Simulation Exercises for robust Flight dispatching solution under thunderstorm disruptions

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EUROPEAN PARTNERSHIP

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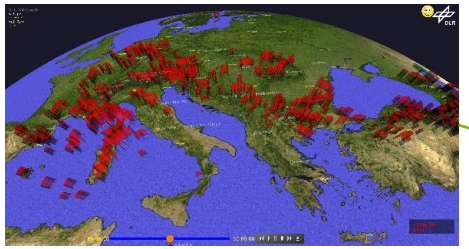
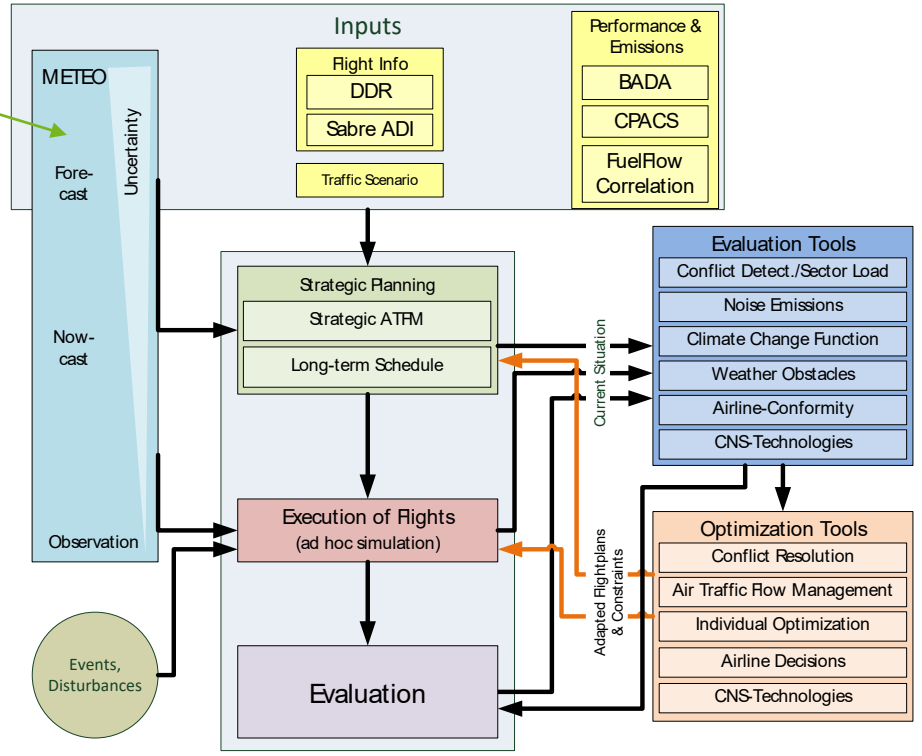
Simulation Setup START project



