



Intelligent Modelling of the air Transport Network

‘Impact of innovative prioritization strategies on delay patterns’

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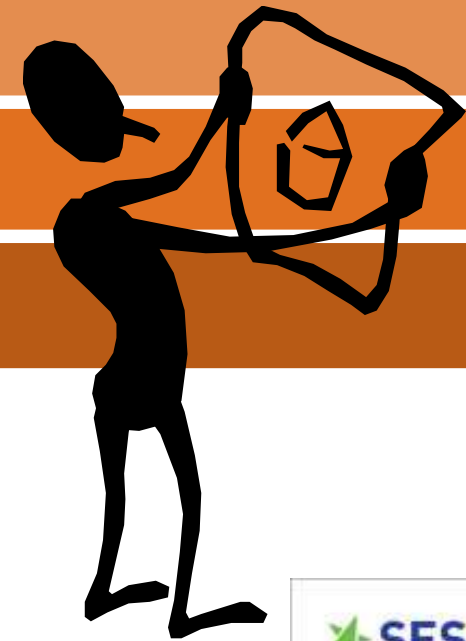
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 **SESAR WPE**
LONG TERM AND
INNOVATIVE RESEARCH



Outline

1. Project Objectives and Methodology;
2. Experimental Plan;
3. Modelling Approach;
4. Simulation Results and conclusions;
5. Q&A





The Problem

- ❖ Limited Availability of the air transportation system resources
 - ❖ On Ground: Limited capacity of an airport (runways, gates, etc)
 - ❖ On the air: Capacity of the sectors is not infinite.
- ❖ According Eurocontrol forecast between 2008 and 2030 an average annual growth between 2,3 and 3,5 % will occur in Europe, up to almost duplicate the traffic
- ❖ The airport capacity will increase by 41 % in the same period. Demand will exceed capacity in 2030 by almost 7 million flights.
- ❖ The capacity is further reduced when an occasional event occurs (either expected or unexpected)
- ❖ When an imbalance happens, a regulation is imposed (either in ground or in the air) and the flights are prioritised on a First Come First Served basis.



Objectives

NEWO stands for “*emerging **NE**twork-**W**ide effects of inventive **O**perational approaches in ATM*”.

Objectives:

1. Explore potential network wide benefits or adverse effects of the application of local approaches

Prioritisation



Propagation



2. Further develop and explore the potential of Network Wide innovative modelling and simulation techniques



Project Meeting

Most Promising Criteria

Exploring
Innovative
Approaches

Priority to flights to airports with higher/lower number of outgoing flights

Priority to flights to more/less congested airports

Priority to hub & spoke airlines

Workshop
for

Priority to last flight of the day (for the aircraft)

Priority to flights with more subsequent flight legs

Priority to flights with greater/smaller turnaround buffer time at next airport

Priority on random basis

TM NEMMO
selling approach

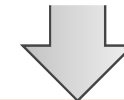
Workshop
Results

Priority to flights to less central destination

Priority to flights connecting different communities

Priority to Most Capable Flights (Most Capable Best Served)

analysis



Conclusions and Strategic Recommendations



Experimental Plan

- ❖ The network-wide effects of the different prioritization criteria are analysed through **Modelling scenarios (5)**
- ❖ A **set of Exercises** is assigned to each Modelling Scenario;
- ❖ A number of runs is conducted in each exercise to assure that is statistically significant
- ❖ For the results analysis different **Performance Indicators (PI)** are monitored per Exercise

KPA	Performance indicator (PI) ID	Local	Global	PI Name (Unit)
Efficiency	EFF.ECAC.PI1	X	X	Percentage of flights departing on time
	EFF.ECAC.PI2	X	X	Average Departure delay per flight
Predictability	PRED.ECAC.PI2	X	X	Average departure delay of departure flights



Scenarios

- ❖ Scenario 1 “Impact of the prioritization criteria on the network stability”
 - ❖ All Criteria compared against FCFS
 - ❖ External Disturbances
- ❖ Scenario 2 “Relation between network stability and equity (α calibration and priority points)”
 - ❖ Designed to investigate how giving priority to airlines interests provides the best impact in terms of network stability;
 - ❖ Flight priority in two parts: $Pr = \alpha (\text{airlines criteria}) + (1 - \alpha)(\text{network criteria})$

