ISTOP

INTER AIRLINE SLOT TRADING OFFER PROVIDER

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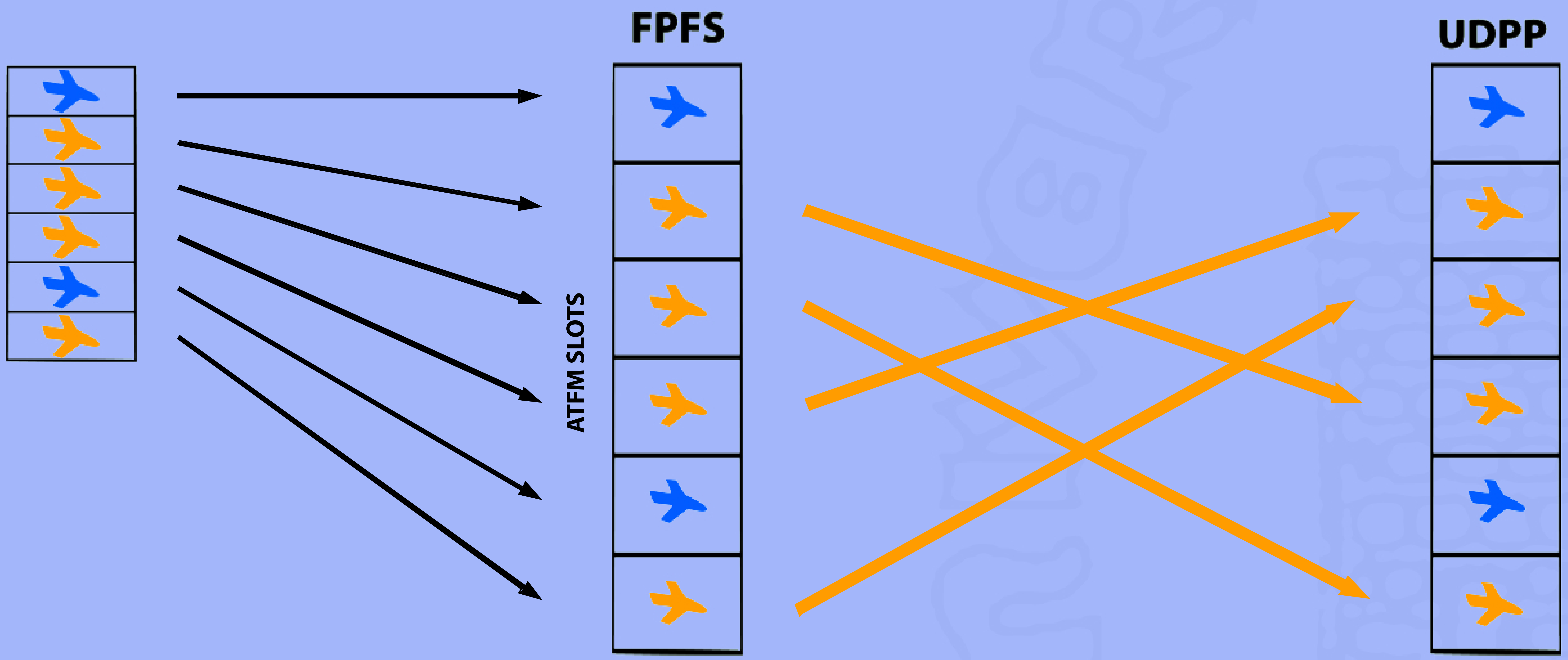
UNIVERSITÀ
DEGLI STUDI
DI TRIESTE

OBJECTIVE: REDUCE DELAY COST IMPACT

SCENARIO: SINGLE HOTSPOT
SINGLE AIRPORT



CHARACTERISTICS:

No cost information

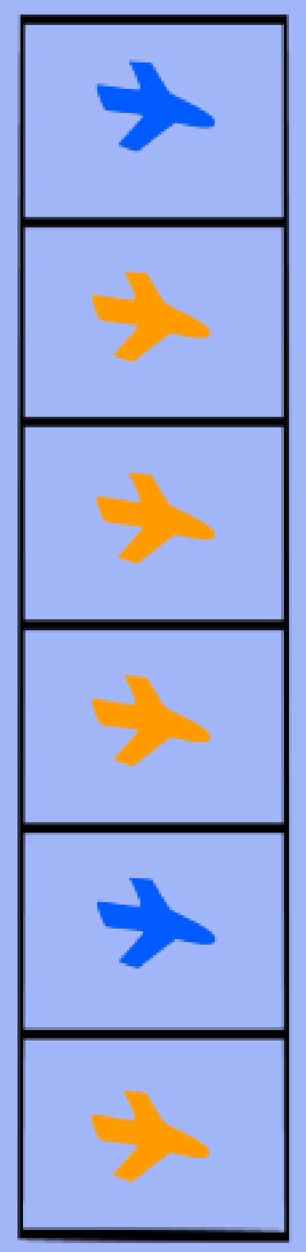
No negative impact on other AUs

Provides a what if scenario

Practical and simple for the AUs

OBJECTIVE: REDUCE DELAY COST IMPACT

UDPP



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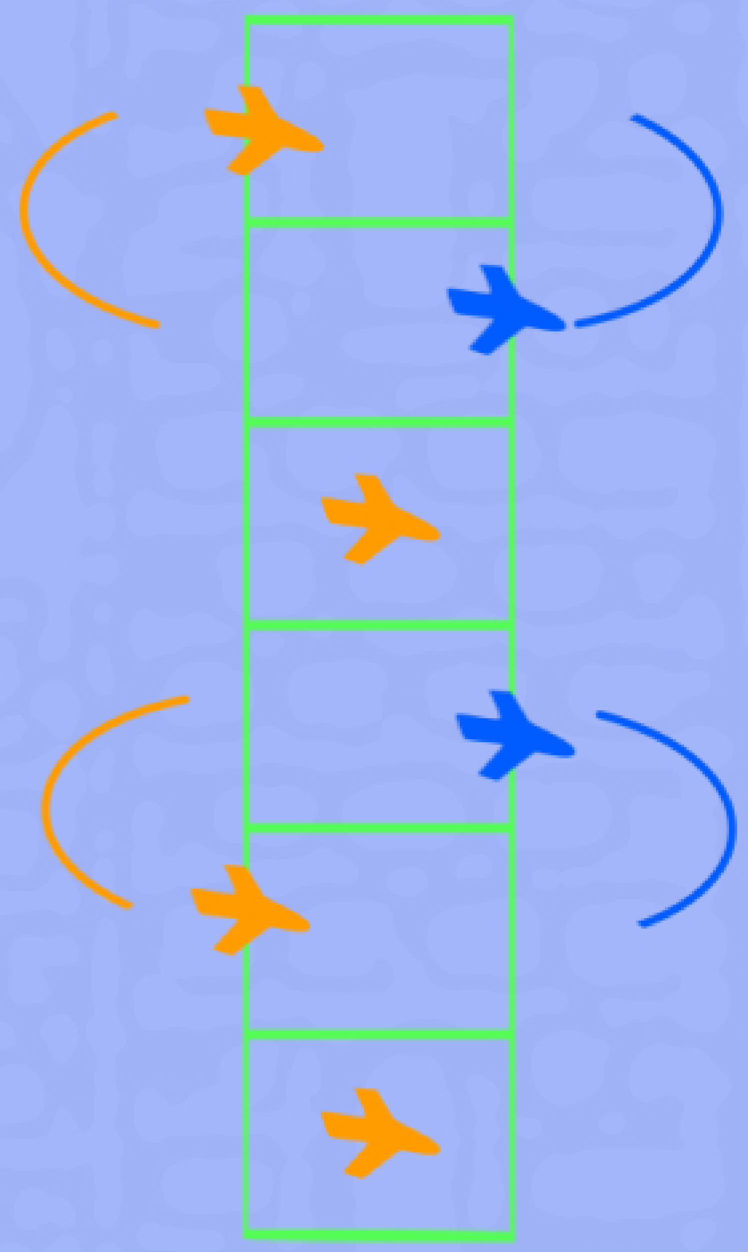
MARKET MECHANISM



HOW MUCH CAN WE IMPROVE?

Assumption

For any flight f its true cost function $\mathcal{C}_f$ exists and it is known by the NM.

FPFS

FLIGHT	COST PER MINUTE	DELAY
A0	8	0
C1	1	1
B2	6	2
A3	5	3
B4	10	4
A5	7	5
B6	4	6
C7	2	7
B8	10	8
C9	3	9
A10	21	10
A11	9	11
B12	11	12
C13	2	13
A14	15	14

$x_{ij} \in \{0, 1\}$ **flight i (the *i*-th according to the current schedule) is assigned to slot *j***

HOW MUCH CAN WE IMPROVE?

