OptiFrame for Trajectory Based Operations (TBO) Decisions Support

OptiFrame Consortium

Brussels, 14th February 2018

Founding Members

Objectives of this presentation

Demonstrate the OptiFrame's decision support capabilities

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The nature of the OptiFrame solutions

The nature of the OptiFrame solutions (1/3)

An OptiFrame solution provides a 4D trajectory for each flight:

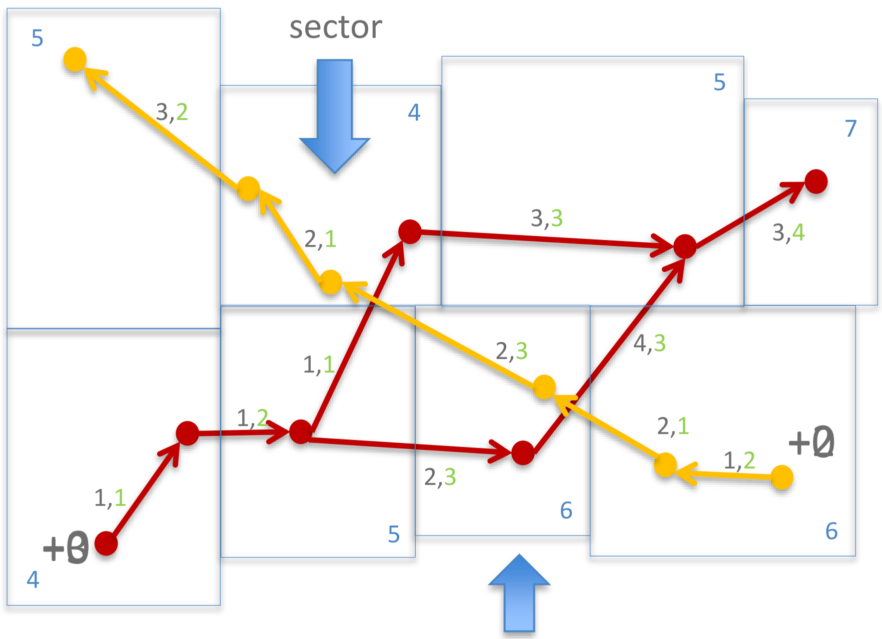
- a trajectory in 3D space,
- the departure time.

Each solution achieves specific values of the three objective functions (delay, flight efficiency, route charges).

In the presence of a trade-off between objectives, there are multiple efficient solutions.

Non-dominated (efficient) solution:
solution that is not outperformed by any other solution in terms of all objectives

The nature of the OptiFrame … (2/3)



Congested sectors / No congestion issues
at time periods [+6,+9]

Δ Delay = +0
Δ Efficiency = +0
Δ Route charges = +0

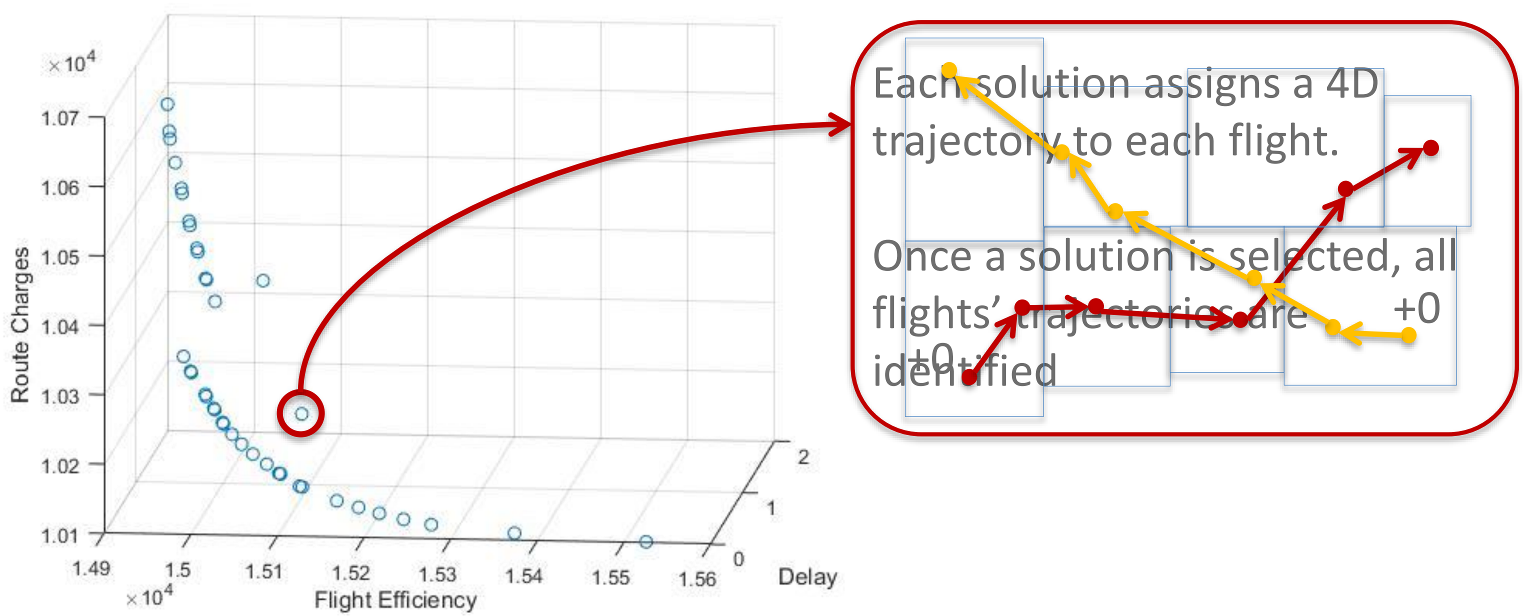
Value path graph: a graphical representation of non-dominated solutions

n,m = cost, time to travel through arc
h = contribution to route charges

The nature of the OptiFrame solutions (3/3)

Pareto Frontier: the collection of all non-dominated solutions.

Each point in the 3D plot – identified by total delay, total flight efficiency, total route charges for all flights – is a non-dominated solution.



Description of the test instances

Description of test instances (1/2)

Data extracted from DDR2 database :

- Choice of a busy day (3rd October 2016)

- two major airports:
  EGLL & EDDF
- 10 flights operated at peak hours (9am - 3pm)
- 21 sectors
- 269 relevant waypoints
- 2 airlines

- four major airports:
  EGLL, LFCG, EHAM, EDDF
- 186 flights operated during the whole day
- 60 sectors
- 694 relevant waypoints
- 6 airlines

- Sectors and airports capacity profiles over time horizon

Description of test instances (1/2)

Realistic instances: built on the basis of real data.