Convective Weather from NetCDFs

Reference Scenario from FK-Server

Resilient Scenario from FK-Server

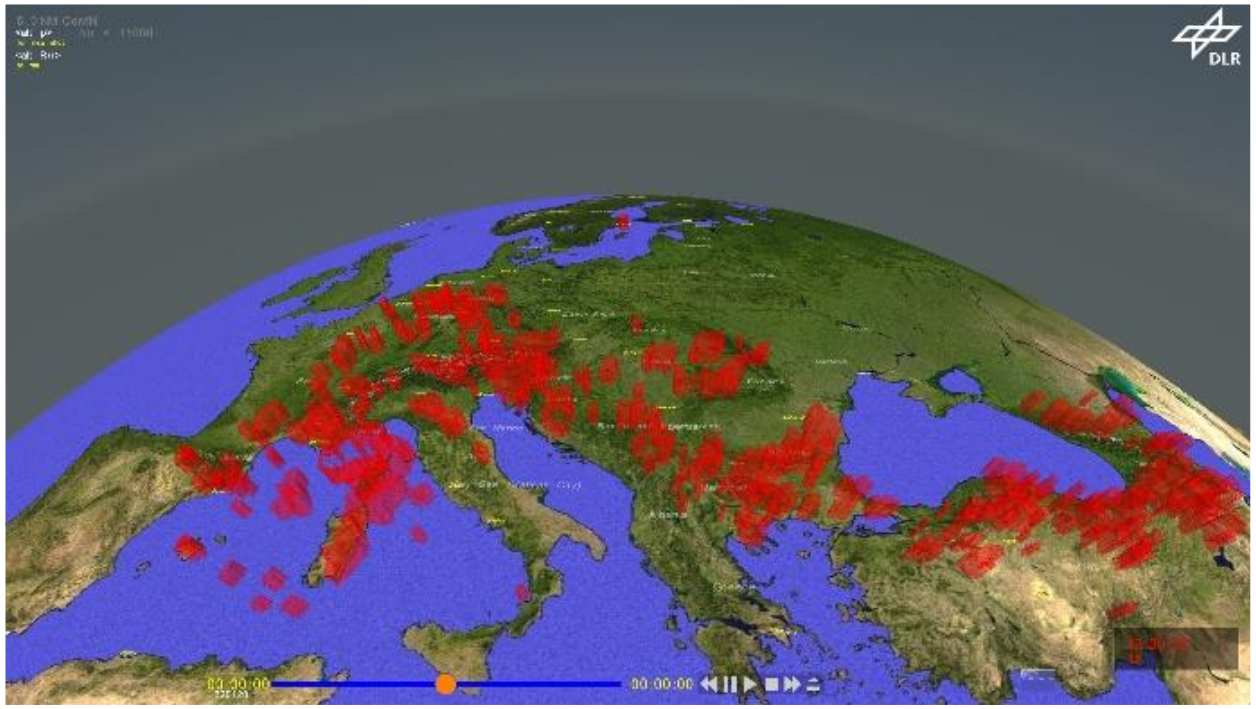


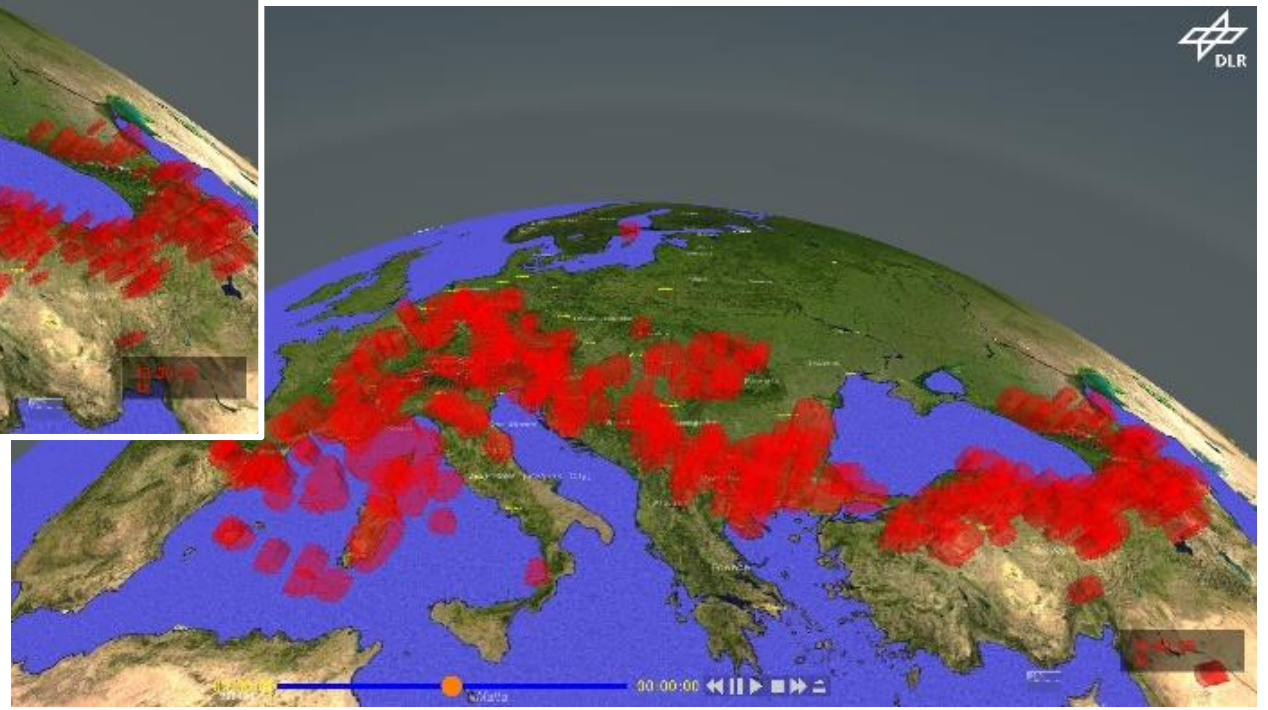
Validation Platform

Metrics (Selection)