α

Airline

Airline specific, based on business models

Network

...first flights to hubs, to less congested airports, arrival slot at destination...
- ❖ Scenario 3 “Airlines interests as a black box”
- ❖ Scenario 4 “Network Critical Load Analysis”
- ❖ Scenario 5 MCBS vs FCFS

Scenario	Traffic Growth	Capacity Growth
4.1	33%	20%
4.2	66%	32%
4.3	100%	40%



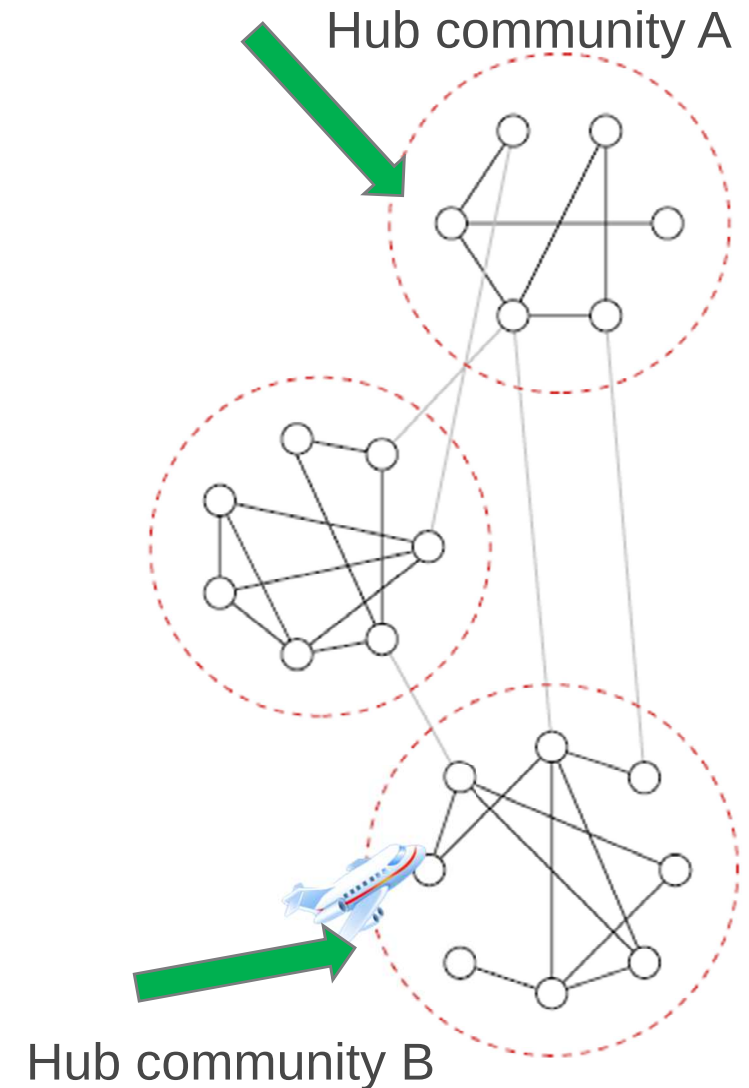
Complexity Science applied to the study of the Air Transport Network

Air Transport Network approach...

- ❖ Airports are nodes with symmetric relationships
- ❖ Elements travelling between nodes are flights or aircrafts;
- ❖ Weight of the links is given by the number of flights connecting two airports;

Air Transport Network's properties

- ❖ Queuing and congestion generation;
- ❖ Delay propagation;
- ❖ Small World property;
- ❖ Scale-free or power-law degree distribution;
- ❖ Community Structures (Hubs)