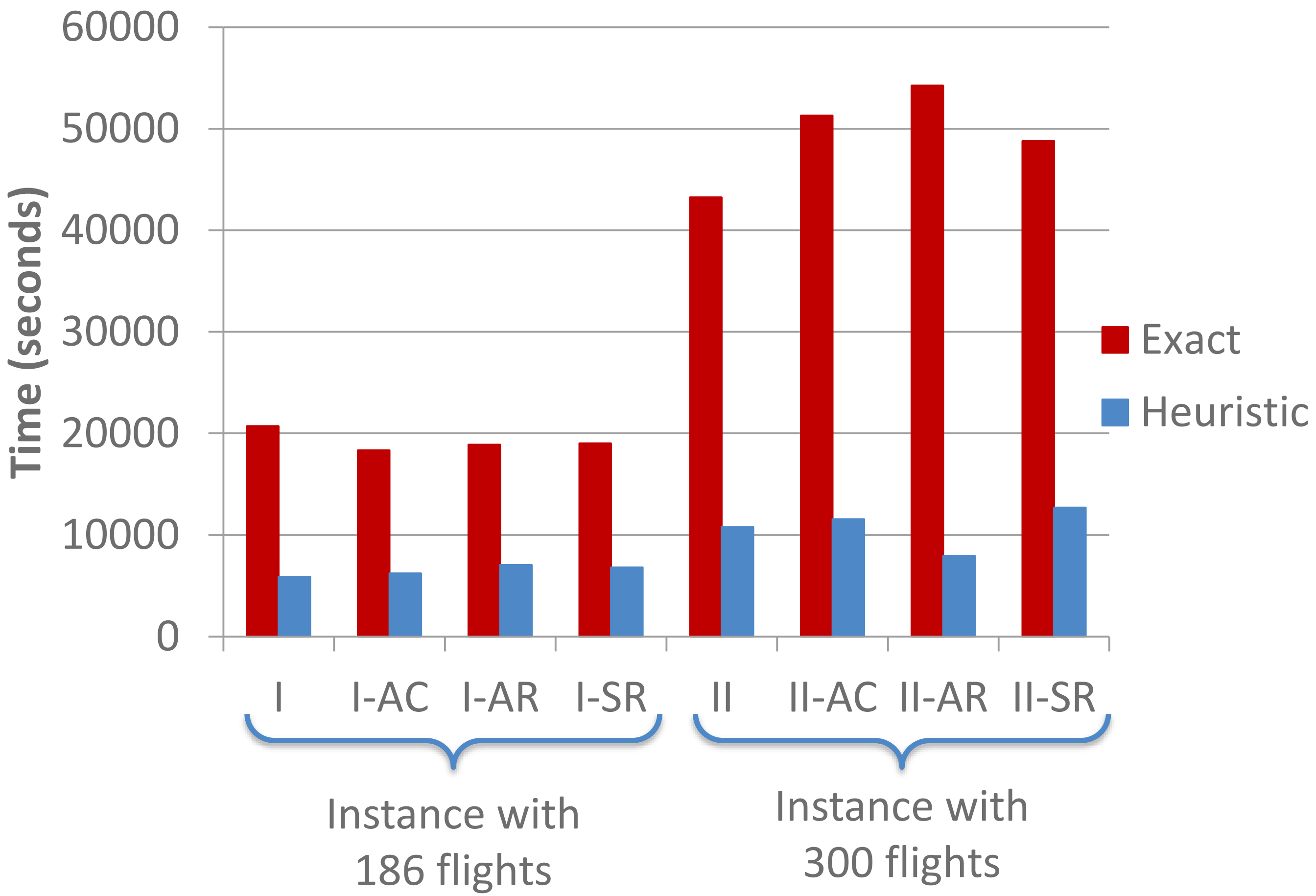
- 4 airports
- 694 waypoints
- 60 sectors
- 24 hours time horizon (10 minutes intervals)

- Instance I: 186 flights
- Instance II: 300 flights (~ +50%)

Exact versus heuristic solutions

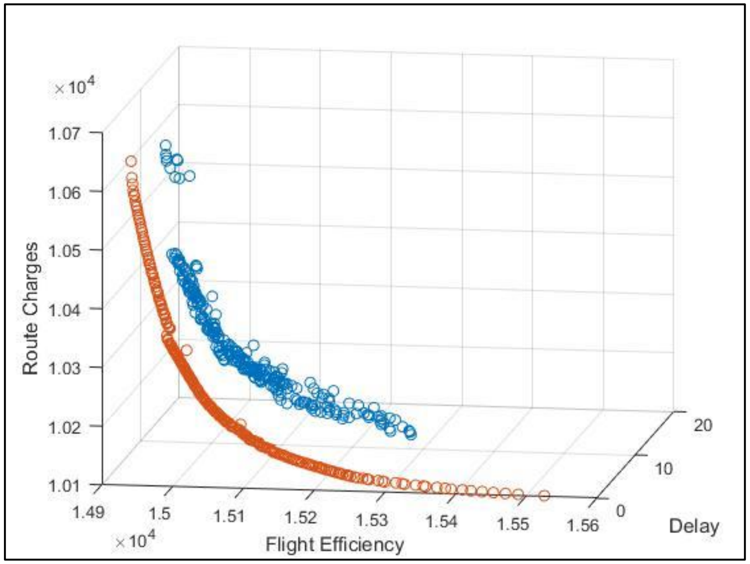
Exact *vs* heuristic solutions (1/3)

Comparison of computational times



Exact *vs* heuristic solutions (2/3)

Comparison of quality of solutions



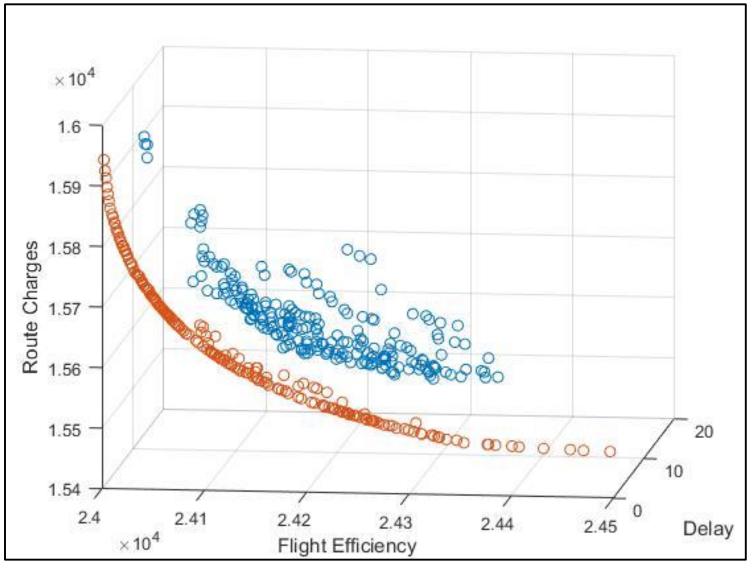
- Instance with 186 flights
- 4 airports

- 232 exact solutions
- 257 heuristic solutions

- Good coverage of the frontier (in terms of spread)
- Fairly close to the exact solutions values
- Consistent number of solutions with Pareto Frontier

Exact *vs* heuristic solutions (3/3)

Comparison of quality of solutions



- Instance with 300 flights
- 4 airports

- 185 exact solutions
- 216 solutions

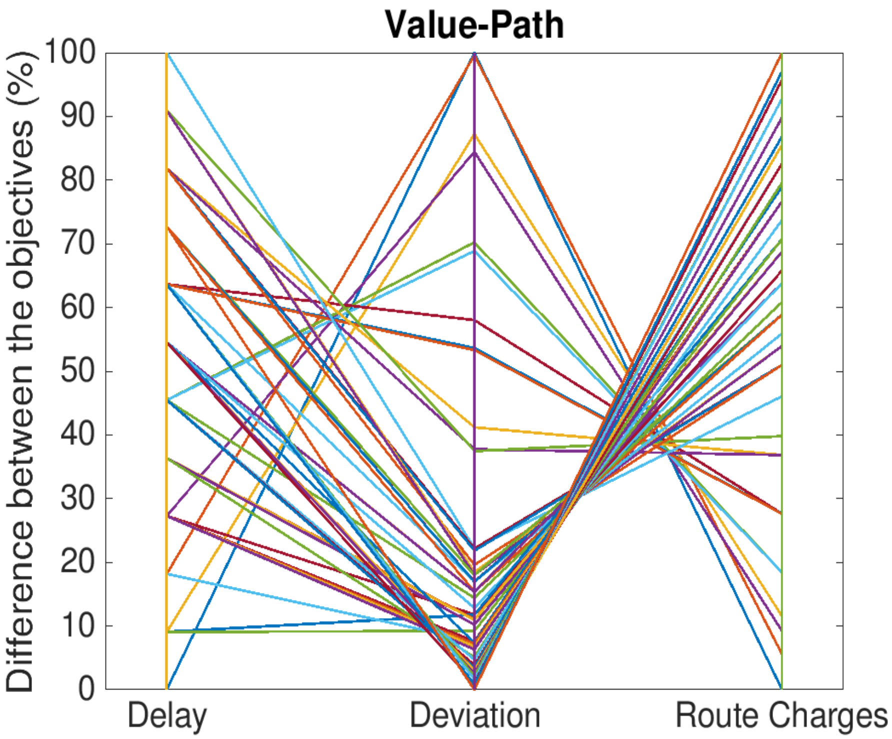
- Good coverage of the frontier (in terms of spread)
- Fairly close to the exact solutions values
- Consistent number of solutions with Pareto Frontier

Using OptiFrame for Decisions Support

OptiFrame for decisions support (1/17)