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C13	2	13
A14	15	14

Assumption

For any flight f its true cost function $\mathcal{C}_f$ exists and it is known by the NM.

Constraint

All flights have to be assigned:

$$\sum_{j \in S} x_{ij} = 1 \quad \forall i \in F$$

Constraint

All flights cannot arrive before their ETA:

$$\sum_{j \in S} x_{ij} = 0 \quad \forall f \in F, \quad \forall j : j < ETA(i)$$

Constraint

A slot can host at most one flight:

$$\sum_{i \in F} x_{ij} <= 1 \quad \forall j \in S$$

Objective

The target is to minimise the overall costs:

$$OBJ := \min \sum_{i \in F, j \in S} x_{ij} \cdot \mathcal{C}_f(d_{ij})$$

MINCOST

FLIGHT	COST PER MINUTE	DELAY
A0	8	0
B2	6	0
B4	10	1
A3	5	2
A5	7	3
B8	10	2
A10	21	2
A11	9	3
B12	11	4
A14	15	4
B6	4	14
C9	3	13
C7	2	17
C13	2	13
C1	1	27

Castelli, Pesenti, Ranieri (2011)

HOW MUCH CAN WE IMPROVE?

FPFS

FLIGHT	COST PER MINUTE	DELAY
A0	8	0
C1	1	1
B2	6	2
A3	5	3
B4	10	4
A5	7	5
B6	4	6
C7	2	7
B8	10	8
C9	3	9
A10	21	10
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B12	11	12
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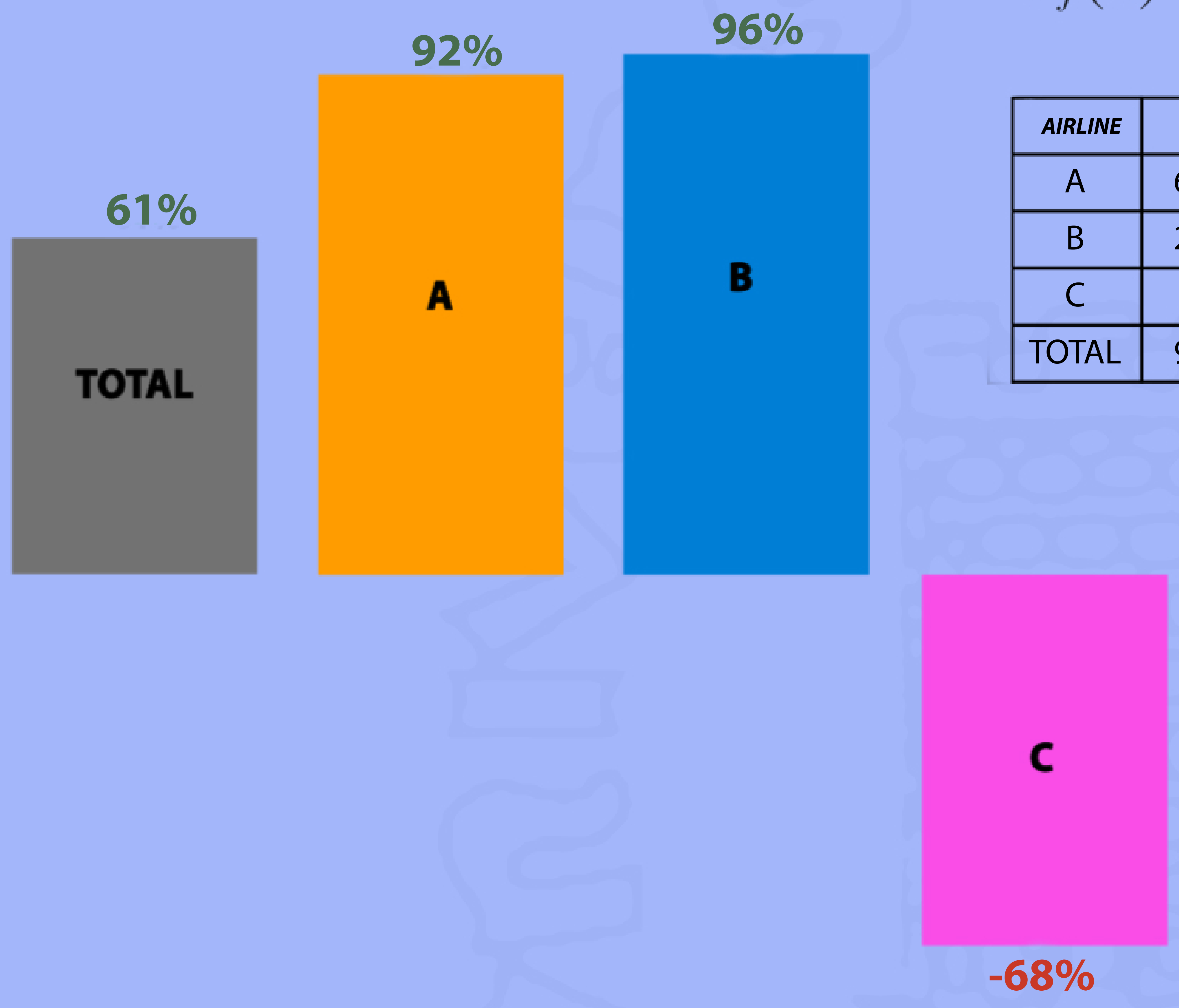
COST REDUCTION



Biased toward high cost flights

$$C_f(d) = c_f \cdot d^2$$

AIRLINE	FPFS	MINCOST
A	6349	513
B	2552	1000
C	680	2152
TOTAL	9581	3665

MINCOST

FLIGHT	COST PER MINUTE	DELAY
A0	8	0
B2	6	0
B4	10	1
A3	5	2
A5	7	3
B8	10	2
A10	21	2
A11	9	3
B12	11	4
A14	15	4
B6	4	14
C9	3	13
C7	2	17
C13	2	13
C1	1	27

HOW MUCH CAN WE IMPROVE?

FPFS

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C9	3	9
A10	21	10
A11	9	11
B12	11	12
C13	2	13
A14	15	14

NO NEGATIVE IMPACT

Constraint

Each airline A must decrease or keep the same costs w.r.t. the FPFS:

$$\sum_{f \in A} f_{ij} * \mathcal{C}_{f^a}(d_{ij}) \leq \sum_{f \in A} \mathcal{C}_f(d_{ii})$$

NNB

FLIGHT	COST PER MINUTE	DELAY
A0	8	0
B2	6	0
B4	10	0
C1	1	5
A5	7	3
B8	10	2
A10	21	2
C9	3	5
B12	11	4
C7	2	11
A14	15	6
A11	9	11
A3	5	21
C13	2	13
B6	4	22

HOW MUCH CAN WE IMPROVE?

