including Airports**
 - Sensitive for unbalance, congestion and overload, but
 - More accurate and stable load, and thus higher declared capacity
- **Local context in space (node) and time (1 hour):**
 - FC-FS → Pre-departure delay for first flight to hit overloaded node
 - Select the best one: **natural trade-off within local context**
 - Option 1: to select within node with minimized penalties
 - Option 2: to look at impact of pre-departure delay on other nodes (before and behind overloaded node)
 - Option 3: to give priority to congested flows
 - Option 4: to give priority to flights on economic value
- **Success criteria:**
 - **DCB model (OPT-ATFM):** Evaluate minimum pre-departure delay and minimum “waiting time”
 - **Operational validation by Fast Time Simulation:** Evaluate minimum flight delay, flight efficiency, workload

ATM: DCB Network and Flight operations Network



DCB Network:

- Airport node capacity: Sustainable/Max. capacity in mov.
- Sector node capacity: Declared capacity
- Air traffic demand: Demand per node per hour

Flight operations:

- Airport load: departure/arrival throughput
- Sector load: workload and complexity
- Air traffic operations: actual departures

Model-based Experiment on Kernel Network Scenario with 15 main (hub) airports

Kernel Network
defined by a wider area
of Europe around the
Core Area.

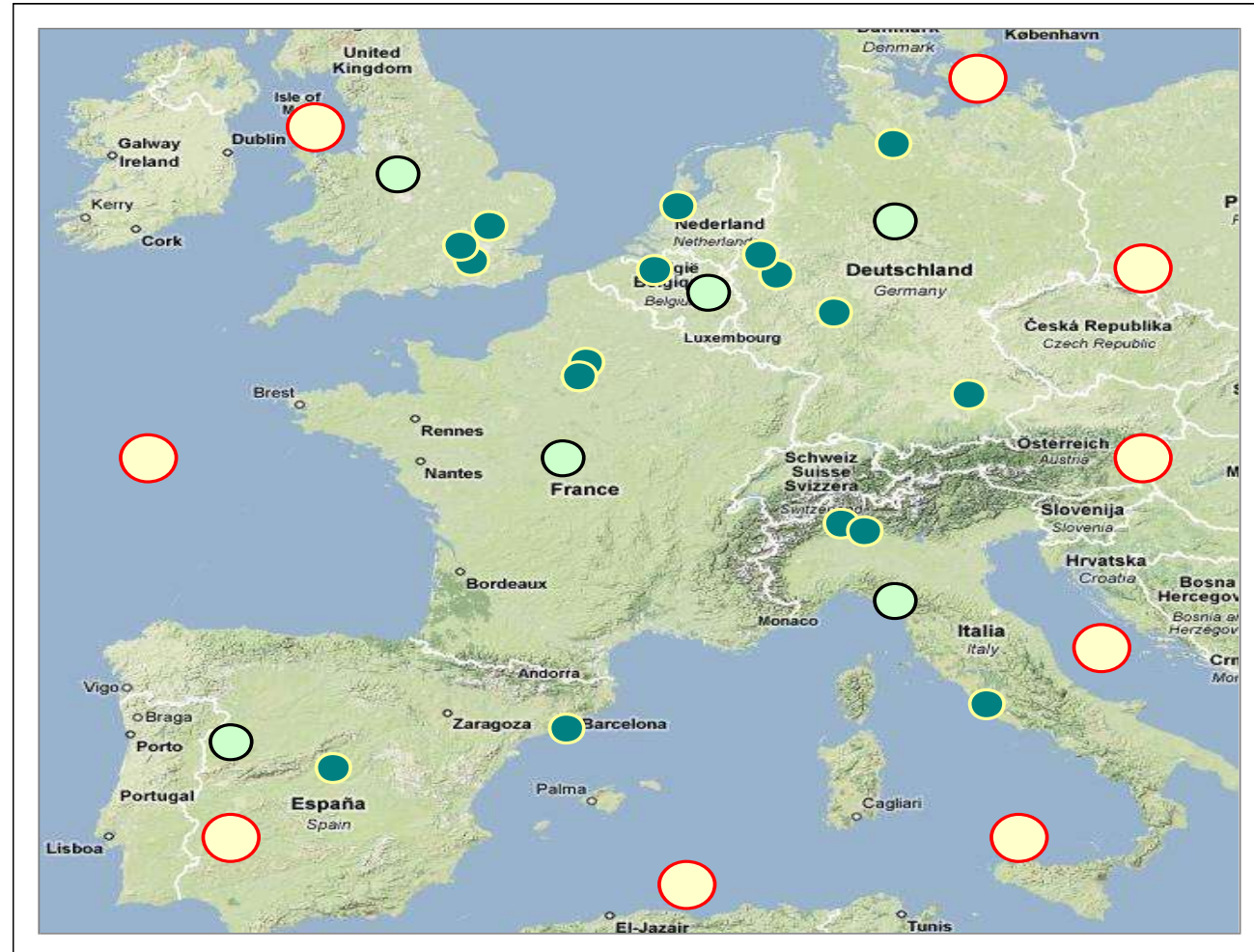
Capacity:

- 15 main (hub) airports
- 514 other airports
- 736 sectors

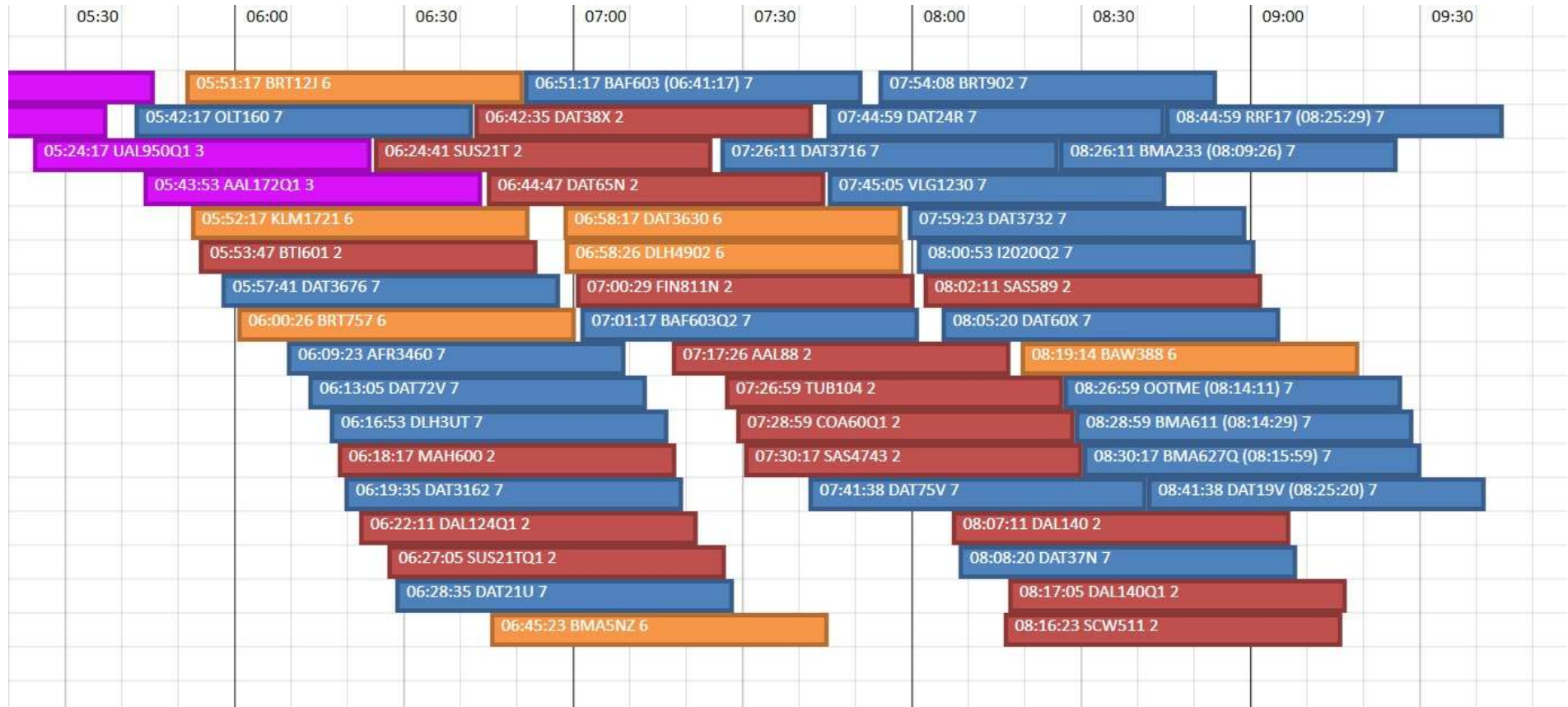
Demand:

- 24.600 flights

-  Main (Hub) Airports
-  Aggregation of smaller airports per country
-  Out Nodes, feeding from outside and functioning as exit nodes for outbounds



OPT-ATFM: slot selection in congested node with minimized imposed delay



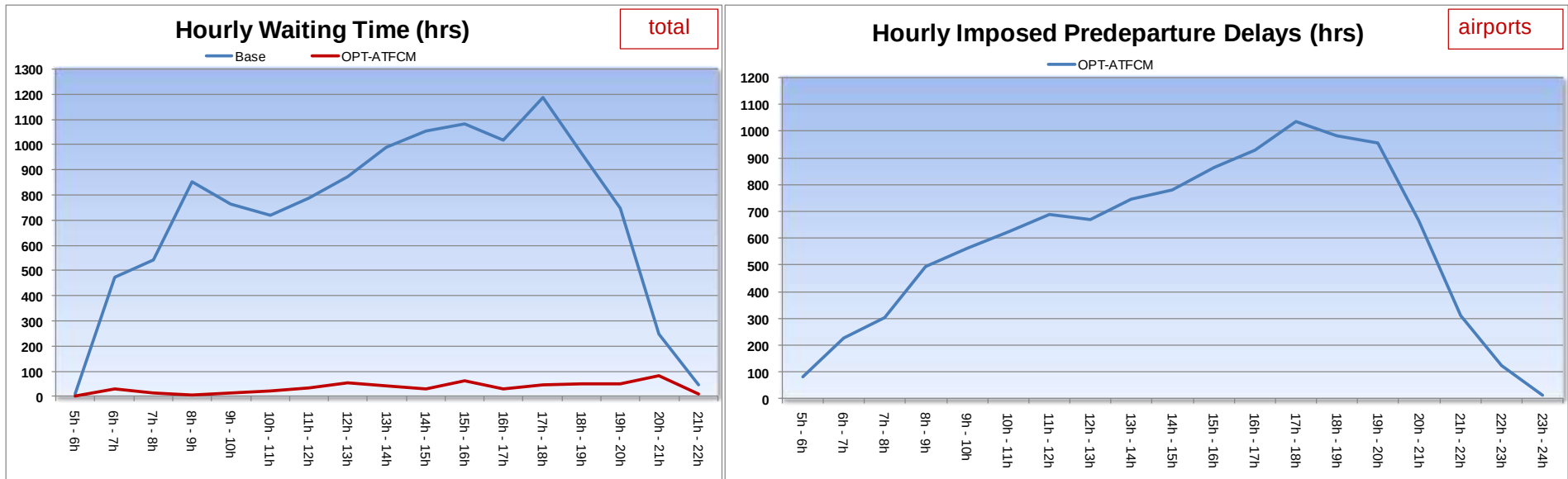
Example in busy Brussels sector, start of the day, optimized ATFM:

- In-flight (lila), in-flight via out-node (orange),
- Flow managed (blue), Flow-managed with penalty in other sector (red)

Experiment to optimize throughput with 5 disrupted / 6 prioritized airports

- **Sensitivity analysis of ATM Network throughput:**
 - Kernel Network, 24.600 flights through Core Area
- **Three runs (OPT-ATFM):**
 - Normal scenario, calculate imposed pre-departure delay
 - Disrupted scenario, 5 airports disrupted (assumed lower capacity: EHAM, EDDF, EDDM, EGKK, LFPG), calculate imposed pre-departure delay
 - Disrupted scenario:
 - 5 airports disrupted (capacity -20% to -30%)
 - 6 airports prioritized (5 disrupted + EGLL added)
 - Calculate imposed pre-departure delay
- **Compare:**
 - Distribution of “Waiting time” over the day
 - Geographical distribution of imposed pre-departure delay
 - Comparing imposed pre-departure delays of large airports