Results for EGLL and EDDF instance

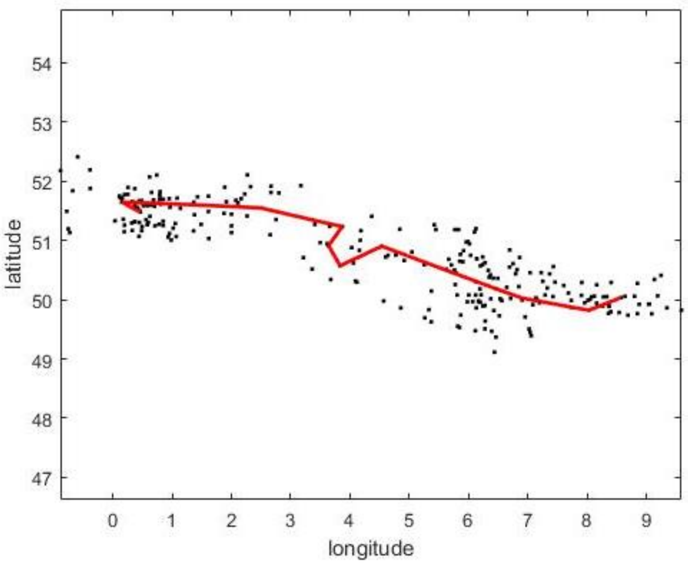
- 56 efficient solutions



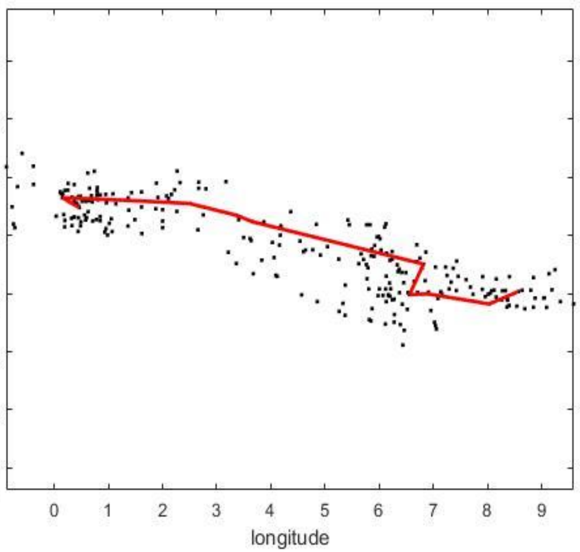
- (Min, Max) Delay: (0, 11)
- (Min, Max) Deviation: (4620, 10764)
- (Min, Max) Route Charges: (800, 1126)

OptiFrame for decisions support (2/17)
Trajectories for a flight

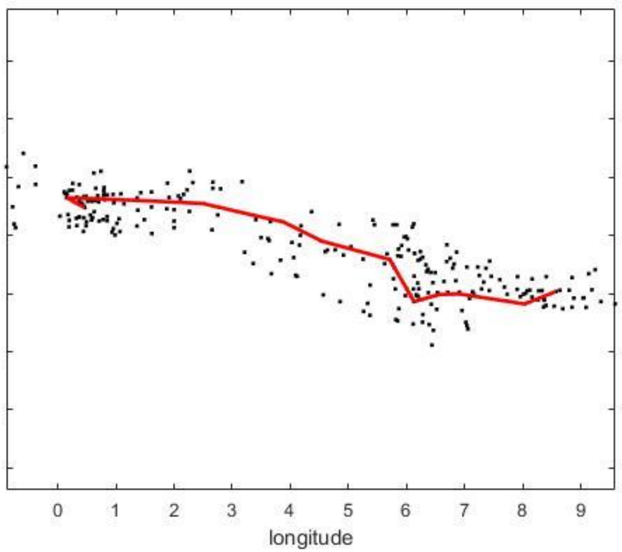
Trajectory A: 5/56



Trajectory B: 19/56



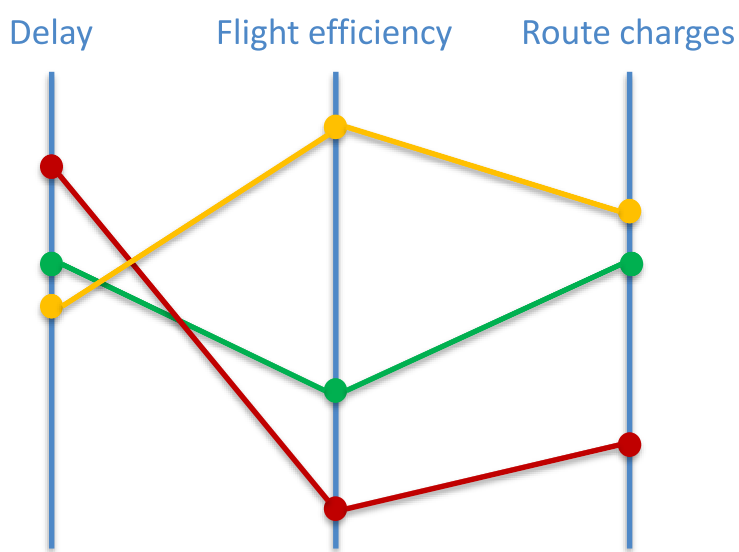
Trajectory C: 32/56



OptiFrame for decisions support (3/17)

Advantages of the multi-objective approach

- The importance to be given to each objective is not decided in advance
- Trade-off between objectives can be investigated to better choose a solution to be implemented



A priori choice: give a reasonable importance to all objectives, according to goals of Stakeholders

A posteriori evaluation: if I give less importance to the minimization of delay, the value of the gain in terms of the other objectives is not relevant

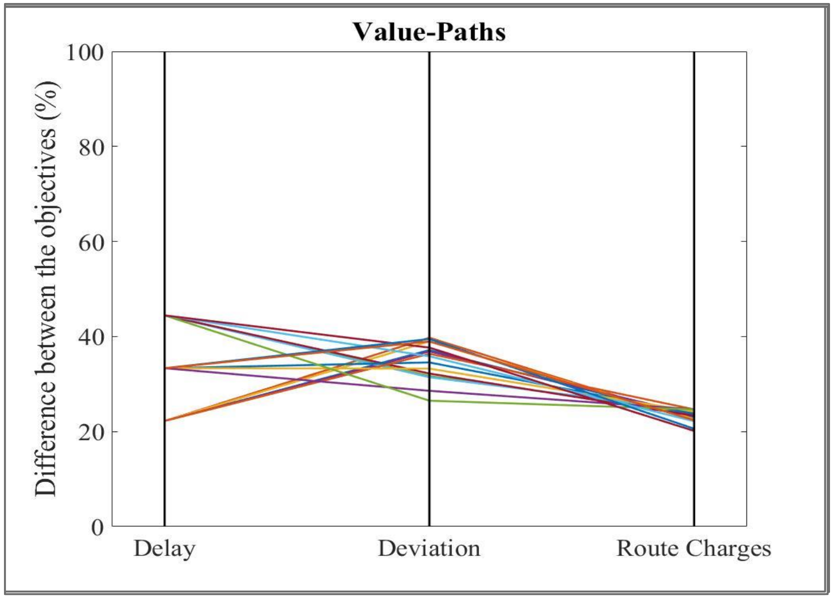
A posteriori evaluation: if I give less importance to the minimization of flight efficiency, the graph shows that I gain a lot within the other objectives

Stakeholders may adjust their views on objectives' importance according to the solutions.

OptiFrame for decisions support (4/17)
A guide to results

- Pareto frontiers identify a large number of candidate solutions.
- Filtering criteria can be used to limit the set candidate solutions.