FPFS

FLIGHT	*COST PER MINUTE*	*DELAY*
A0	8	0
C1	1	1
B2	6	2
A3	5	3
B4	10	4
A5	7	5
B6	4	6
C7	2	7
B8	10	8
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B12	11	12
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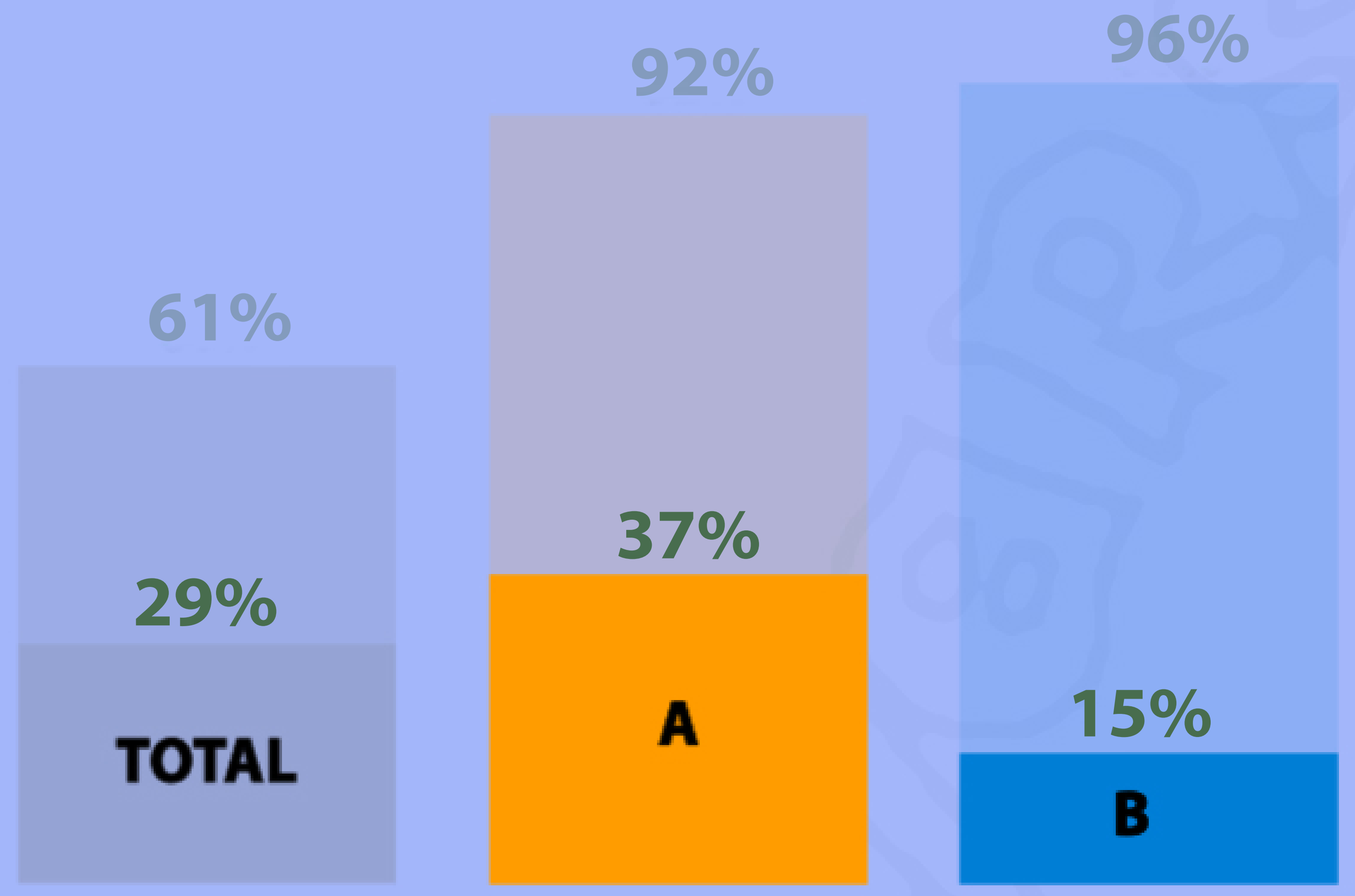
COST REDUCTION



AIRLINE	*INITIAL COST*	*FINAL COST*
A	6349	3981
B	2552	2152
C	680	680
TOTAL	9581	6813

STILL NO FAIRNESS

AN UPPERBOUND TO REDUCTION

POSSIBLE METRIC TO COMPARE MODELS

NNB

FLIGHT	*COST PER MINUTE*	*DELAY*
A0	8	0
B2	6	0
B4	10	0
C1	1	5
A5	7	3
B8	10	2
A10	21	2
C9	3	5
B12	11	4
C7	2	11
A14	15	6
A11	9	11
A3	5	21
C13	2	13
B6	4	22

NM as offer provider

- PRIORITISATION

↓

UDPP

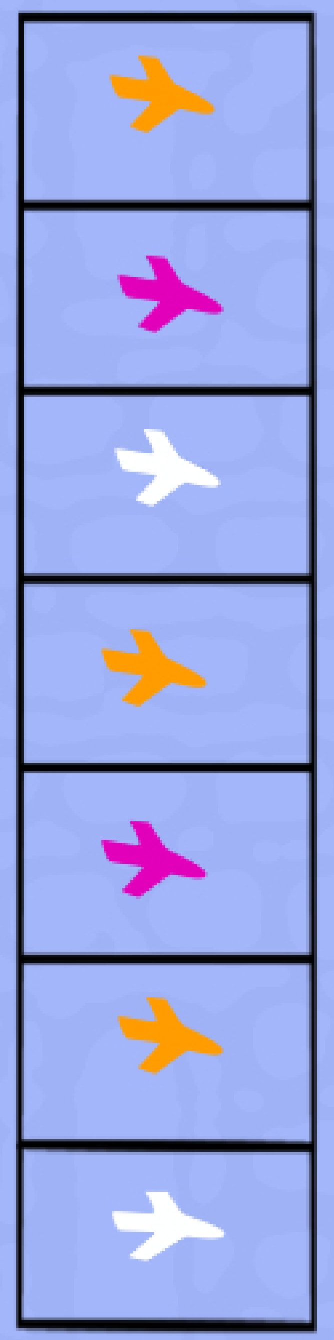
AIRLINE

NETWORK MANAGER

AIRLINE

AIRLINE

Improve UDPP solution
No cost information
No negative impact on other AUs
Improves CDM
Provides a *what if scenario*
Practical and simple for the AUs



NM as offer provider

PARAMETRISATION

PRIORITISATION

UDPP

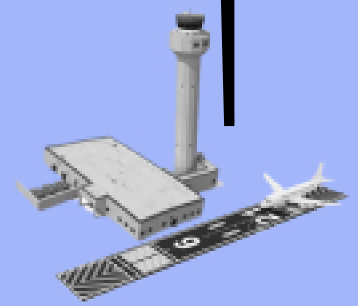
COMPUTE
SLOT SWAP OFFERS

1 OFFER 1

2 OFFER 2

AIRLINE

2



NETWORK
MANAGER

1 2

1

AIRLINE

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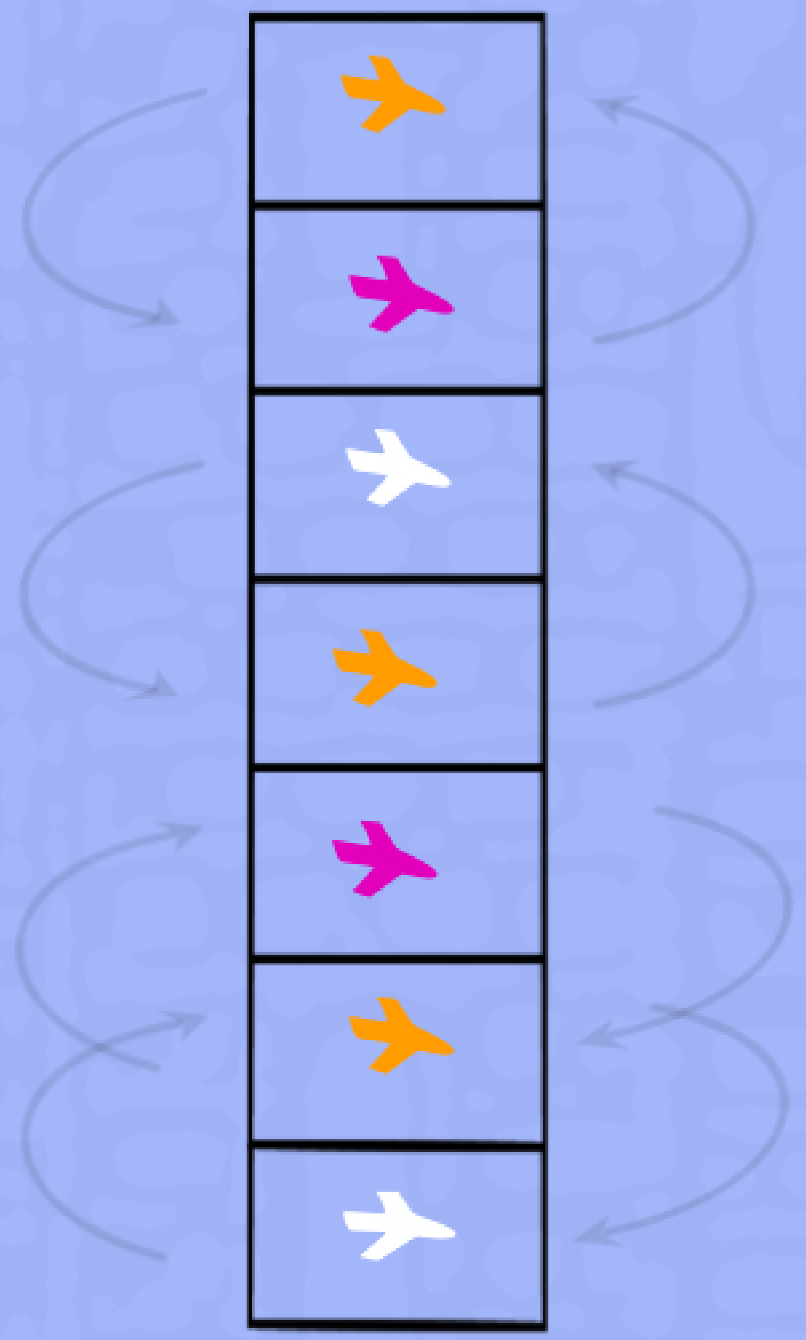
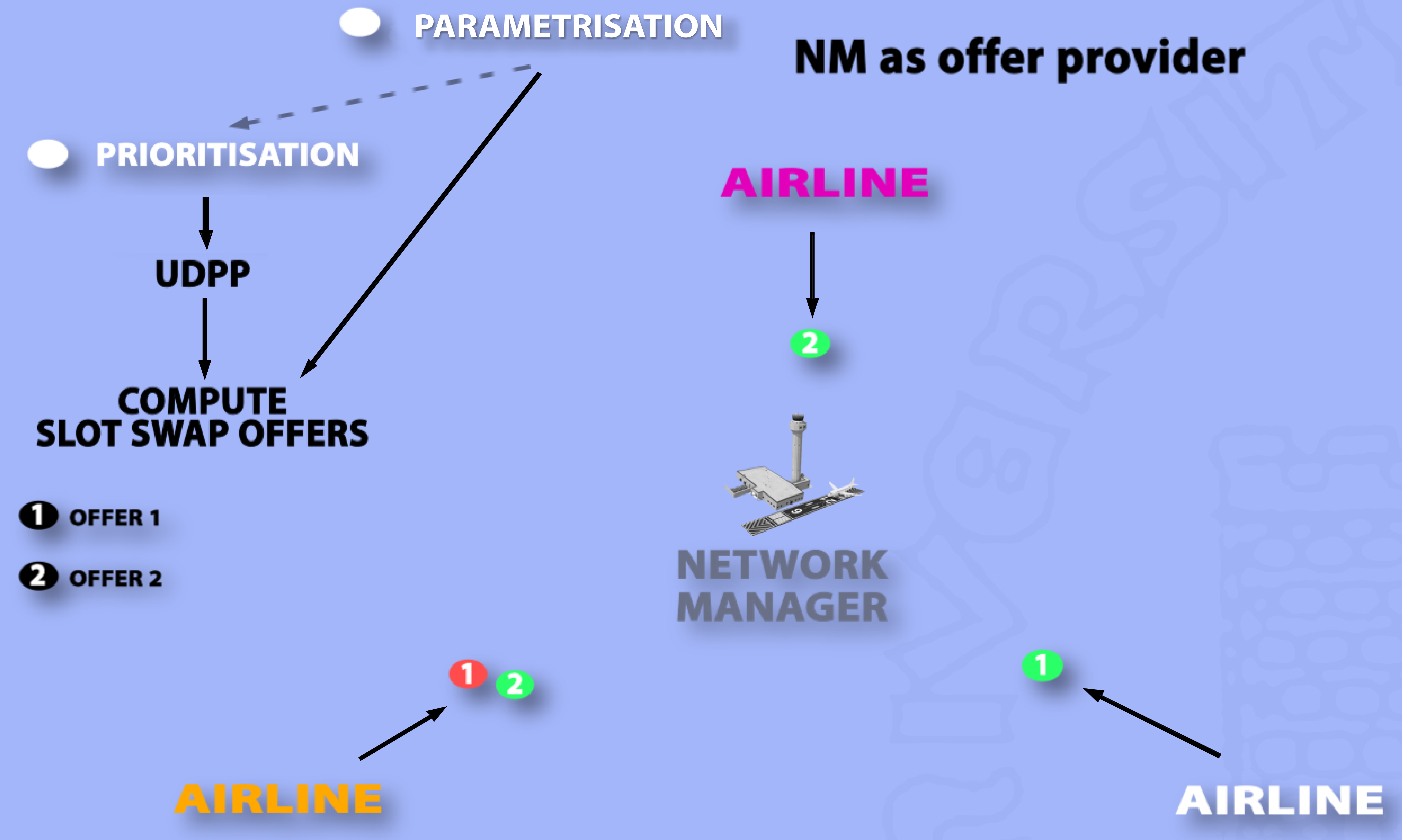