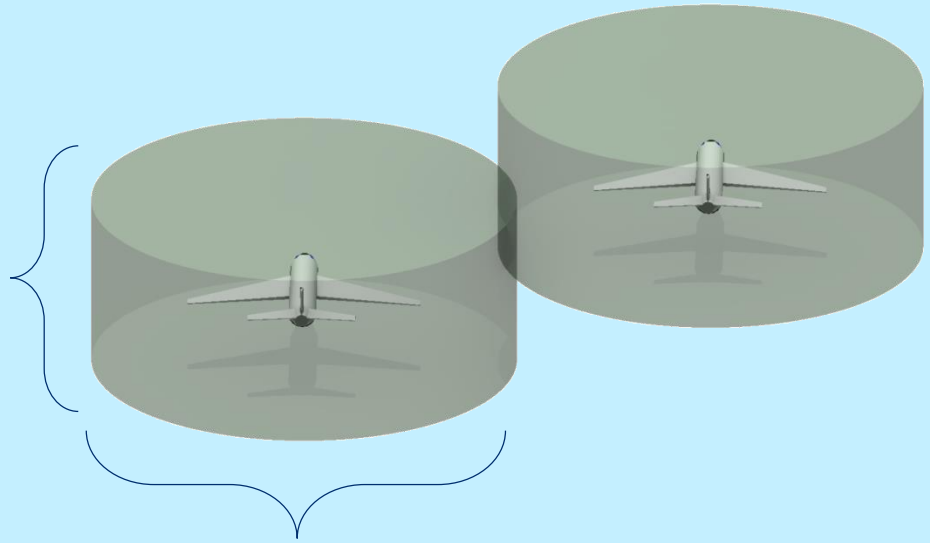
KPA/KPI	Objective	Metrics
Safety Incident Risk	Constant or less	Number and total duration [s] of separation violations
Capacity Capacity shortfalls around severe weather	Less capacity shortfalls	Number of flights in inflated (e.g. 10 NM) weather polygons
Capacity Number of cancellations	Less flight cancellations for resilient scenario	Number of cancellations
Efficiency Flight duration	Max 10 min increase of flight duration	Flight duration [s]
Environment Fuel Burn/CO2	Max 5% increase in fuel burn/CO2 without disturbances	Inflight Fuel burn/CO2 [kg]