Examples:
- All objectives between 10% and 90% of extreme values
- All objectives between 20% and 80% of extreme values
- Sequential restriction of objectives
  - delay between 20% and 50% of extreme values
  - deviation between 20% and 40%
  - route charges between 20% and 25%

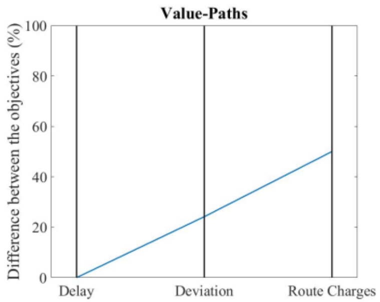


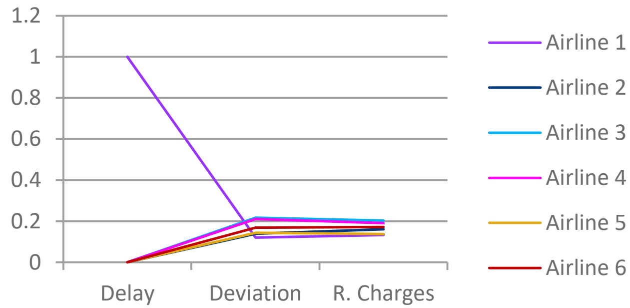
Instance I, Nominal Scenario

OptiFrame for decisions support (5/17)

Instance I

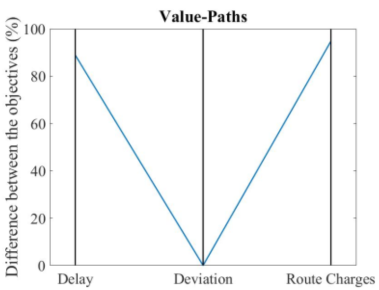
Minimum Delay. Total: Delay = 2, Deviation = 15029, R. Charges = 10392

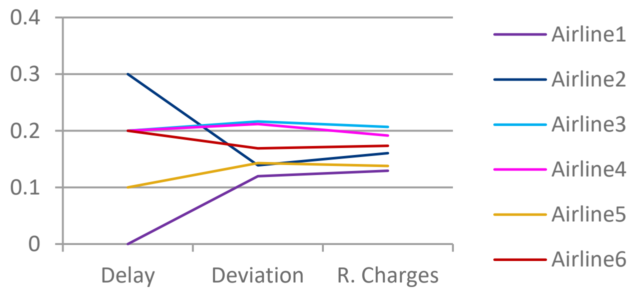




	#flights	Delay	Deviation	RouteCharges
Airline 1	25	2	1805	1387
Airline 2	29	0	2088	1676
Airline 3	38	0	3257	2114
Airline 4	36	0	3176	1984
Airline 5	27	0	2155	1439
Airline 6	31	0	2548	1792

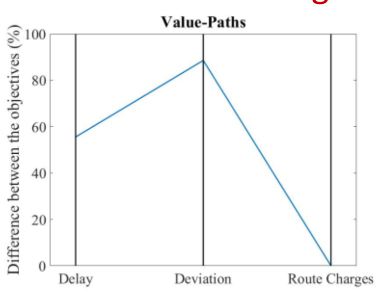
Minimum Deviation. Total: Delay = 10, Deviation = 14936, R. Charges = 10590

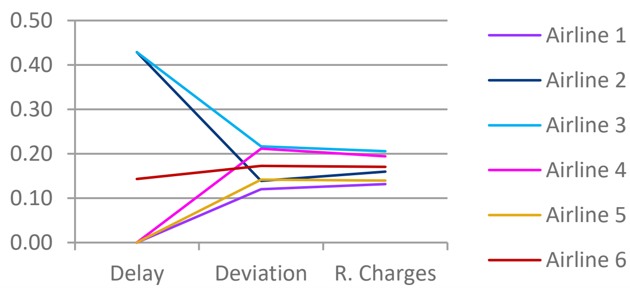




	#flights	Delay	Deviation	RouteCharges
Airline 1	25	0	1795	1369
Airline 2	29	3	2077	1698
Airline 3	38	2	3237	2189
Airline 4	36	2	3167	2032
Airline 5	27	1	2136	1464
Airline 6	31	2	2524	1838

Minimum Route Charges. Total: Delay = 7, Deviation = 15277, R. Charges = 10171



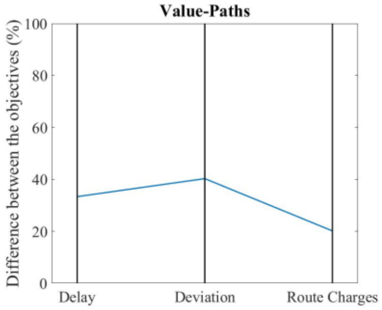


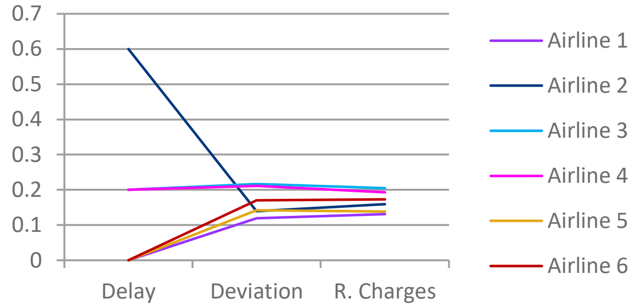
	#flights	Delay	Deviation	RouteCharges
Airline 1	25	0	1837	1335
Airline 2	29	3	2115	1619
Airline 3	38	3	3302	2090
Airline 4	36	0	3224	1973
Airline 5	27	0	2167	1421
Airline 6	31	1	2632	1733

OptiFrame for decisions support (6/17)

Instance I

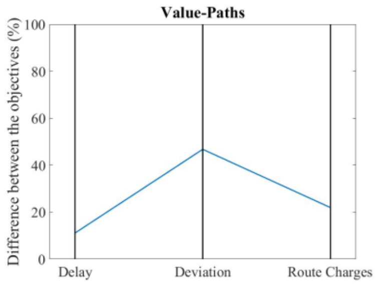
Random1. Total: Delay = 5, Deviation = 15091, R. Charges = 10260

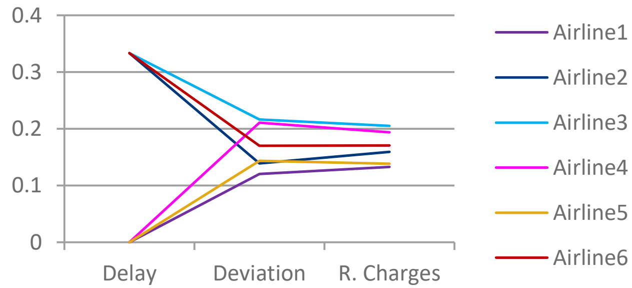




	#flights	Delay	Deviation	RouteCharges
Airline 1	25	0	1809	1344
Airline 2	29	3	2103	1635
Airline 3	38	1	3272	2104
Airline 4	36	1	3193	1983
Airline 5	27	0	2149	1422
Airline 6	31	0	2565	1772

Random2. Total: Delay = 3, Deviation = 15116, R. Charges = 10268



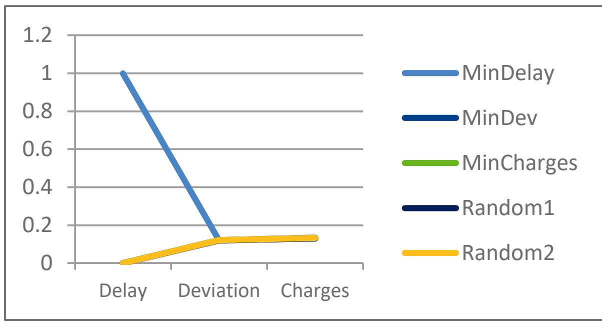


	#flights	Delay	Deviation	RouteCharges
Airline 1	25	0	1820	1361
Airline 2	29	1	2099	1637
Airline 3	38	1	3272	2104
Airline 4	36	0	3182	1989
Airline 5	27	0	2174	1424
Airline 6	31	1	2569	1753

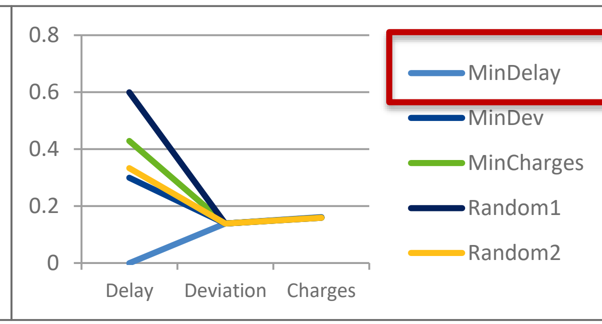
OptiFrame for decisions support (7/17)

Instance I : airlines perspective

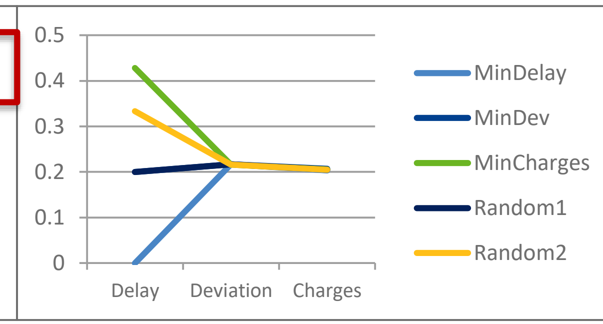
Airlines' share in total objectives for different solutions