NM as offer provider



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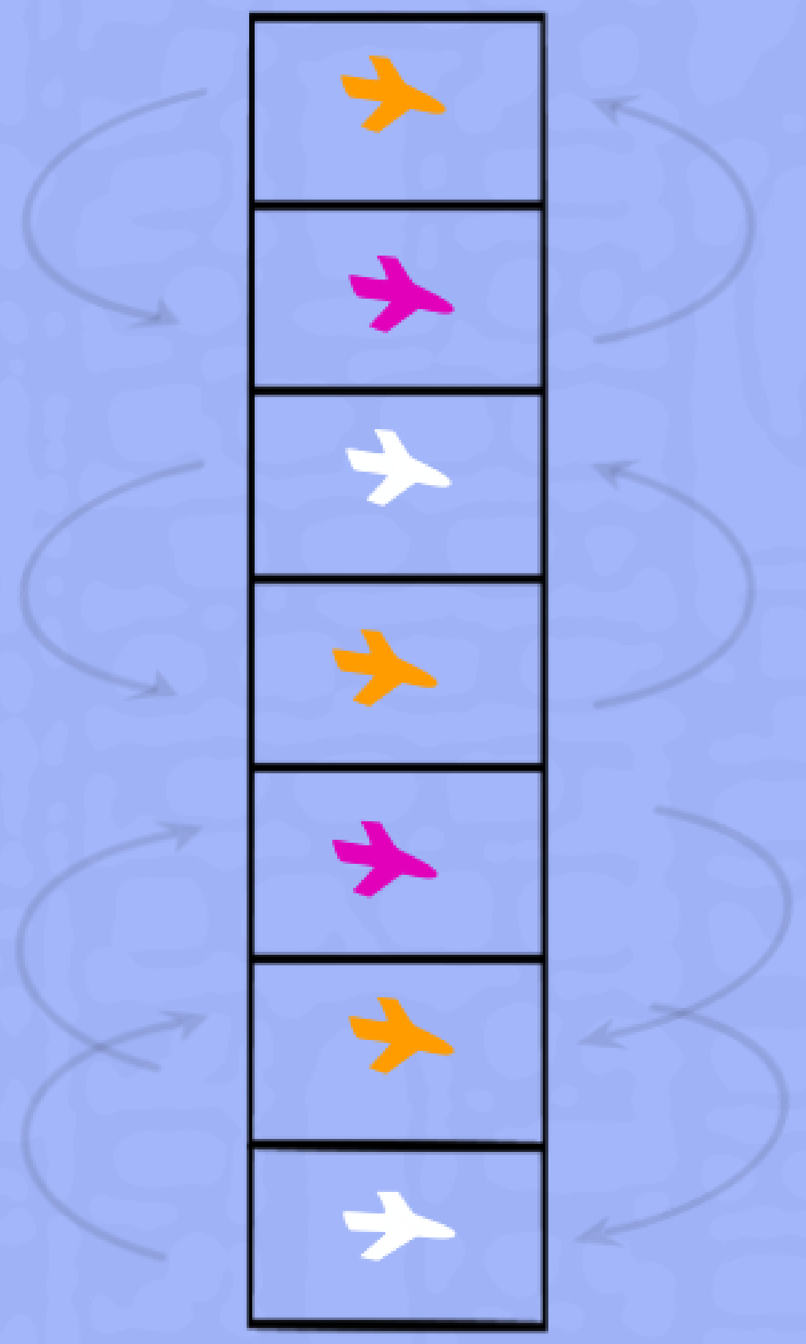