The Approach: ATM-NEMMO

Mesososcopic model

Nodes

Structure

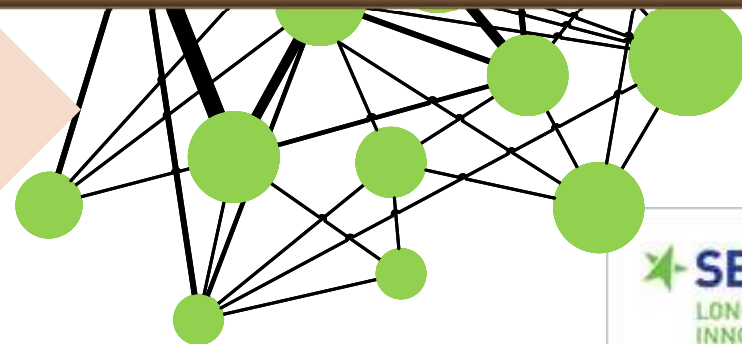
Links

Routing
rules

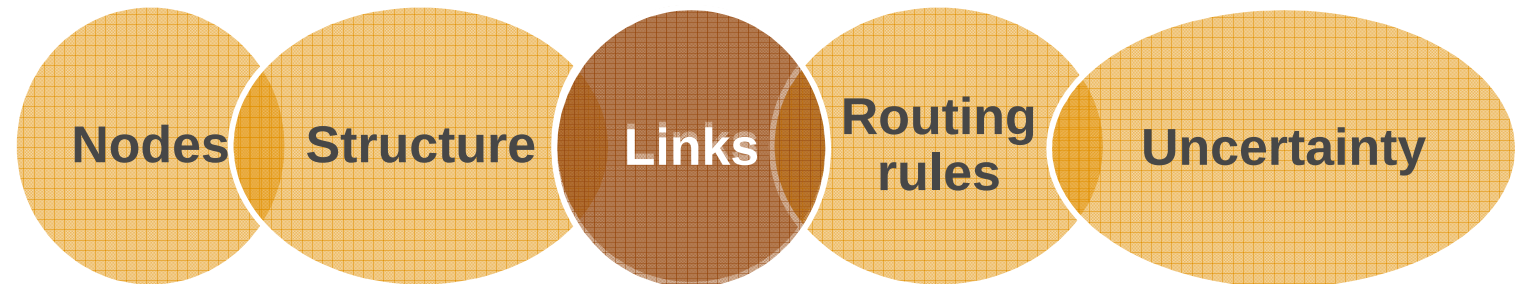
Uncertainty

- ❖ First European airports: 133 nodes handling 90% of the traffic
- ❖ 5 nodes called AREA (from 1 to 5) collecting departures from/ arrivals to airports outside ECAC area grouped by geographical areas;
- ❖ OTHER: 1 node representing the flows of secondary airports.
- ❖ SAMPLE: 1 day of flown traffic in Europe from April 2012 (27658 Flights).

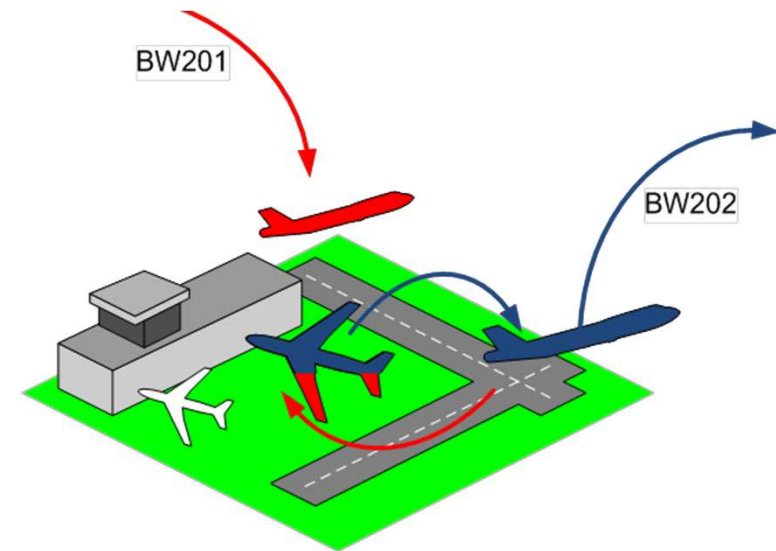
Elements travelling between two nodes are aircraft