Weather Polygon Inflation by 10 NM

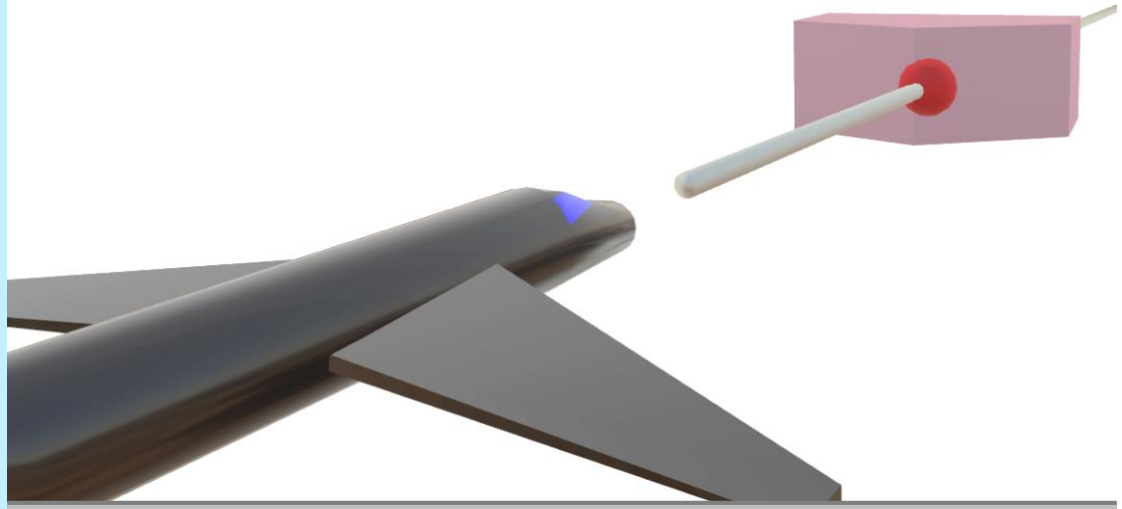




Conflict Metrics



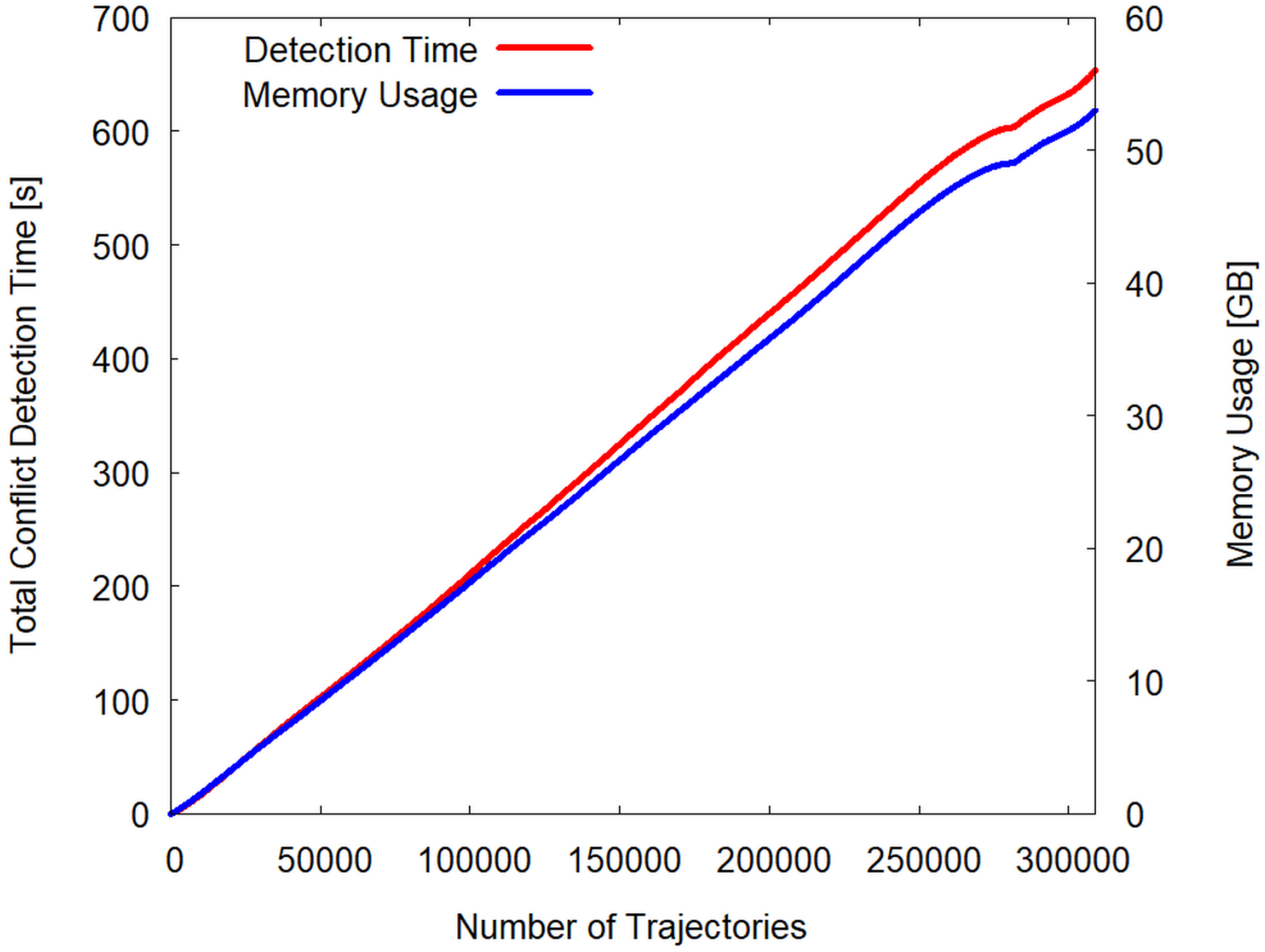
En-Route: 5 NM
TMA: 3 NM



Weather Object: Penetration

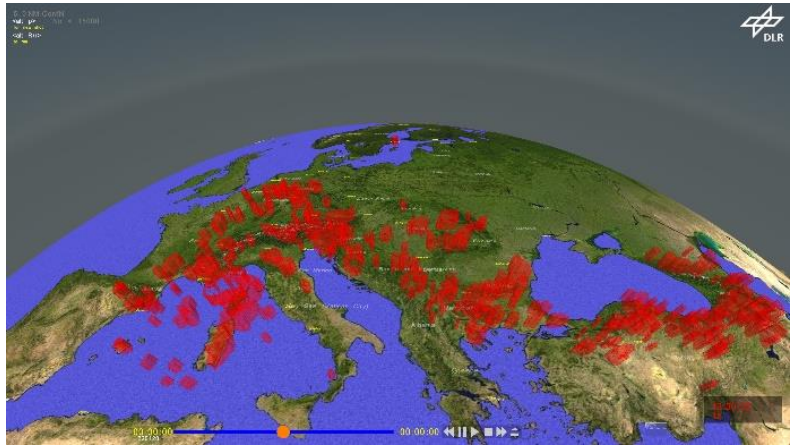
Conflict Detection: NDMap

- 4D Conflict Detection
- Spans Hexadecimal Tree
- Almost linear performance
  - 2 ms/Trajectory
  - 170 kb/Trajectory
- Objects
  - 4D Trajectories
  - 4D Polygons
    - 2D Polygon
    - Altitude Interval
    - Time Interval



Reference scenario and conflicts

- 07.06.2018, 12:00-16:00
- 10939 flights
- 4075 weather polygons
- 19718 conflicts => 1117 Conflict hours



4287 flights have at least 1 conflict with convective weather

2487 weather polygons have at least 1 conflict

Simulation Exercise Plan

Exercise Name	1. General	2. Departure Uncertainty	3. Increased Uncertainty	4. Resolution Costs
Input	Reference and Resilient Scenarios	Reference and Resilient Scenarios	Reference and Resilient Scenarios	Reference and Resilient Scenarios
Conflict Detection	Yes	Yes	Yes	Yes
Conflict Avoidance	No	No	No	**Yes for FL>100 (lateral and vertical)**
Departure Time Uncertainty	No	5 minutes standard deviation	**Increased SD**	No
Simulation Mode	Single Run	Monte Carlo	Monte Carlo	Single Run
Expectation	**Many conflicts, less thunderstorm conflicts for resilient scenario**	**Benefits decrease compared to the General exercise**	**Which standard deviation destroys the benefits (if any)**	**Benefits (= less costs) for resilient scenario**

Major Findings: 1. General

Scenario	Reference June 7th		Resilient June 7th	
	All Traffic	Star Alliance	All Traffic	Star Alliance
Number of Flights	10 939	2 165	10 939	2165
Aircraft Conflicts	4 836	1 595	4824	1583