NM as offer provider

PARAMETRISATION

PRIORITISATION

UDPP

COMPUTE
SLOT SWAP OFFERS

1 OFFER 1

2 OFFER 2

AIRLINE

NETWORK
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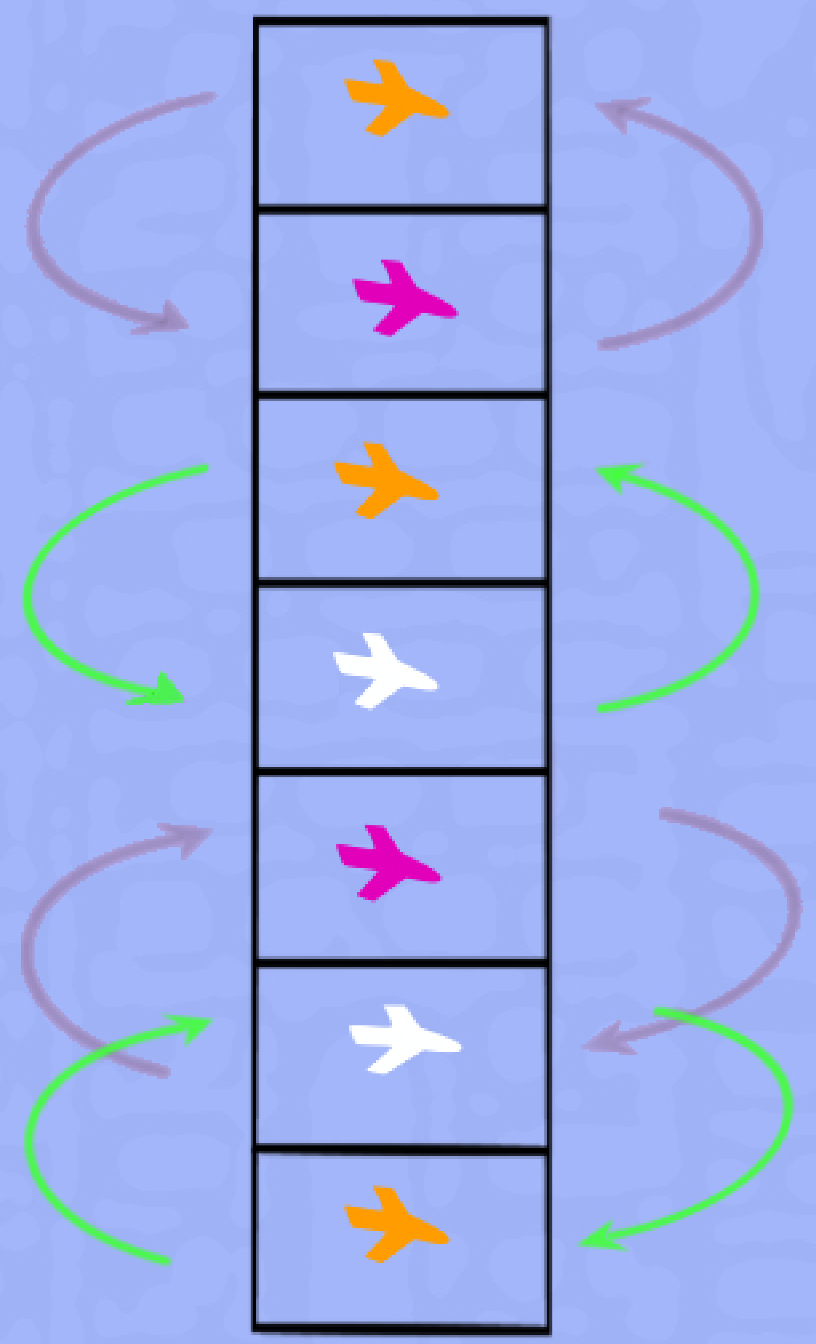
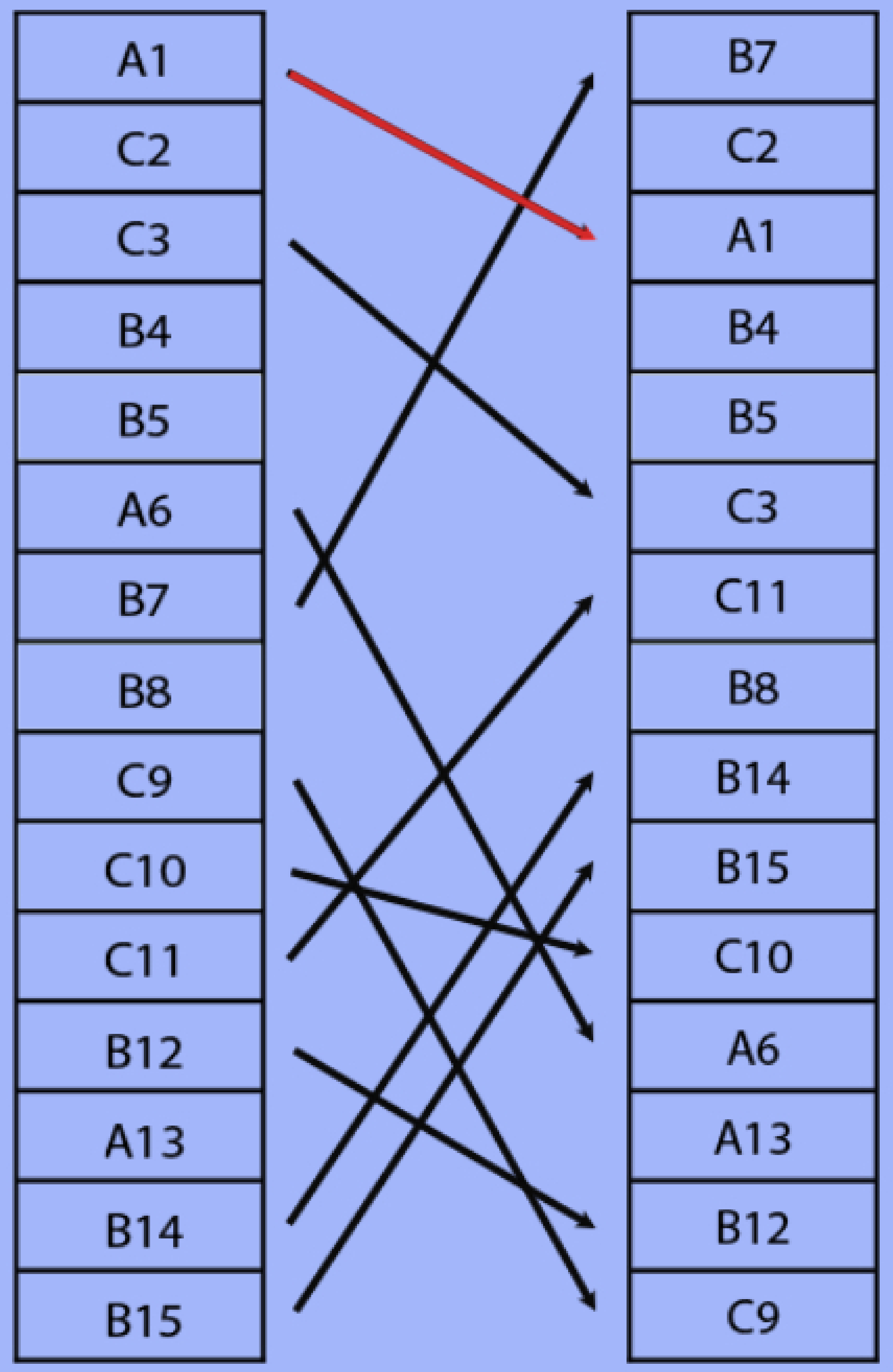
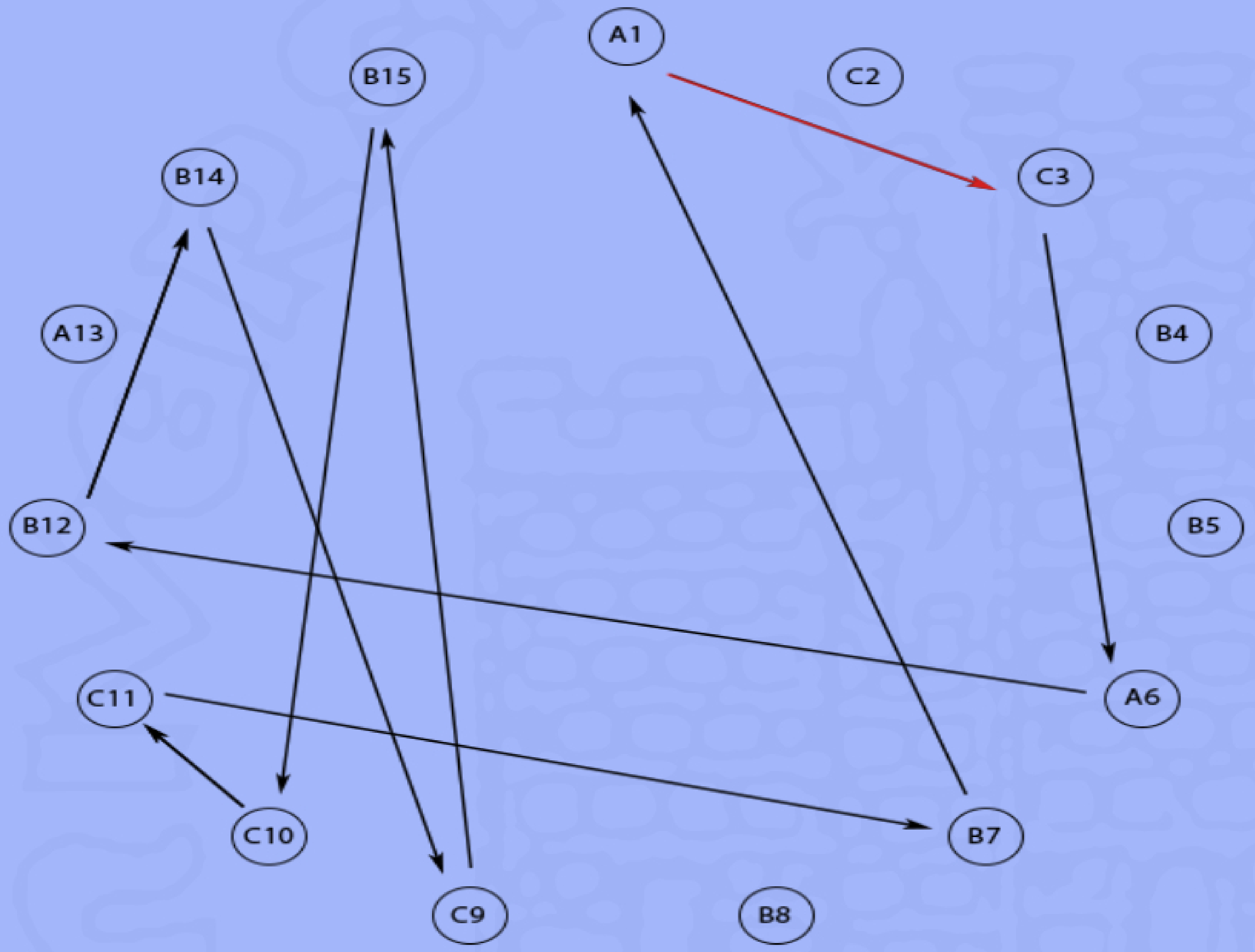
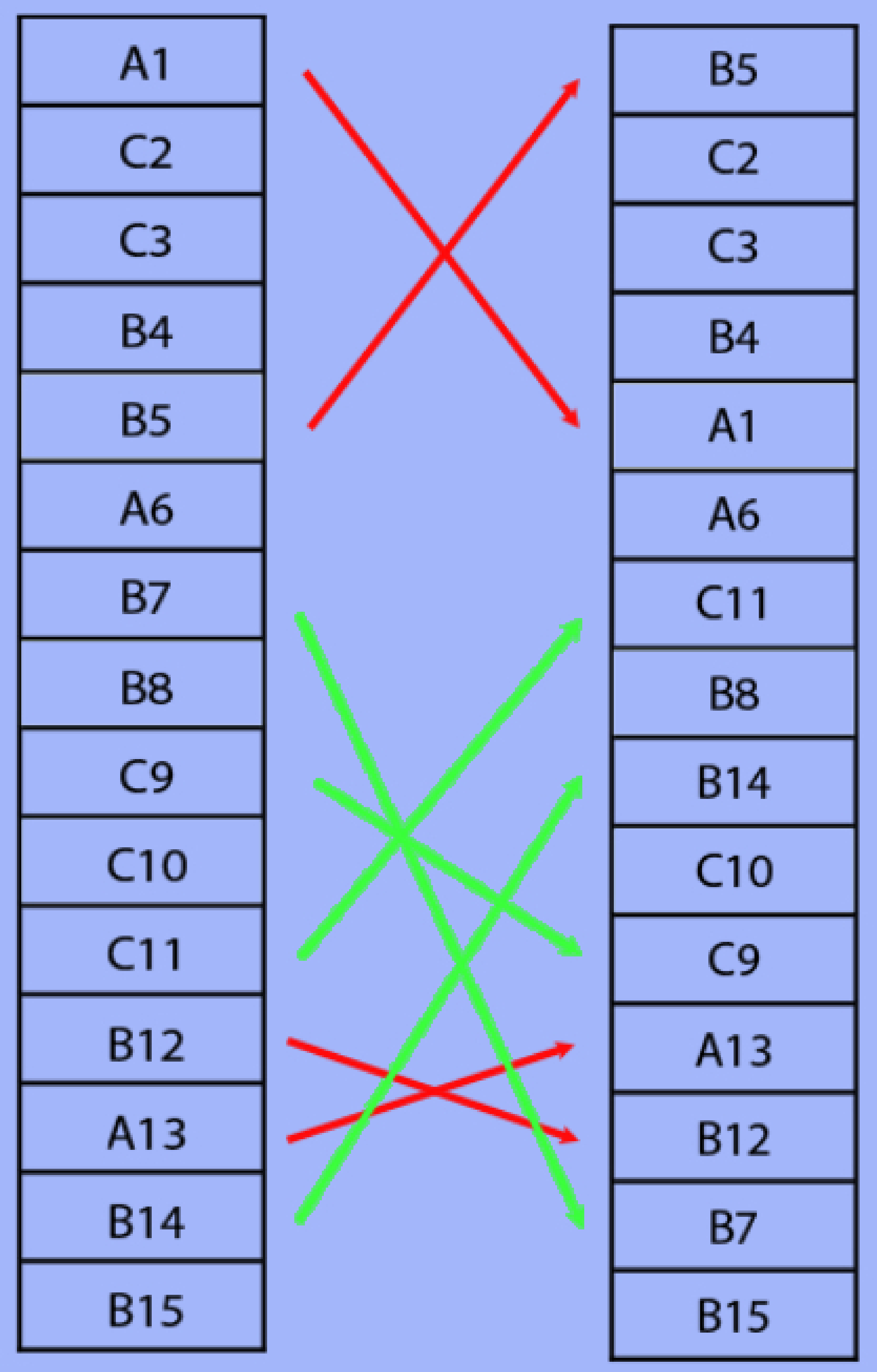