The Approach: ATM-NEMMO



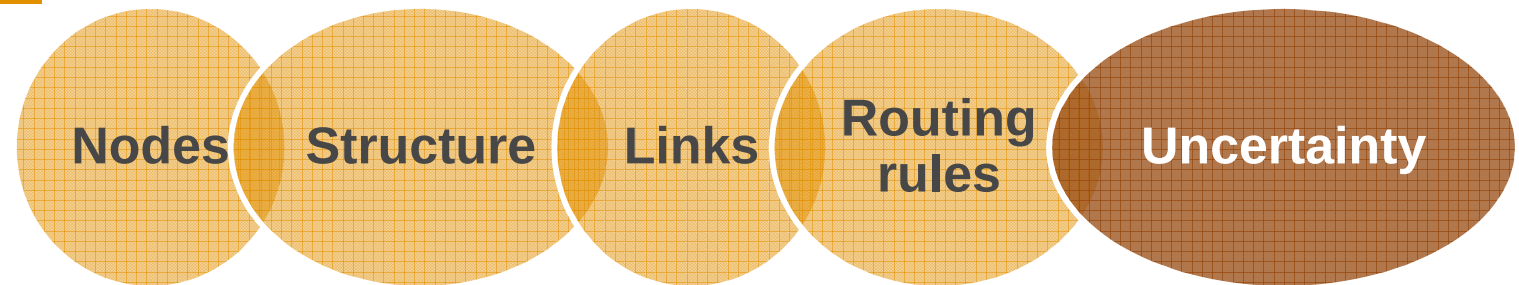
- ◆ Links: the interaction between elements facilitates the propagation of the delays.



- ◆ The different type of delays are modelled similarly in the tool: target times are updated (i.e.: Estimated Take Off Time –Delayed Take Of Time);



The Approach: ATM-NEMMO



❖ Network is subject to internal and external disturbances:

❖ **Internal Disturbances**

- ❖ related to the variability associated to air traffic processes or elements and are inherent to the air traffic network

Uncertainty= stochastic variable following a probability distribution

❖ **External Disturbances**

- ❖ Produced by elements not part of the Air Traffic Network, unexpected events leading to abnormal conditions

Modelled as Capacity shortfalls at airports



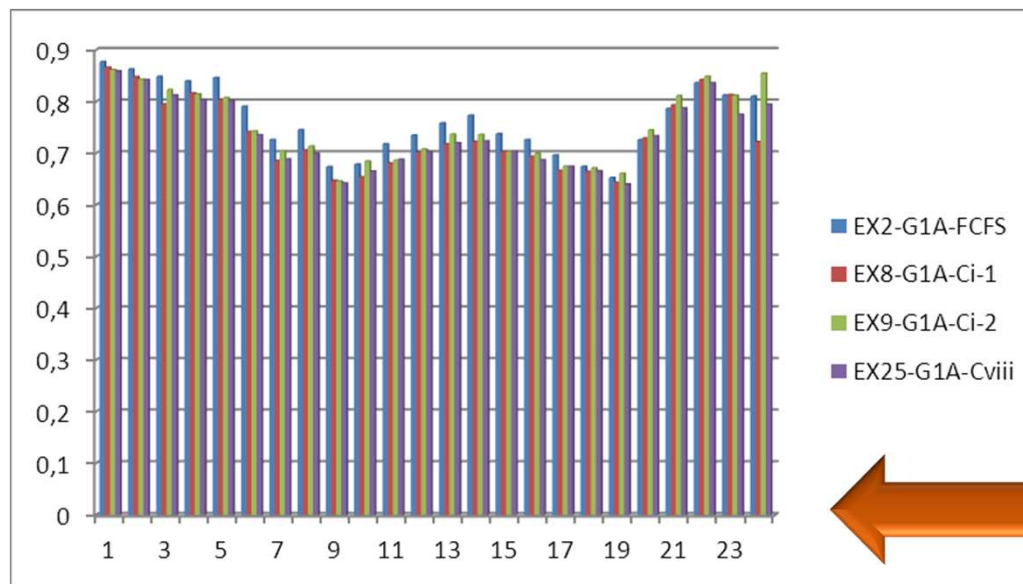
Simulation Results

Impact of prioritization criteria on the network stability (SCENARIO 1)

- ❖ FACTS:
 - ❖ More than 30 exercises conducted (over 6000 simulation runs)
 - ❖ Results analysed both at global and local level.
 - ❖ All the criteria analysed one by one and vs FCFS

- ❖ Some Examples ...