Weather Conflicts	14 882	**4 046**	14 239	**3440**
Total Time in Conflict	**1117 hrs**	**285 hrs**	**1077 hrs**	**244 hrs**
Avg Flight Distance	1183 NM	963 NM	1184 NM	970 NM
Avg Flight Duration	2:47:12	2:18:08	2:47:24	2:19:07
Avg Fuel Burn	12 436 kg	10 421 kg	12 425 kg	10 372 kg
Avg CO_2 emissions	39 172 kg	32 826 kg	39 141 kg	32 670 kg
Avg Costs	15 679 €	13 015 €	15 689 €	13 074 €

Major Findings: 2. Departure Uncertainty Monte Carlo SD 5 min (>100 iterations)

Conflict Type		Reference Scenario SD 5 min		Resilient Scenario SD 5 min	
		Count	Duration [m:ss]	Count	Duration [m:ss]
Weather Polygons	Departure	529 [10]	3:17.6 [5.5]	531 [9]	3:12.5 [4.7]
	Climb	3813 [32]	2:46.8 [1.3]	3566 [29]	2:44.0 [1.5]
	Cruise	7301 [39]	2:41.3 [0.9]	7094 [40]	2:42.0 [0.9]
	Descent	2 758 [27]	3:05.0 [2.0]	2610 [27]	3:02.1 [2.0]
	Arrival	480 [9]	5:10.0 [8.4]	459 [9]	5:15.6 [8.0]
Between Aircraft		4919 [64]	4:28.8 [17.1] Total 367 hrs	4897 [73]	4:16.3 [17.1] Total 349 hrs
Total		19 801 [81]	3:16.9 [4.4] **Total 1083 hrs**	19156 [86]	3:13.0 [4.4] **Total 1027 hrs**

Major Findings: 3. Increased Departure Uncertainty Monte Carlo SD 30 min

Conflict Type		Reference Scenario SD 30 min		Resilient Scenario SD 30 min	
		Count	Duration [m:ss]	Count	Duration [m:ss]
Weather Polygons	Departure	504 [16]	3:17.5 [6.7]	514 [16]	3:15.0 [6.5]
	Climb	3748 [48]	2:47:9 [1.9]	3542 [48]	2:45.5 [2.0]
	Cruise	7275 [77]	2:41.3 [1.3]	7063 [69]	2:41.5 [1.3]
	Descent	2707 [40]	3:06.5 [2.7]	2549 [39]	3:04.1 [2.6]
	Arrival	463 [15]	5:12.3 [10.3]	440 [15]	5:14.3 [9.9]
Between Aircraft		4760 [71]	4:10.5 [15.3] Total 331 hrs	4747 [73]	4:01.4 [14.3] Total 318 hrs
Total		19458 [129]	3:12.4 [3.9] **Total 1040 hrs**	18855 [130]	3:09.9 [3.7] **Total 995 hrs**