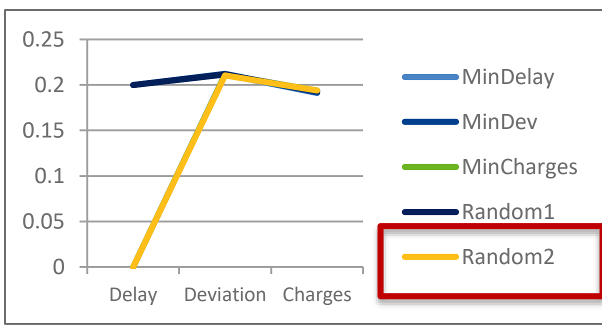
Airline 1



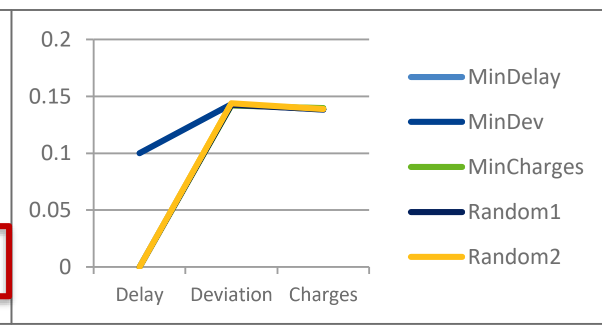
Airline 2



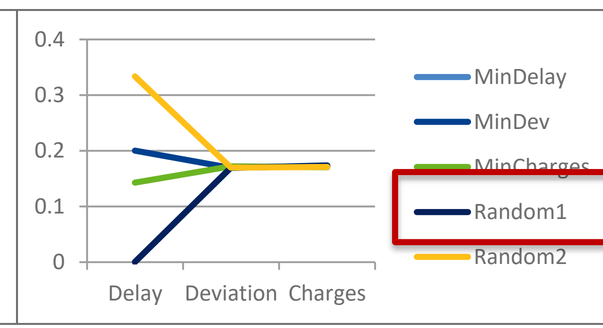
Airline 3



Airline 4



Airline 5



Airline 6

OptiFrame for decisions support (8/17)

Disturbance Scenarios

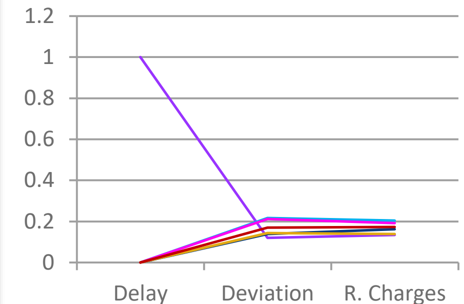
- Airport Closure (AC): one airport is closed for one hour, both for departures and arrivals.
- Airport Restriction (AR): the capacity at one airport is reduced for one hour at take off and landing.
- Sector Restriction (SR): a sector has reduced capacity throughout the day.

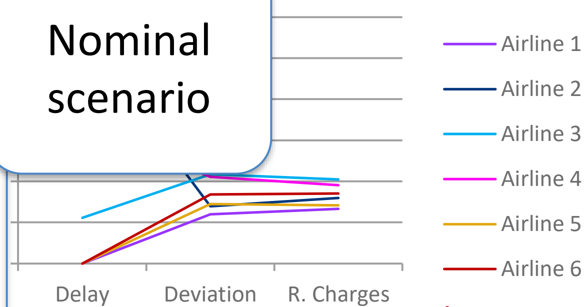
OptiFrame for decision support (9/17)
Instance I: Airport Closure

Minimum Delay. Total: Delay = 9 … 8, R. Charges = 10447

Nominal scenario

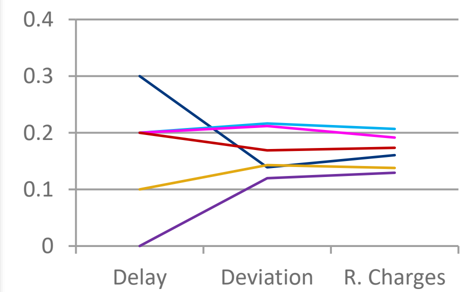
Airport Closure

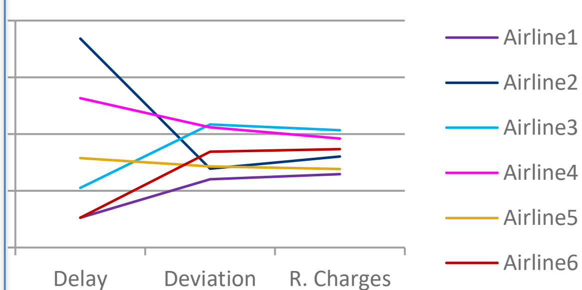




			Deviation		RouteCharges	
			1805	1808	1387	1389
			2088	2110	1676	1666
			3257	3281	2114	2138
Airline 4	0	3	3176	3189	1984	1996
Airline 5	0	0	2155	2185	1439	1478
Airline 6	0	0	2548	2545	1792	1780

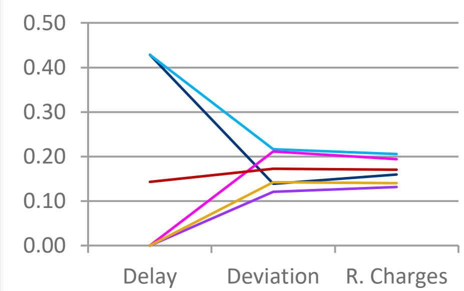
Minimum Deviation. Total: Delay = 19, Deviation = 14936, R. Charges = 10590

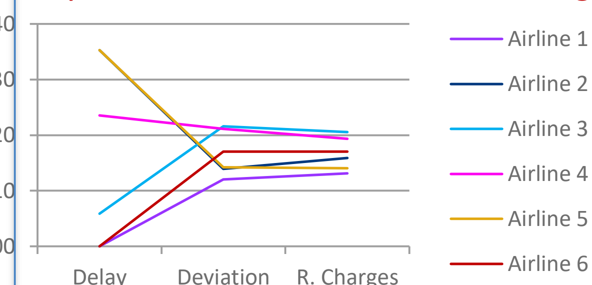




	Delay		Deviation		RouteCharges	
Airline 1	0	1	1795	1795	1369	1369
Airline 2	3	7	2077	2077	1698	1698
Airline 3	2	2	3237	3237	2189	2189
Airline 4	2	5	3167	3167	2032	2032
Airline 5	1	3	2136	2136	1464	1464
Airline 6	2	1	2524	2524	1838	1838

Minimum Route Charges. Total: Delay = 17, Deviation = 15245, R. Charges = 10198



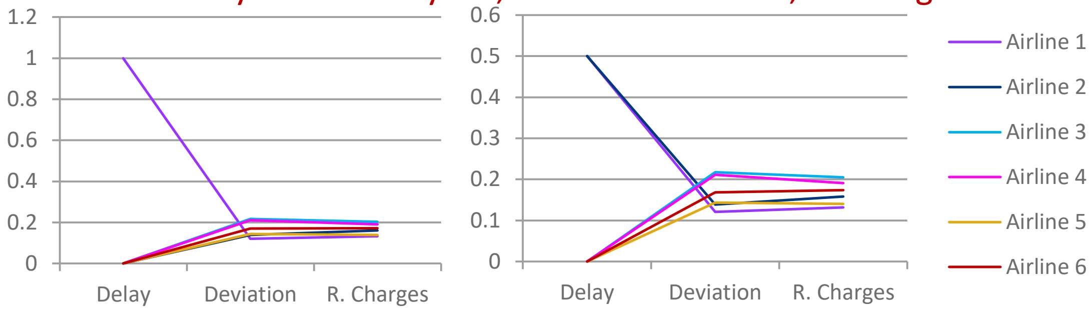


	Delay		Deviation		RouteCharges	
Airline 1	0	0	1837	1839	1335	1337
Airline 2	3	6	2115	2127	1619	1620
Airline 3	3	1	3302	3289	2090	2094
Airline 4	0	4	3224	3221	1973	1974
Airline 5	0	6	2167	2166	1421	1433
Airline 6	1	0	2632	2603	1733	1740