Percentage of flights



FCFS

CRITERION1a

CRITERION1b

CRITERION7

1 hour time intervals

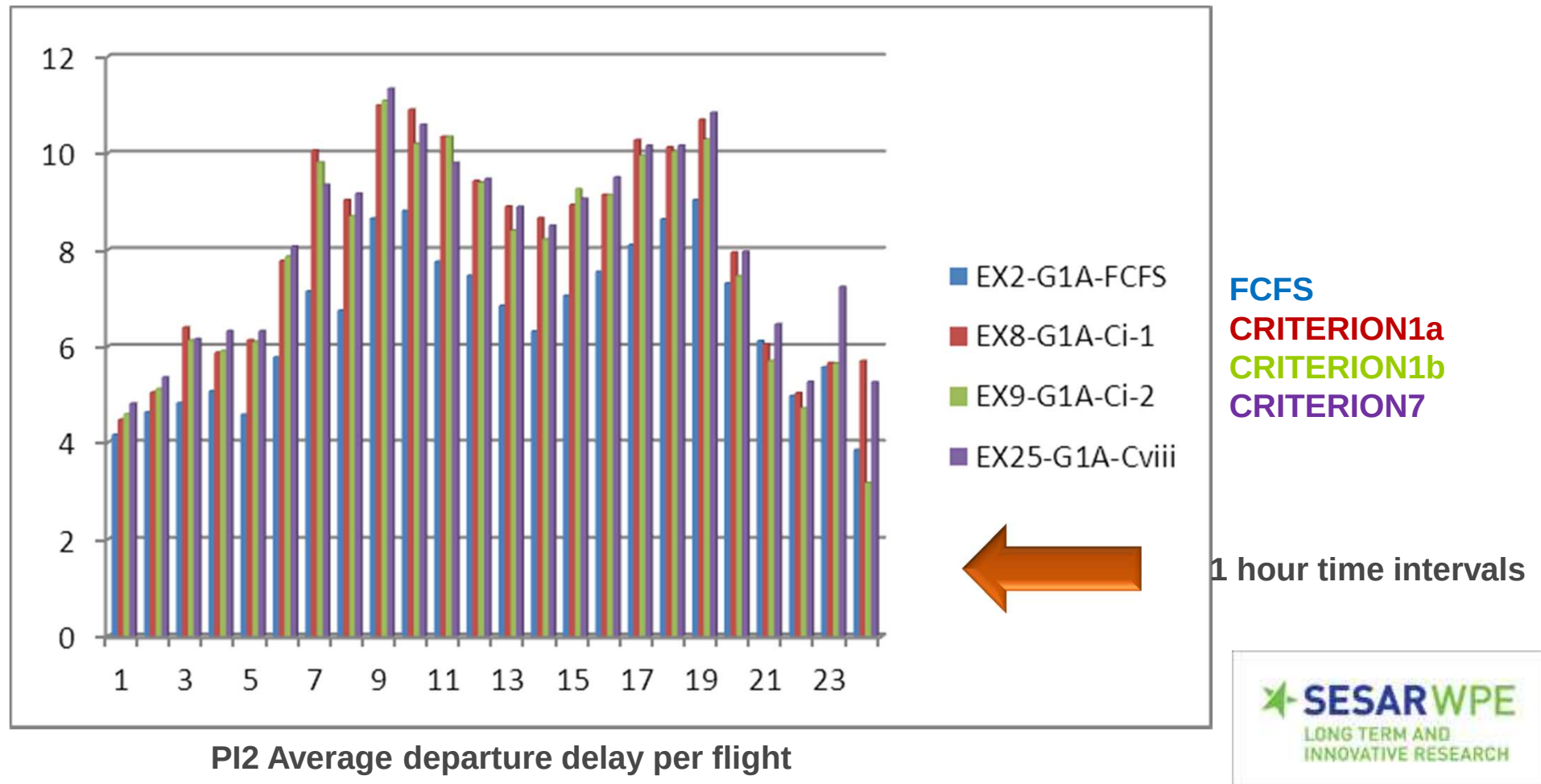
PI1 Percentage of flights departing on time



Simulation Results

Impact of prioritization criteria on the network stability (SCENARIO 1)

◆ Examples of the values of Performance Indicators at network level:





Simulation Results

Impact of prioritization criteria on the network stability (SCENARIO 1)