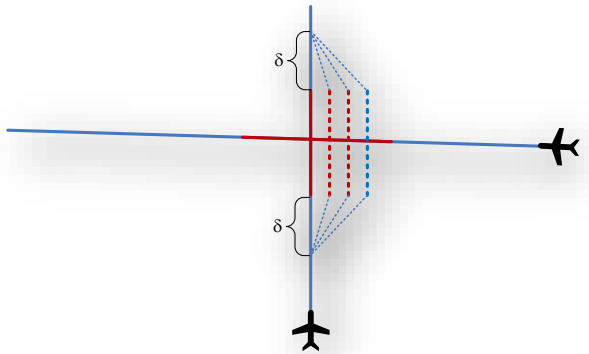
Conflict Resolution: NDMap

- Time for insertion+CD: 2 ms/Trajectory
- Time for deletion: 1 ms/Trajectory

➔~300 trials/second for CR

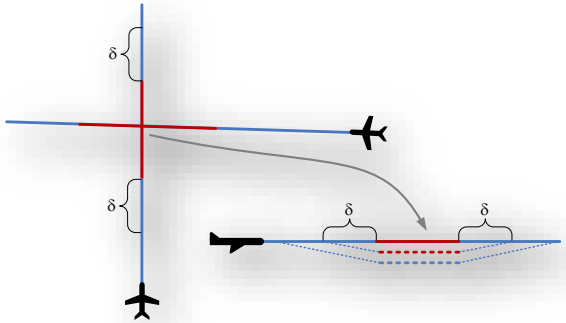
Idea: CR after deparature, no departure uncertainty

1. Lateral



Extra miles

2. Vertical



Extra climb feet

3. Cancelation

- Cancel flight with most conflicts
- Until no conflict left

Cancel-costs

Major Findings: 4. Resolution Costs (Star Alliance), >=FL150

Scenario	Reference June 7th		Resilient June 7th	
	Original	Resolved	Original	Resolved
Number of Flights	2 165	**1 687**	2 165	**1 719**
Aircraft Conflicts	1 595	0	1 583	0
Weather Conflicts	4 046	0	3 440	0
Avg Flight Distance	963 NM	996 NM	970 NM	973 NM
Avg Flight Duration	2:18:08	2:23:09	2:19:07	2:20:23
Avg Fuel Burn	10 421 kg	**10 820 kg**	10 372 kg	**10296 kg**
Avg CO2 emissions	32 826 kg	34084 kg	32 670 kg	32431 kg
Avg Costs	13 015 €	13 495 €	13 074 €	13002 €
Lateral Detour	**5.6 NM (+78 s)**		**4.5 NM (+59 s)**	
Add. Vertical Climb	**208 ft**		**219 ft**	
Flights cancelled	**478**		**446**	

Results (Selection)

KPA/KPI	Objective	Metrics	Results
Safety Incident Risk	Constant or less	Number and total duration [s] of separation violations	3.6-6.5% global **decrease of conflict** hours (SA: 14.4-34.6%). Even in case of departure uncertainty of 30 min: 4-5%.
Capacity Capacity shortfalls around severe weather	Less capacity shortfalls	Number of flights in inflated (e.g. 10 NM) weather polygons	Although the major reduction originates from the polygon itself, reduction around the polygons is also significant with 2.4-2.6%.
Capacity Number of cancellations	Less flight cancellations for resilient scenario	Number of cancellations	2.1-2.4% **less cancelations** for conflict free scenario.
Efficiency Flight duration	Max 10 min increase of flight duration	Flight duration [s]	Flight **duration increases** by 0.7-1.1% for the resilient Star Alliance flights. 2.4% got a change of more than 10 min.
Environment Fuel Burn/CO2	Max 5% increase in fuel burn/CO2 without disturbances	Inflight Fuel burn/CO2 [kg]	**Fuel burn/CO2 decreases** for the resilient scenario by 0.5-2.3% for the Star Alliance fleet.

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THANK YOU FOR YOUR ATTENTION

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