Hourly distribution “Waiting time” and Hourly distribution imposed pre-departure delay



- **Example of applying OPT-ATFM with prioritisation:**
 1. Measure “**Waiting time**” over Kernel Network (5 airports disrupted (Blue line left))
 2. Calculate **pre-departure delays** for 6-airports prioritised scenario (blue line right)
 3. Measure “**Waiting time**” per node accepting imposed delays (**red line left**)

5-airports disrupted scenario

Apply OPT-ATFM without prioritisation

Kernel Network:

- Apply OPT-ATFM

ATFM, no prioritisation:

- #flights "waiting" time:
 - ~4.800
- Total "waiting" time:
 - ~12.000 hrs.
- #flights imposed delay:
 - ~5.300
- Av. imposed delay:
 - 34,9 min.
- At main airports:
 - 53,5 min.

Conclusion: Waiting time resulting from reduction in capacity at main airports solved mainly by assigning pre-departure delays to these airports.



5-airports disrupted scenario

Apply OPT-ATFM with prioritisation (6 airports)

Kernel Network:

- Apply OPT-ATFM (+ prio)

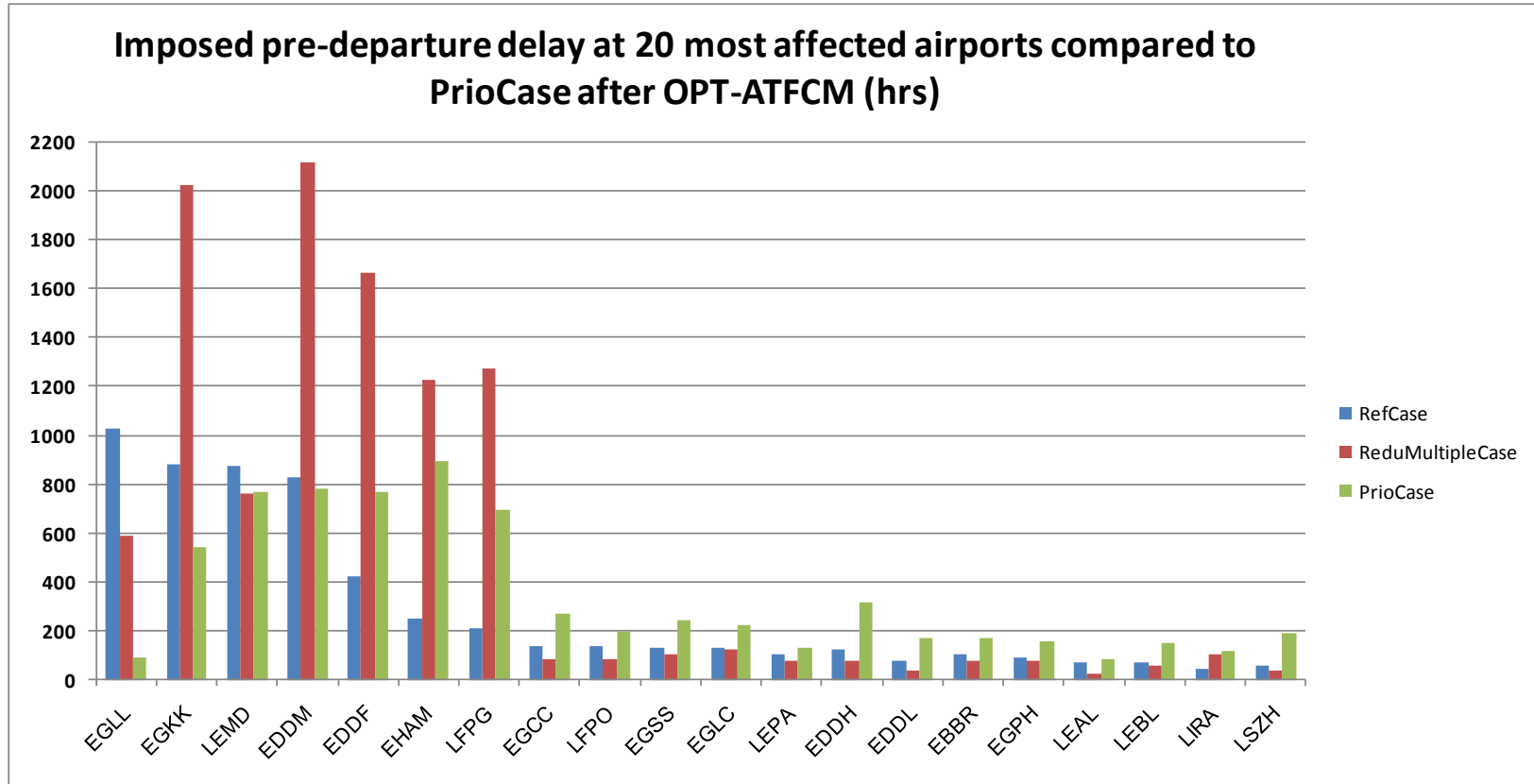
ATFM, with prioritisation:

- #flights "waiting" time:
 - ~6.000
- Total "waiting" time:
 - ~11.200 hrs.
- #flights imposed delay:
 - ~6.400
- Av. imposed delay:
 - 31,7 min.
- At main airports:
 - 29,9 min.

Conclusion: Waiting time resulting from reduction in capacity at main airports distributed and largely assigned to less congested small airports.



Compare OPT-ATFM without and with prioritisation (per airport)



Blue: Reference case, no excessive delays

Red: No prioritisation, 5-airports disrupted, 5 airports heavy delayed

Green: With prioritisation, 6 airports enhanced performance, other airports decreased performance

Some conclusions

- **Feasibility evaluated:**

- Analysis of ATM network as a network, not by assessment of operational performance
- Assessment of DCB, using 4D trajectory predictions
- Flow management within local context of space and time
- And with **optimisation** and **prioritisation**

- **Transparency:**

- Penalties/benefits per node per priority class

- **Experimental results (of first experiment):**

- Comparing a 5-airports disrupted scenario with and without prioritisation to/from congested destinations:
 - Decrease of total amount of delay
 - Decrease of average delay
 - Strong decrease of delay at main airports (-40%)

- **All together a more efficient re-distribution of imposed delays**

Thank you

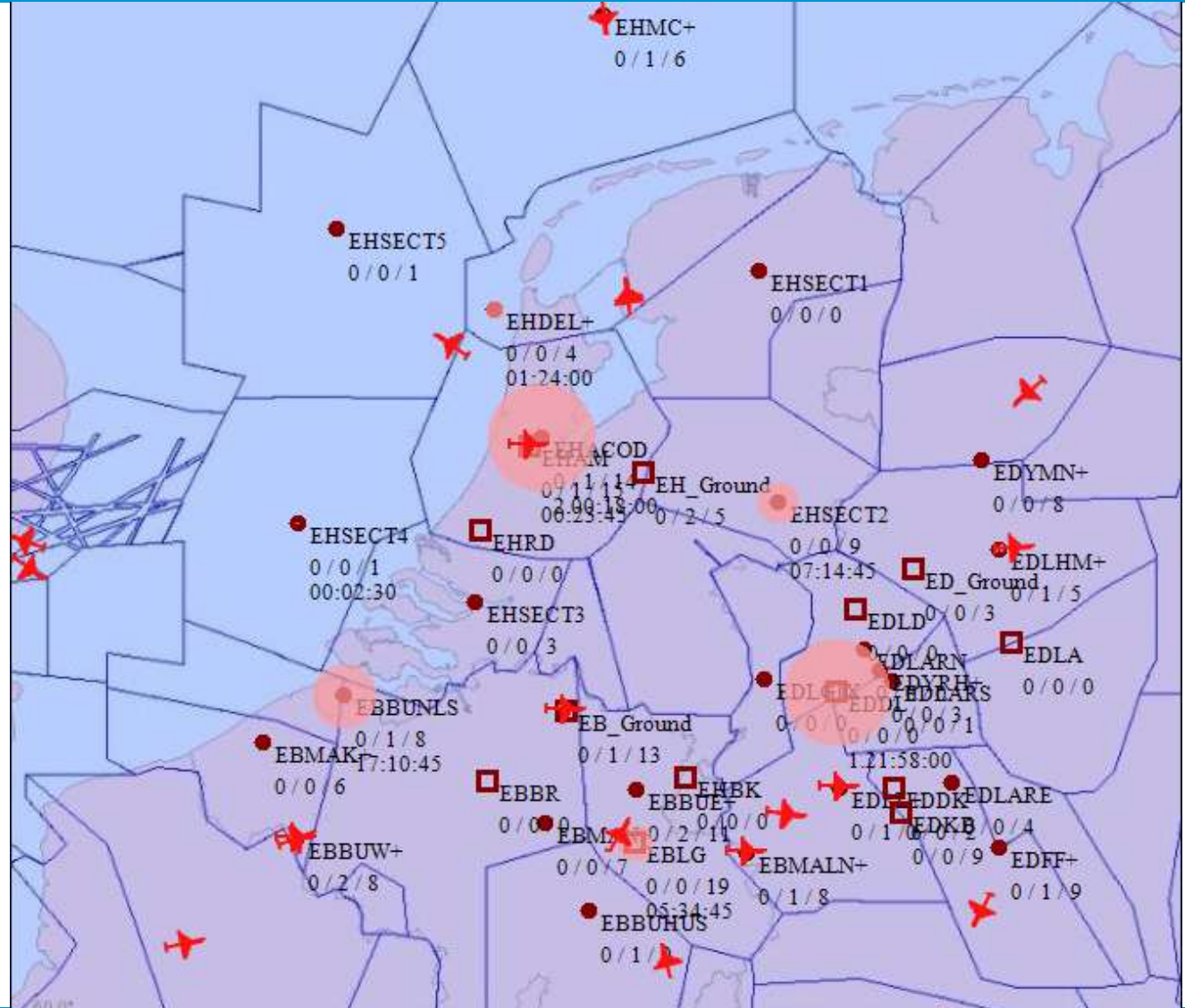
Recent reports:

- **NLR-TP-2007-650**, Jonge, H.W.G. de, Beers, J.N.P., Seljée, R.R., "Flow Management on the ATM Network in Europe", October 2007.
- **NLR-CR-2011-379**, Jonge, H.W.G. de, Seljée R.R., "Preliminary validation of Network Analysis Model (NAM) and Optimising Air Traffic Flow Management (OPT-ATFM)", December 2011.
- **NLR-TP-2011-567**, Jonge, H.W.G. de, Seljée R.R., "Optimisation and Prioritisation of Flows of Air Traffic through an ATM Network", December 2011.

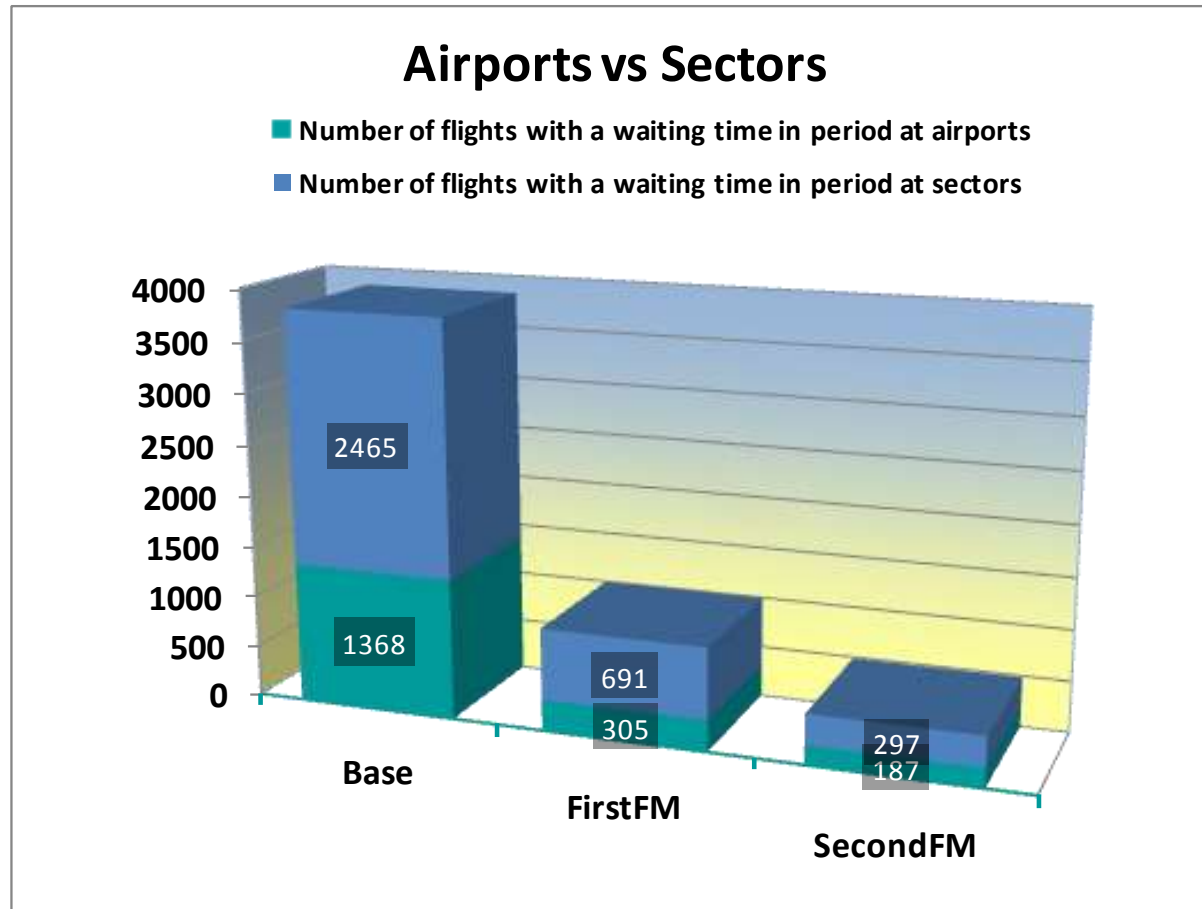
Demand and Capacity Balancing (DCB) Solution Strategy

- **Balancing Demand and Capacity (static picture)**
 - Capacity per sector:
 - Over-dimensioned network: Aggregation
 - Capacity per Airport:
 - Peak capacity, operational achievable throughput
 - Varying demand/capacity, solved e.g. by hourly capacity over the day
 - No differentiation between departure and arrival flows
 - Demand (converging and layered planning):
 - 4D Reference Business Trajectories (RBTs) and SWIM
- **DCB (dynamic picture):**
 - Flows through network (unconstrained) → Bottlenecks
 - Flows through network (constrained) → Throughput and “waiting Time”
 - Pre-departure imposed delays → to suppress waiting time
 - Question: How to optimize “**Pre-departure delay**” versus “**waiting time**”?

- Applicable to **sub-networks**
- **Airports** and **Sectors** treated as identical nodes in the network
- Used:
 - To detect **hot-spots** at airspace and airport level
 - To analyse **balance** in the network
 - To optimise towards minimal “**waiting periods**”