Ex

Percent

Departure Airport	ICAO CODE	Disturbance A-FCFS			Disturbance A-CI-1 higher n. of outgoing flights			Disturbance A-CI-1 lower n. of outgoing flights			Disturbance A-CV11 Random		
		% flights departing on time	Av. Dep. Delay per flight	Av. Dep. delay per delayed flight	% flights departing on time	Av. Dep. Delay per flight	Av. Dep. delay per delayed flight	% flights departing on time	Av. Dep. Delay per flight	Av. Dep. delay per delayed flight	% flights departing on time	Av. Dep. Delay per flight	Av. Dep. delay per delayed flight
MADRID	LEMD	80,35%	6,93	32,08	74,55%	8,11	30,65	77,40%	7,44	30,54	75,54%	7,55	30,00
SARAJEVO	LRPT	57,33%	6,13	21,59	55,70%	6,24	20,39	48,56%	6,16	24,25	58,71%	6,63	26,09
PALMA DE MALLORCA	LEPA	60,03%	11,83	47,92	57,25%	7,26	24,16	57,25%	12,19	43,97	55,16%	7,74	27,71
MANCHESTER	EGCC	56,44%	5,11	22,25	53,24%	5,65	20,54	51,50%	6,40	24,61	53,27%	5,71	26,10
PARIS CHARLES DE GAULLE	LFRG	79,92%	7,06	30,91	75,85%	7,82	28,83	77,49%	7,36	31,12	75,55%	7,79	30,87
LONDON LUTON	EGGW	63,04%	5,75	16,49	62,83%	6,91	17,05	59,82%	5,13	18,39	59,77%	6,32	19,65
ALICANTE	LEAL	64,97%	5,21	15,15	60,55%	6,21	17,10	64,88%	4,91	17,91	61,13%	5,86	20,02
FRANKFURT	EDDF	75,06%	6,58	31,15	68,53%	7,51	28,61	65,83%	7,61	29,01	69,01%	7,30	27,15
MALAGA	LEMG	63,51%	5,69	19,85	58,21%	6,74	20,04	59,29%	6,59	22,69	59,46%	6,56	23,04
ROME FUMICINO	LIRF	66,67%	5,85	25,63	68,83%	6,04	24,12	67,59%	6,46	27,97	66,57%	6,86	28,75
LONDON GATWICK	EGKK	55,92%	5,20	23,03	52,38%	6,05	21,97	52,66%	5,93	25,53	52,68%	5,94	27,00
LONDON HEATHROW	EGLL	76,76%	6,75	32,47	71,78%	7,89	30,47	72,86%	7,63	31,47	72,24%	7,73	30,45
BARCELONA EL PRAT	LEBL	75,58%	7,09	31,29	71,06%	8,04	29,08	70,03%	8,36	29,09	69,15%	8,49	28,72
AMSTERDAM SCHIPHOL	EHAM	75,49%	7,25	30,55	70,90%	8,12	27,33	65,69%	8,43	29,03	69,53%	8,43	28,25
BUDAPEST FERIHEGY	LHBP	55,99%	5,08	16,50	49,71%	5,64	17,56	48,98%	5,60	20,35	53,42%	5,73	21,12
MUNICH	EDDM	73,90%	6,72	40,41	69,19%	8,59	28,51	69,31%	9,66	35,64	69,22%	8,89	29,31
MILANO MALPENSA	LIML	73,03%	6,69	25,32	66,55%	6,85	23,81	65,19%	8,79	28,92	69,05%	7,55	26,01
NICE	LFMN	70,03%	6,18	24,69	68,06%	6,36	24,41	62,30%	6,57	23,98	66,56%	7,22	24,57
PARIS ORLY	LFPO	57,22%	4,90	23,78	53,04%	5,84	22,72	56,41%	4,89	25,96	59,04%	5,25	26,09
WARSAW	EPWA	67,11%	5,72	23,65	62,77%	6,70	23,20	64,35%	6,27	26,14	63,31%	6,67	27,32

la

lb

7

intervals



Simulation Results

Impact of prioritization criteria on the network stability (SCENARIO 1)

Results:

- ❖ The undesirable network effects (delay propagation and overloads at airport not impacted by external Disturbances) are not better absorbed when applying specific criteria instead of FCFS.
- ❖ However, slight improvements are detected at airport level in specific timeframes.

Conclusions:

- ❖ None of the selected prioritization criteria improves the situation at global level with respect to the FCFS basis;
- ❖ Further research to analyse if any of the criteria could improve problematic hours at local level;
- ❖ This would require the local switch on/off of criteria at specific times and the study of which timeframe is the most efficient in terms of reducing undesirable effects.