OptiFrame for decisions support (10/17)

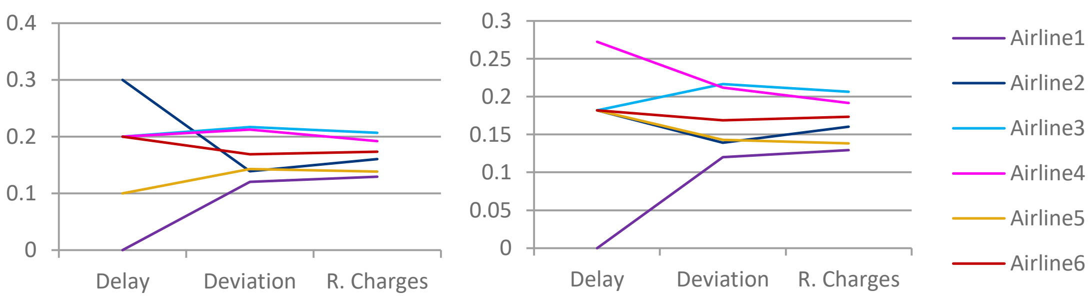
Instance I: Airport Restriction

Minimum Delay. Total: Delay = 2, Deviation = 15078, R. Charges = 10355



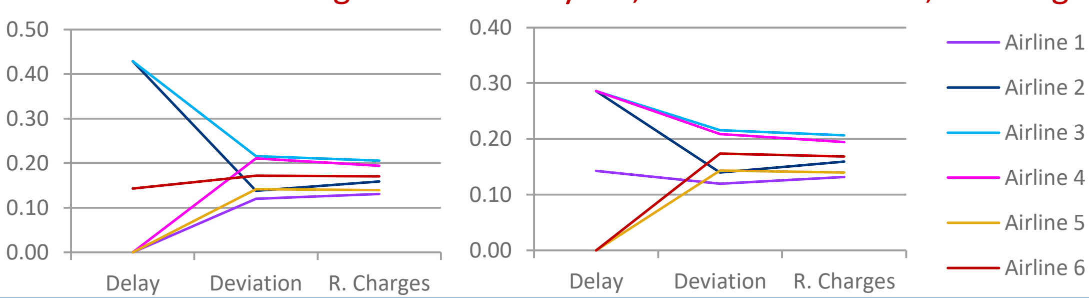
	Delay		Deviation		RouteCharges	
Airline 1	2	1	1805	1821	1387	1361
Airline 2	0	1	2088	2095	1676	1640
Airline 3	0	0	3257	3278	2114	2122
Airline 4	0	0	3176	3179	1984	1977
Airline 5	0	0	2155	2162	1439	1455
Airline 6	0	0	2548	2543	1792	1800

Minimum Deviation. Total: Delay = 11, Deviation = 14936, R. Charges = 10590



	Delay		Deviation		RouteCharges	
Airline 1	0	0	1795	1795	1369	1369
Airline 2	3	2	2077	2077	1698	1698
Airline 3	2	2	3237	3237	2189	2189
Airline 4	2	3	3167	3167	2032	2032
Airline 5	1	2	2136	2136	1464	1464
Airline 6	2	2	2524	2524	1838	1838

Minimum Route Charges. Total: Delay = 7, Deviation = 15243, R. Charges = 10173

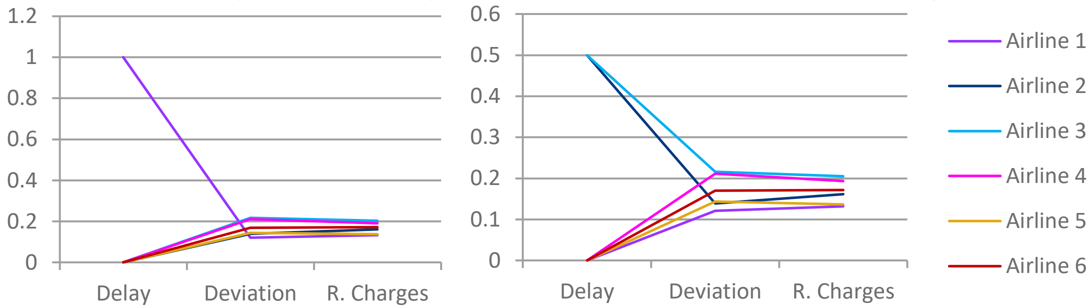


	Delay		Deviation		RouteCharges	
Airline 1	0	1	1837	1819	1335	1337
Airline 2	3	2	2115	2127	1619	1620
Airline 3	3	2	3302	3290	2090	2103
Airline 4	0	2	3224	3179	1973	1977
Airline 5	0	0	2167	2185	1421	1420
Airline 6	1	0	2632	2643	1733	1716

OptiFrame for decisions support (11/17)

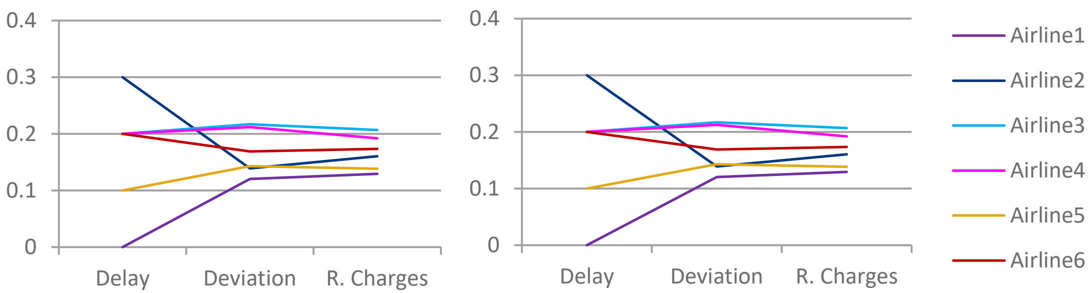
Instance I: Sector Restriction

Minimum Delay. Total: Delay = 2, Deviation = 150293 R. Charges = 10457



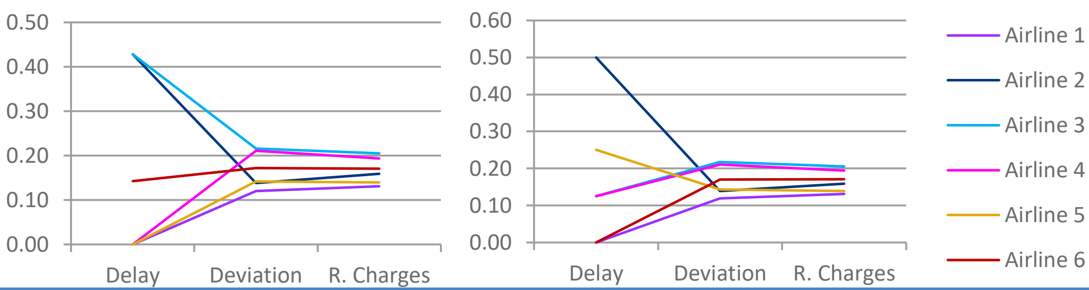
	Delay		Deviation		RouteCharges	
Airline 1	2	0	1805	1812	1387	1378
Airline 2	0	1	2088	2080	1676	1692
Airline 3	0	1	3257	3250	2114	2144
Airline 4	0	0	3176	3173	1984	2024
Airline 5	0	0	2155	2156	1439	1425
Airline 6	0	0	2548	2552	1792	1794

Minimum Deviation. Total: Delay = 10, Deviation = 14936, R. Charges = 10590



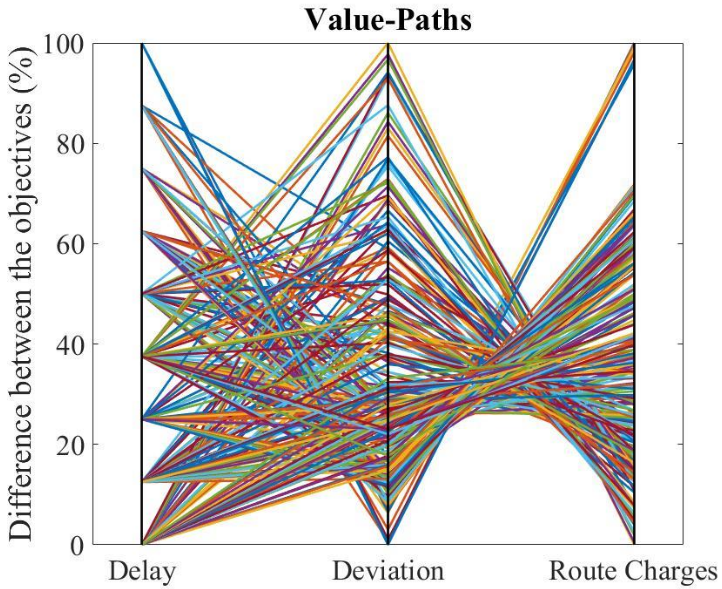
	Delay		Deviation		RouteCharges	
Airline 1	0	0	1795	1795	1369	1369
Airline 2	3	3	2077	2077	1698	1698
Airline 3	2	2	3237	3237	2189	2189
Airline 4	2	2	3167	3167	2032	2032
Airline 5	1	1	2136	2136	1464	1464
Airline 6	2	2	2524	2524	1838	1838