Iteration of ATFM: Reduced waiting time by Imposed pre-departure delays



- **Conclusion:**

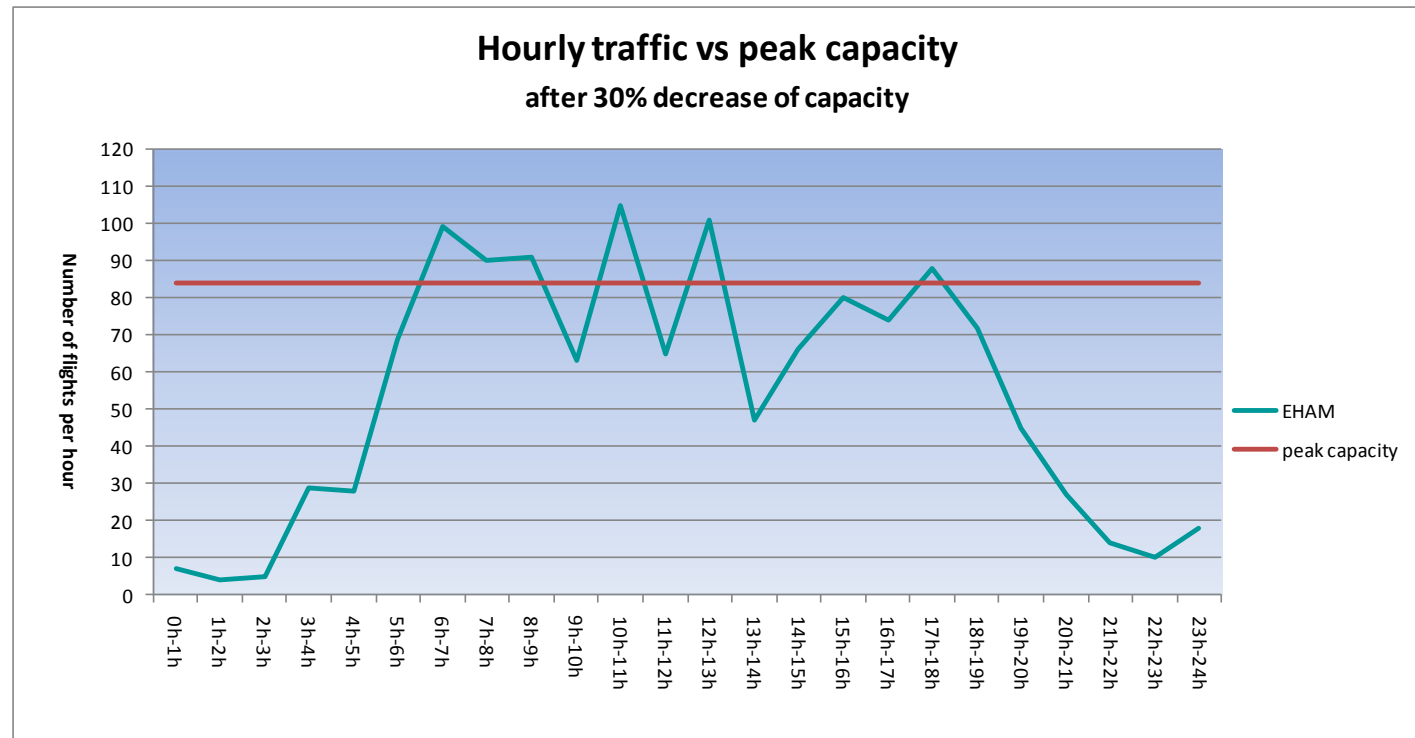
Under nominal conditions (no disruption and no connectivity) fairly equalised balance between waiting periods at sectors and at airports (40%-60%).

Experiment, comparing FC-FS ATFM with OPT-ATFM (PRIO)

● Conduct of experiment:

1. Measure "Waiting time" per node
2. Calculate pre-departure delays to mitigate "waiting time"
3. Measure "Waiting time" per node accepting imposed delays

Example (EHAM) of disruption by (30%) reduction of capacity



Compare ATFM without and with prioritisation



Throughput analysis by measuring "Waiting time"			
Total number of flights	ATFM FC-FS	PrioCase	Percent.
Number of flights with a waiting time in period	4774	5998	26%
Total waiting time	ATFM FC-FS	PrioCase	Percent.
Total waiting time in period (hrs)	12003	11246	-6%
Calculated imposed pre-departure constraints			
Total number of flights	ATFM FC-FS	PrioCase	Percent.
Number of flights with a pre-departure delay in period at airports	5324	6387	20%
Number of flights with a pre-departure delay in period at main airports	3448	3368	-2%
Total pre-departure delay after each run	ATFM FC-FS	PrioCase	Percent.
Total pre-departure delay in period at airports (hrs)	12199	11076	-9%
Pre-departure delay in period at main airports (hrs)	10010	5589	-44%
Average per flight after each run	ATFM FC-FS	PrioCase	Percent.
Pre-departure delay in period (min)	34.9	31.7	-9%
Pre-departure in period at main airports (min)	53.5	29.9	-44%
Pre-departure in period at remaining airports (min)	13.7	34.4	151%



Dedicated to innovation in aerospace



DEFENSE & PEACEKEEPING MISSIONS



INNOVATION



JOB CREATION



MOBILITY



SAFETY



ENVIRONMENT



www.nlr.nl - info@nlr.nl