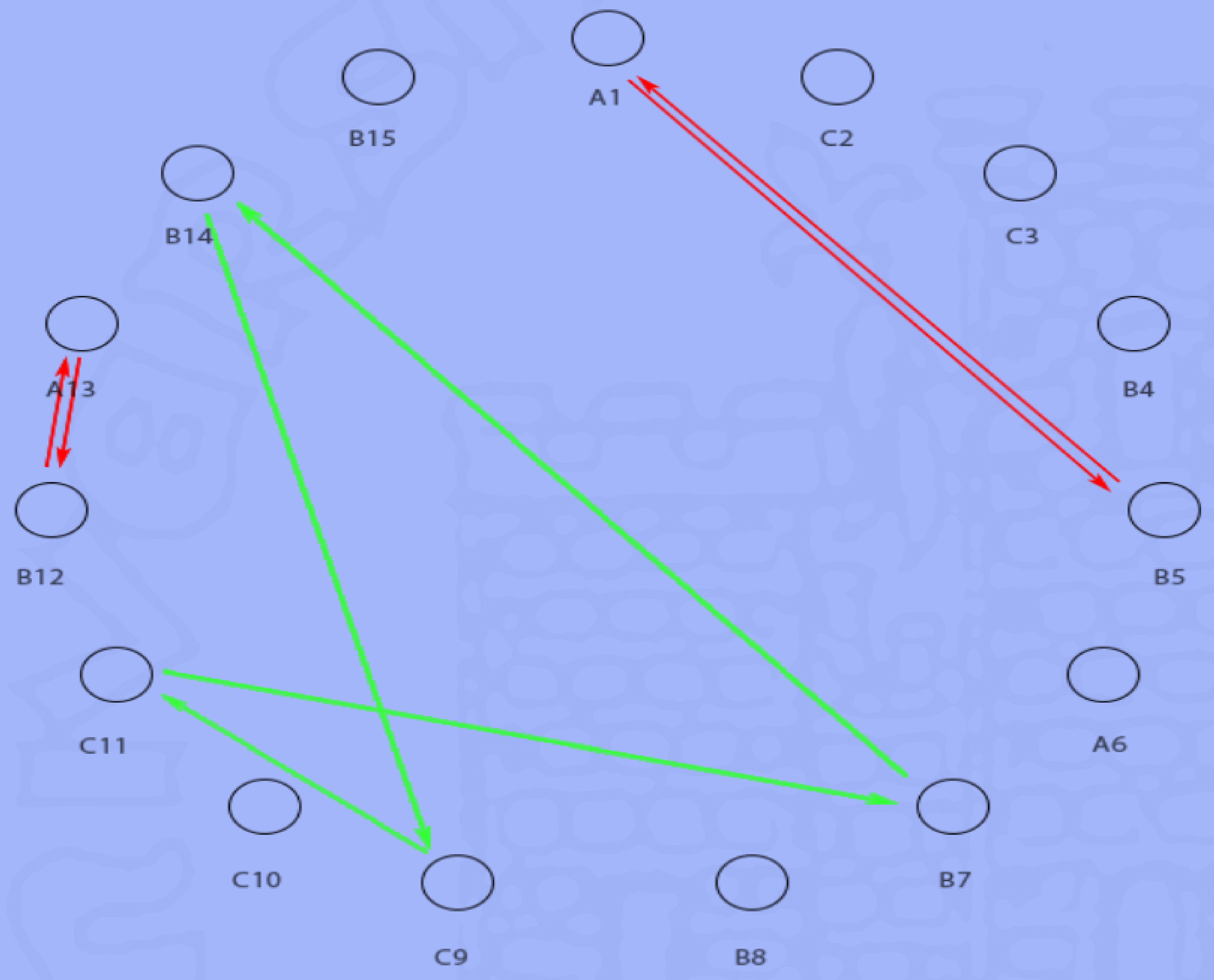
TRADING GRAPH INTERPRETATION





SOLUTION





Limit the number of airlines and flights for each offer

HOW TO COMPUTE OFFERS part 1

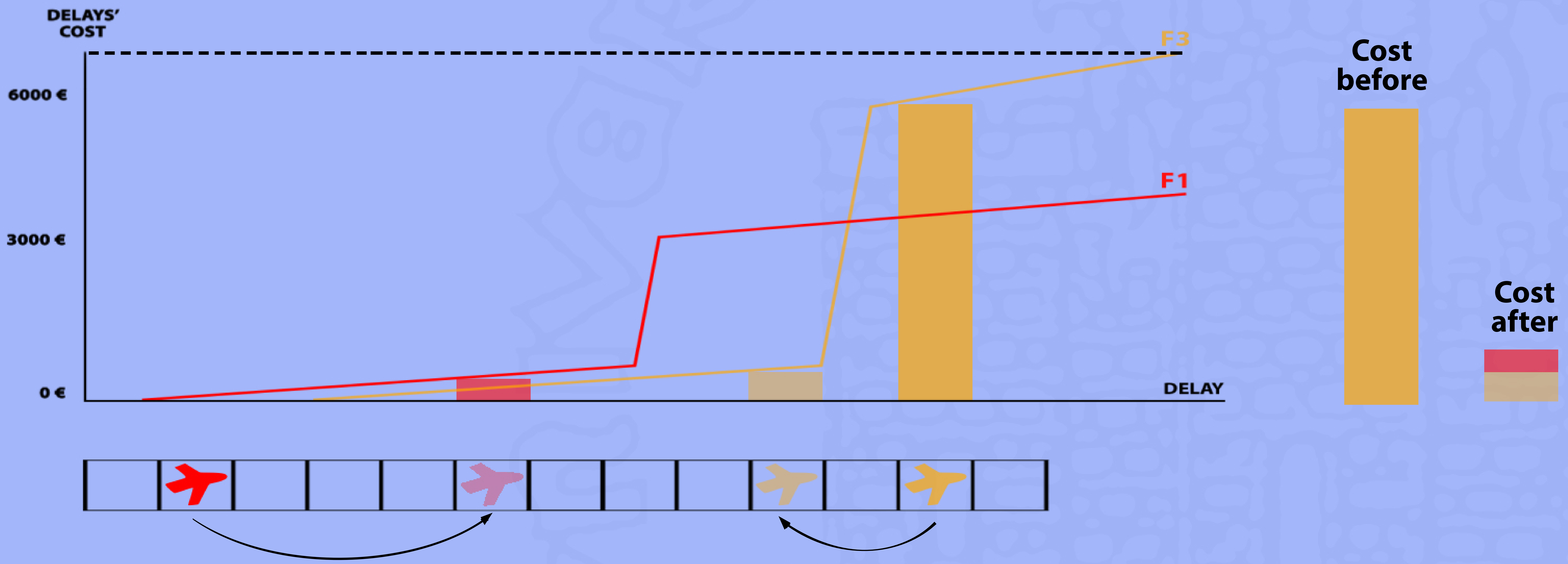
AT DISPOSAL

Cost function PARAMETRISATION

Reproduce the SHAPE of the cost function

GOAL

Extimate the relative importance of flights within the airlines



HOW TO COMPUTE OFFERS part 1

AT DISPOSAL

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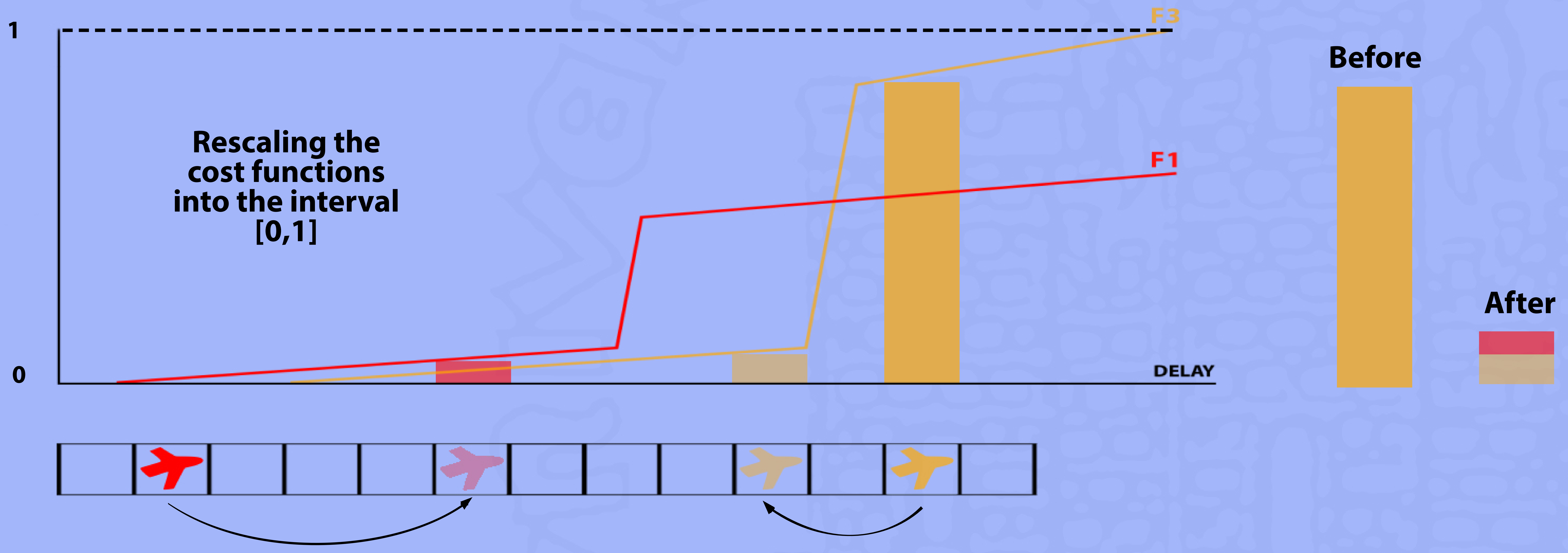


HOW TO SELECT OFFERS

Minimise the *Penalty score function*

Objective

$$OBJ := \min \sum_{i,j \in S} \mathcal{PF}(p_i, d_{ij}) \cdot x_{ij}$$

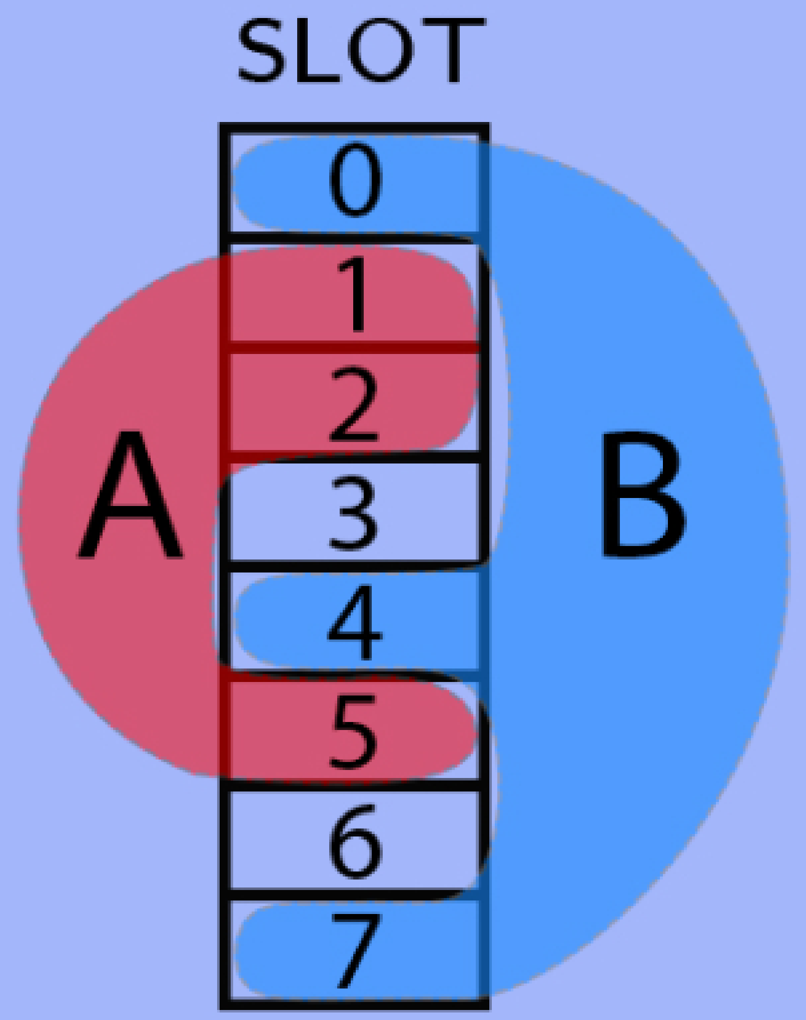
The model is NOT anymore biased to favour high cost flights