Simulation Results

Relation between network stability and equity (SCENARIO 2)

Results:

- ❖ The **best network performance results** were obtained with **alpha closer to one**;

- ❖ Flight priority in two parts: $Pr = \alpha (\text{airlines criteria}) + (1 - \alpha)(\text{network criteria})$

α

Airline

Airline specific, based
on business models

Network

...first flights to hubs,
to less congested
airports, arrival slot at
destination...

- ❖ What is good for airlines might be also good for the network (since airline performance relies on network performance);
- ❖ Note that for designing this scenario, there was not direct input from airlines;

Conclusion:

- ❖ Need of further exploring if what is good for one particular airline or for a set of airlines operating at the airport where a local problem arise, might be good for the whole network;



Simulation Results

Airlines interests as a black box (SCENARIO 3)

- ◆ The approach is just the same as for the Scenario 2

$$Pr = \alpha (\text{random function between 1 and 0}) + (1 - \alpha) (\text{network criteria})$$

Results:

- ◆ The values of the Indicators showed that giving less weight to network-driven prioritisation criteria provided better network performance;

Conclusions

- ◆ As in Scenario 2, values for α closer to 1 give better results
- ◆ There were very different performance responses between time intervals suggesting that **for optimising the network management the application of criteria should be restricted to specific airports at specific timeframes;**



Simulation Results

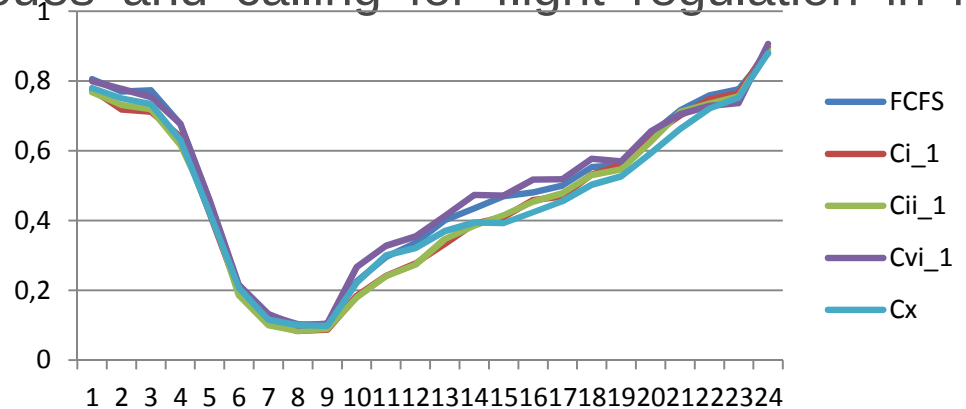
Network critical load analysis (SCENARIO 4)

Results:

- ❖ For all the Performance Indicators and CRITERIA analysed, the situation became unstable in the peak hours of the day;
- ❖ All the prioritization criteria under analysis presented worse results than the ones obtained with FCFS basis, showing high delay queues and calling for flight regulation in most cases;
- ❖ An improvement on average delays was observed at the end of the simulation exercise for 1,33 CURRENT TRAFFIC and 1,66 CURRENT TRAFFIC load levels giving signs of potential system recovery;

Conclusions:

- ❖ the application of certain prioritization criteria for long periods of time improves the negative effects of the network and absorbs the systems delays;



Example of graphical results for Percentage of flights departing on time. 1,33xCurrent traffic



Simulation Results

Most Capable Best Served (SCENARIO 5)

Approach:

- ❖ How to reward operationally investing airlines in the transition period where ground systems are not prepared to give them any technical advantage?

Facts:

- ❖ Most Capable: 4 Exercises, with different percentages of capable flights.
- ❖ Best Served: These flights will be given priority on departure

Conclusions:

- ❖ The number of capable flights for all the exercises is between 10%-35% **so giving priority to such a percentage of flights** (labelled as capable on the tool) **does not represent an improvement to the global situation;**
- ❖ As for the airlines interests, the results could be interpreted the other way around:
 - ❖ To give precedence to capable flights, which means an advantage at local level for the airline, **has not meaningful harmful effect for the global network behaviour.**



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