Minimum Route Charges. Total: Delay = 8, Deviation = 15278, R. Charges = 10170

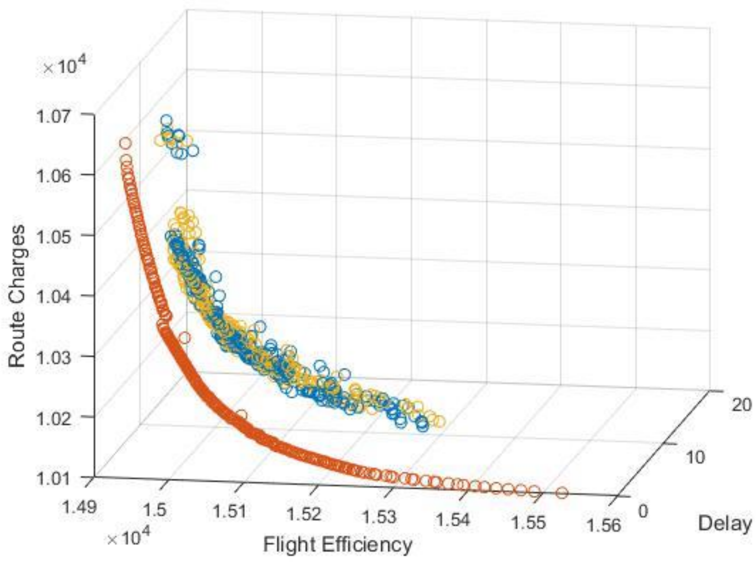


	Delay		Deviation		RouteCharges	
Airline 1	0	0	1837	1819	1335	1337
Airline 2	3	4	2115	2130	1619	1614
Airline 3	3	1	3302	3318	2090	2089
Airline 4	0	1	3224	3221	1973	1974
Airline 5	0	2	2167	2196	1421	1416
Airline 6	1	0	2632	2594	1733	1740

Application of the FDR priorities scheme (1/2)

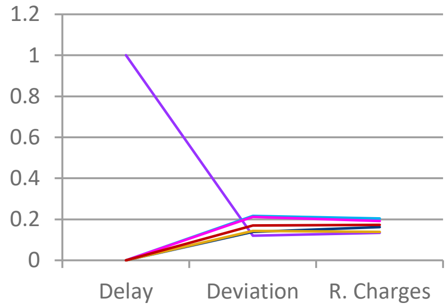


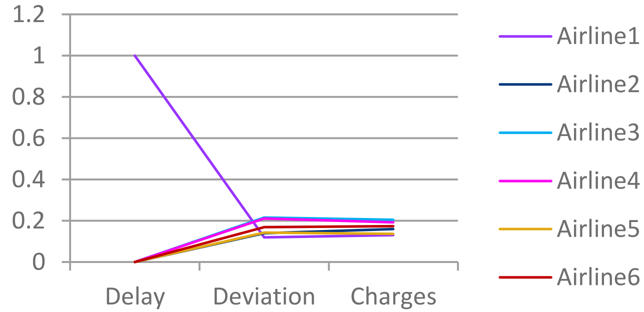
- Pareto Frontier
- Efficient frontier – no priorities
- Efficient frontier – FDR



Application of the FDR priorities scheme (2/2)

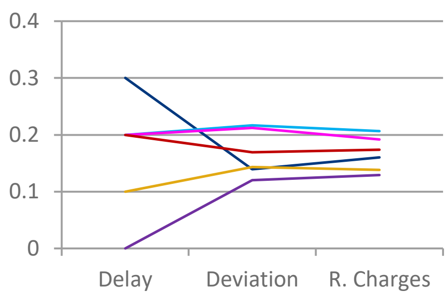
Minimum Delay. Total: Delay = 2, Deviation = 15093 R. Charges = 10321

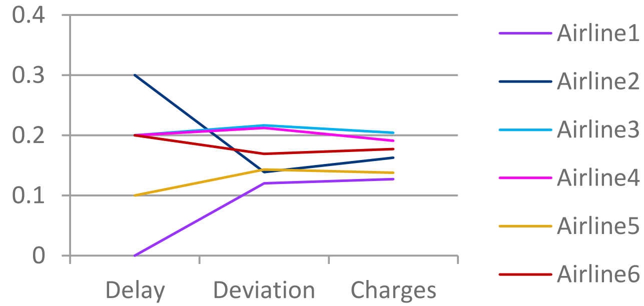




	Delay		Deviation		RouteCharges	
Airline 1	2	2	1805	1813	1387	1349
Airline 2	0	0	2088	2112	1676	1646
Airline 3	0	0	3257	3264	2114	2114
Airline 4	0	0	3176	3191	1984	1989
Airline 5	0	0	2155	2149	1439	1419
Airline 6	0	0	2548	2564	1792	1804

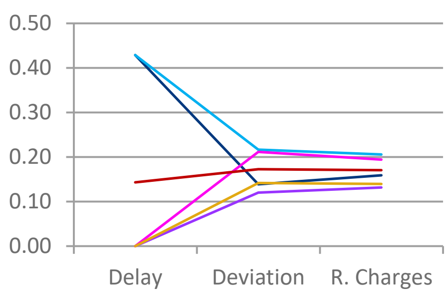
Minimum Deviation. Total: Delay = 10, Deviation = 14936, R. Charges = 10590

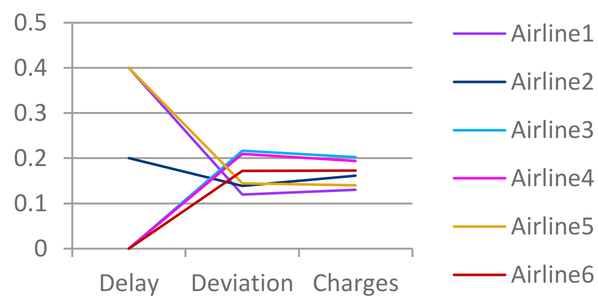




	Delay		Deviation		RouteCharges	
Airline 1	0	0	1795	1795	1369	1369
Airline 2	3	3	2077	2077	1698	1698
Airline 3	2	2	3237	3237	2189	2189
Airline 4	2	2	3167	3167	2032	2032
Airline 5	1	1	2136	2136	1464	1464
Airline 6	2	2	2524	2524	1838	1838

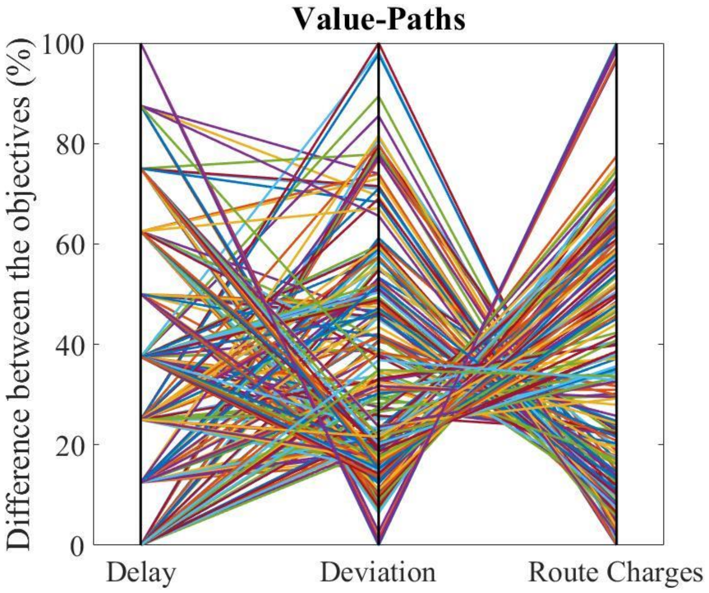
Minimum R. Charges. Total: Delay = 5, Deviation = 15331, R. Charges = 10168

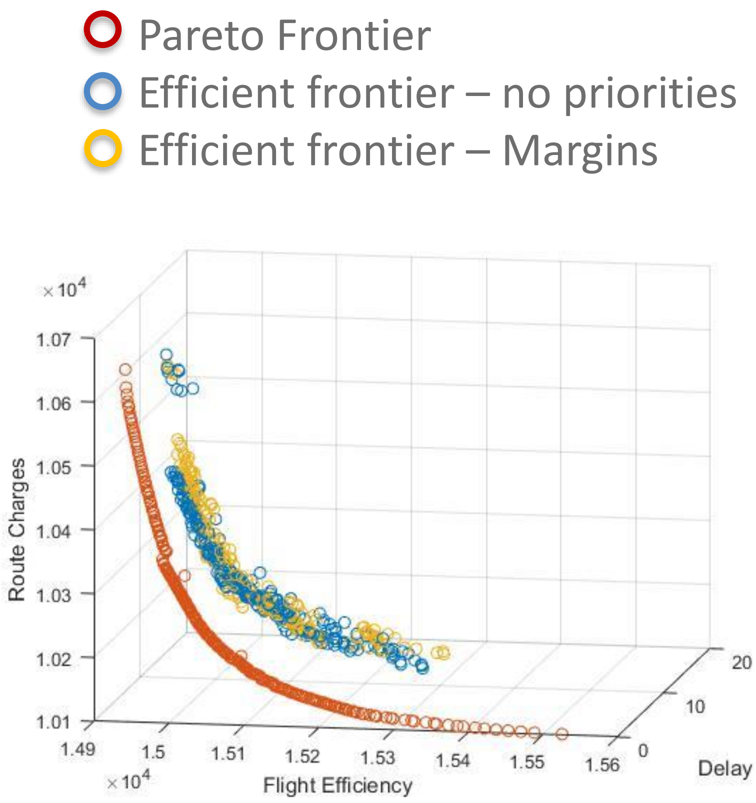




	Delay		Deviation		RouteCharges	
Airline 1	0	2	1837	1833	1335	1321
Airline 2	3	1	2115	2122	1619	1640
Airline 3	3	0	3302	3317	2090	2061
Airline 4	0	0	3224	3212	1973	1970
Airline 5	0	2	2167	2210	1421	1422
Airline 6	1	0	2632	2637	1733	1754

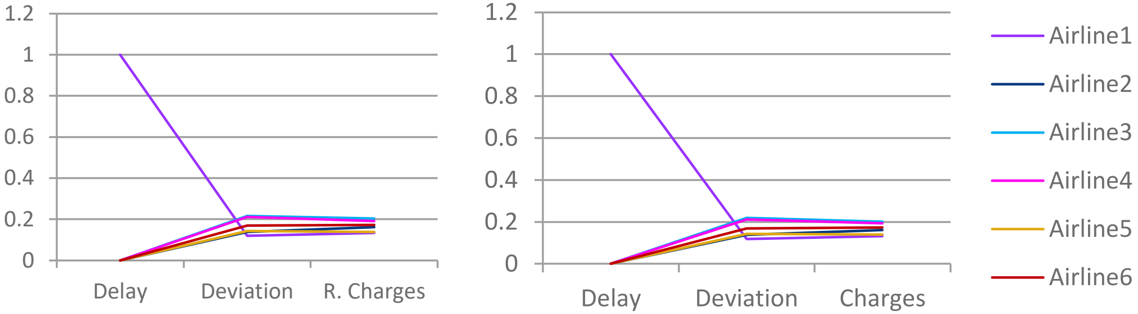
Application of the "Margins" priorities scheme (1/2)





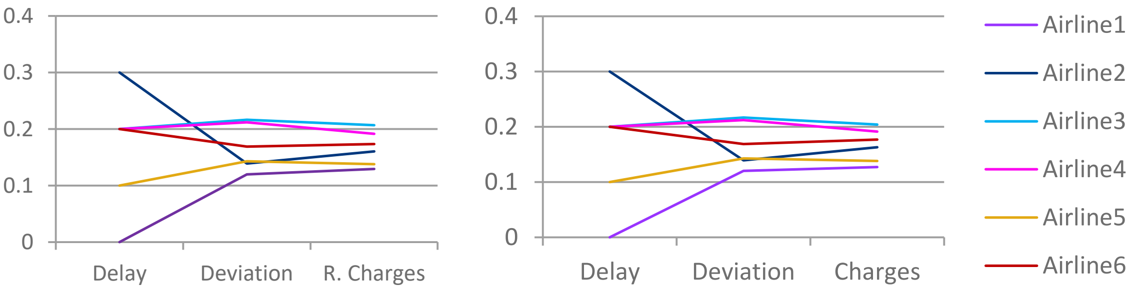
Application of the "Margins" priorities scheme (2/2)

Minimum Delay. Total: Delay = 2, Deviation = 15249 R. Charges = 10246



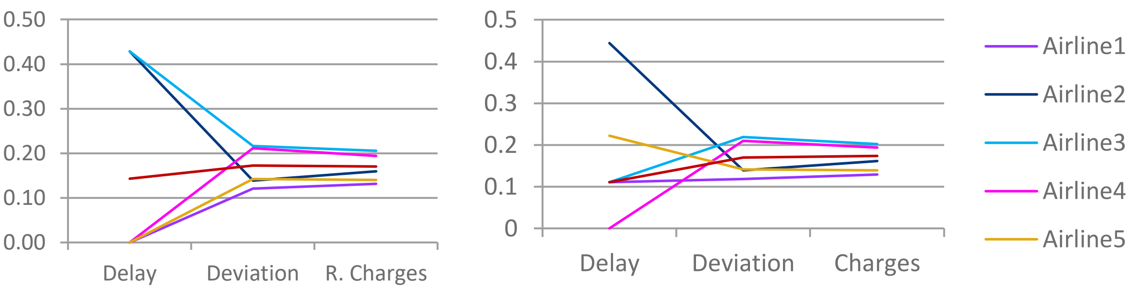
	Delay		Deviation		RouteCharges	
Airline 1	2	2	1805	1813	1387	1351
Airline 2	0	0	2088	2112	1676	1649
Airline 3	0	0	3257	3333	2114	2056
Airline 4	0	0	3176	3237	1984	1974
Airline 5	0	0	2155	2184	1439	1435
Airline 6	0	0	2548	2570	1792	1781

Minimum Deviation. Total: Delay = 10, Deviation = 14936, R. Charges = 10590



	Delay		Deviation		RouteCharges	
Airline 1	0	0	1795	1795	1369	1369
Airline 2	3	3	2077	2077	1698	1698
Airline 3	2	2	3237	3237	2189	2189
Airline 4	2	2	3167	3167	2032	2032
Airline 5	1	1	2136	2136	1464	1464
Airline 6	2	2	2524	2524	1838	1838

Minimum R. Charges. Total: Delay = 9, Deviation = 15237, R. Charges = 10186



	Delay		Deviation		RouteCharges	
Airline 1	0	1	1837	1813	1335	1319
Airline 2	3	4	2115	2127	1619	1645
Airline 3	3	1	3302	3340	2090	2063
Airline 4	0	0	3224	3204	1973	1971
Airline 5	0	2	2167	2160	1421	1418
Airline 6	1	1	2632	2593	1733	1770

Conclusions

- The OptiFrame framework is able to solve the ATFM problem with preferences and priorities incorporated.
- Recent priorities mechanisms are taking into account via a pre-processing phase.
- Computational results provide a set of non-dominated solutions, among which Stakeholders can identify the most suitable solution.
- A set of a posteriori criteria must be identified to select the solution to be implemented.

Duscussion

1. Data availability for further testing the framework
2. Other potential prioritization schemes
3. How the choice of the preferred solution should be made?
4. How useful is the presentation of information at different level of details?
5. Do you see any barrier for the implementation of the proposed approach?

OptiFrame for Trajectory Based Operations (TBO) Decisions Support

Thank you very much for your attention!

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