HOW TO COMPUTE OFFERS part 2

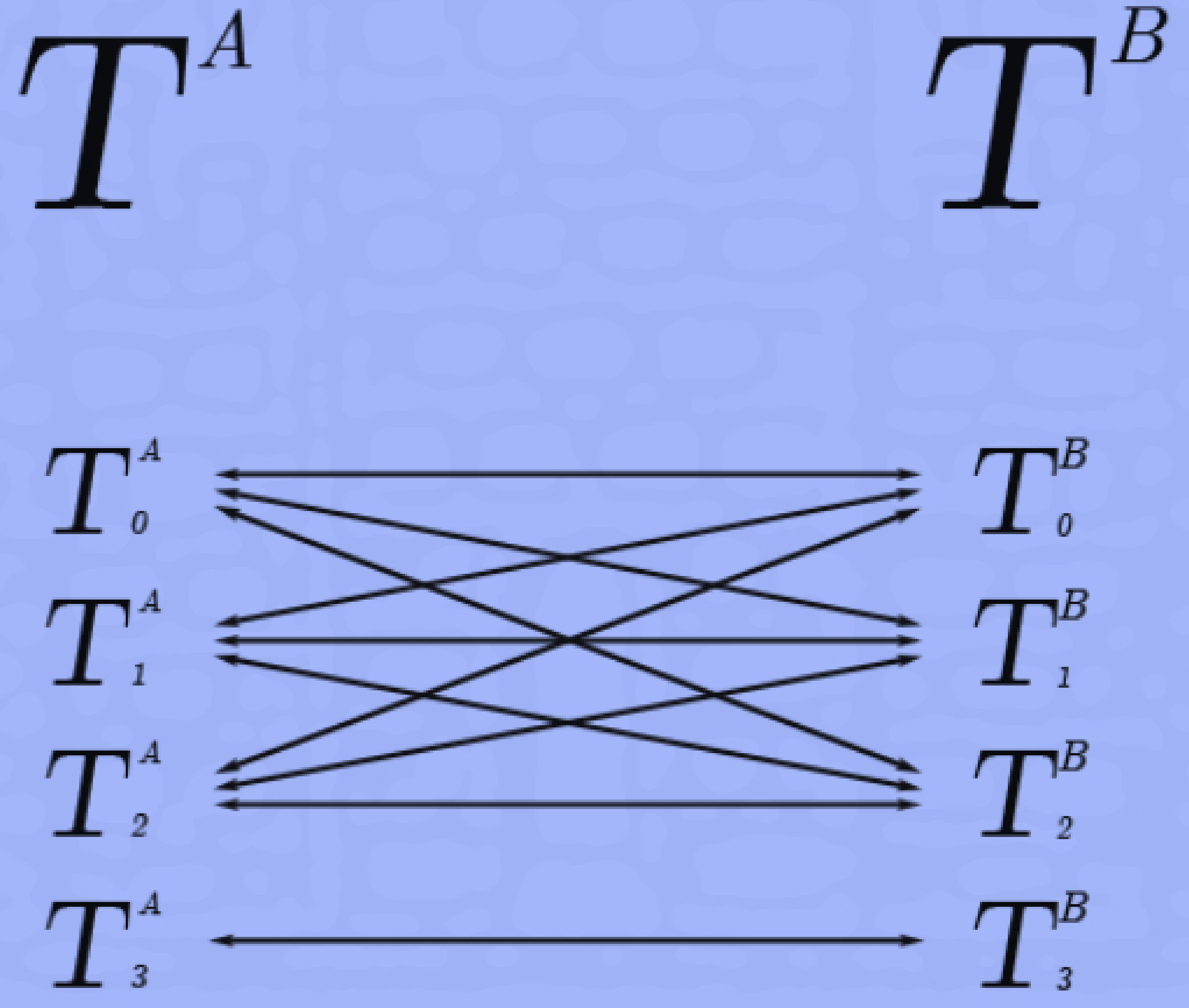
Definition

An **offer** consists of an exchange of tuples of slots of the same size, between two airlines; so if T^k_s belongs to A_k and $T^w_{s'}$ belongs to A_w, the offer of exchanging T^k_s and $T^w_{s'}$ can be represented as:

$$T^k_s \sim T^w_{s'} \quad \longleftrightarrow \quad o^{kw}_{ss'} \in \{0,1\} \text{ offer variables}$$



T^A		T^B	
{0,4}	T^A_0	{1,2}	T^B_0
{0,7}	T^A_1	{1,5}	T^B_1
{4,7}	T^A_2	{2,5}	T^B_2
{0,4,7}	T^A_3	{1,2,5}	T^B_3



ISTOP
INTER AIRLINE SLOT TRADING OFFER PROVIDER

Constraint

All flights have to be assigned either to their initial slot or to a slot owned by another airline

$$\sum_{j \notin A_k} x_{ij} + x_{ii} = 1 \quad \forall i \in A_k, \ \forall k \in \mathbb{A}$$

$$\sum_{j \in A_k,\ j \neq i} x_{ij} = 0 \quad \forall i \in A_k$$

Constraint

No flight can be assigned to a slot earlier than its expected arrival time

$$x_{ij} = 0 \quad \forall j \in S : \ j < ETA(i), \quad \forall i \in S$$

Constraint

All slots can host at most a single flight

$$\sum_{i \in S} x_{ij} \leq 1 \quad \forall j \in S$$

Constraint

If $x_{ij} = 1$, for some $j \neq i$, then it must exist a tuple, including flight i, that has been selected for some offer, which implies that the correspondent offer variable is equal to one:

$$\sum_{j \in S,\, j \neq i} x_{ij} = \sum_{k \in O(i)} o_k \quad \forall i \in S$$

Constraint

If an offer is activated the respective flights decision variables have to be equal to one:

$$\sum_{\substack{i \in T_s^k \\ j \in T_{s'}^w}} x_{ij} + \sum_{\substack{i \in T_s^k \\ j \in T_{s'}^w}} x_{ji} \ \geq \ 2 \cdot \left| \, T_s^k \sim T_{s'}^w \, \right| \cdot o_{ss'}^{kw}$$

$$\forall \, T_s^k \sim T_{s'}^w \in \mathcal{O}$$

No negative impact

$o_{ss'}^{kw} = 1$ the offer has been selected

Constraint

$$\sum_{\substack{i \in T_s^k \\ j \in T_{s'}^w}} x_{ij} \cdot \mathcal{PF}(p_i, d_{ij}) - (1 - o_{ss'}^{kw}) \cdot \mathcal{M} \leq \sum_{\substack{i \in T_s \\ j \in T_{s'}}} x_{ij} \cdot \mathcal{PF}(p_i, d_{ii}) - \varepsilon \quad \forall\, T_s^k \sim T_{s'}^w \in \mathcal{O};$$

$$\sum_{\substack{i \in T_s \\ j \in T_{s'}}} x_{ji} \cdot \mathcal{PF}(p_j, d_{ji}) - (1 - o_{ss'}^{kw}) \cdot \mathcal{M} \leq \sum_{\substack{i \in T_s^k \\ j \in T_{s'}^w}} x_{ji} \cdot \mathcal{PF}(p_j, d_{jj}) - \varepsilon \quad \forall\, T_s^k \sim T_{s'}^w \in \mathcal{O}$$

where $\mathcal{M} >> 0$ *and* $\varepsilon > 0$ *are appropriate dummy constants.*

No negative impact

$o_{ss'}^{kw} = 1$ the offer has been selected

Constraint

Penalty afer the swap **Penalty before the swap**

$$\sum_{\substack{i \in T_s^k \\ j \in T_{s'}^w}} x_{ij} \cdot \mathcal{PF}(p_i, d_{ij}) \leq \sum_{\substack{i \in T_s \\ j \in T_{s'}}} x_{ij} \cdot \mathcal{PF}(p_i, d_{ii}) - \varepsilon \quad \forall\, T_s^k \sim T_{s'}^w \in \mathcal{O};$$

$$\sum_{\substack{i \in T_s \\ j \in T_{s'}}} x_{ji} \cdot \mathcal{PF}(p_j, d_{ji}) \leq \sum_{\substack{i \in T_s^k \\ j \in T_{s'}^w}} x_{ji} \cdot \mathcal{PF}(p_j, d_{jj}) - \varepsilon \quad \forall\, T_s^k \sim T_{s'}^w \in \mathcal{O}$$

where $\mathcal{M} >> 0$ and $\varepsilon > 0$ are appropriate dummy constants.

RESULTS

MODELS TESTED

- MINCOST
-NN BOUND
-UDPP (FDR+SFP)
-UDPP + ISTOP

SCENARIO

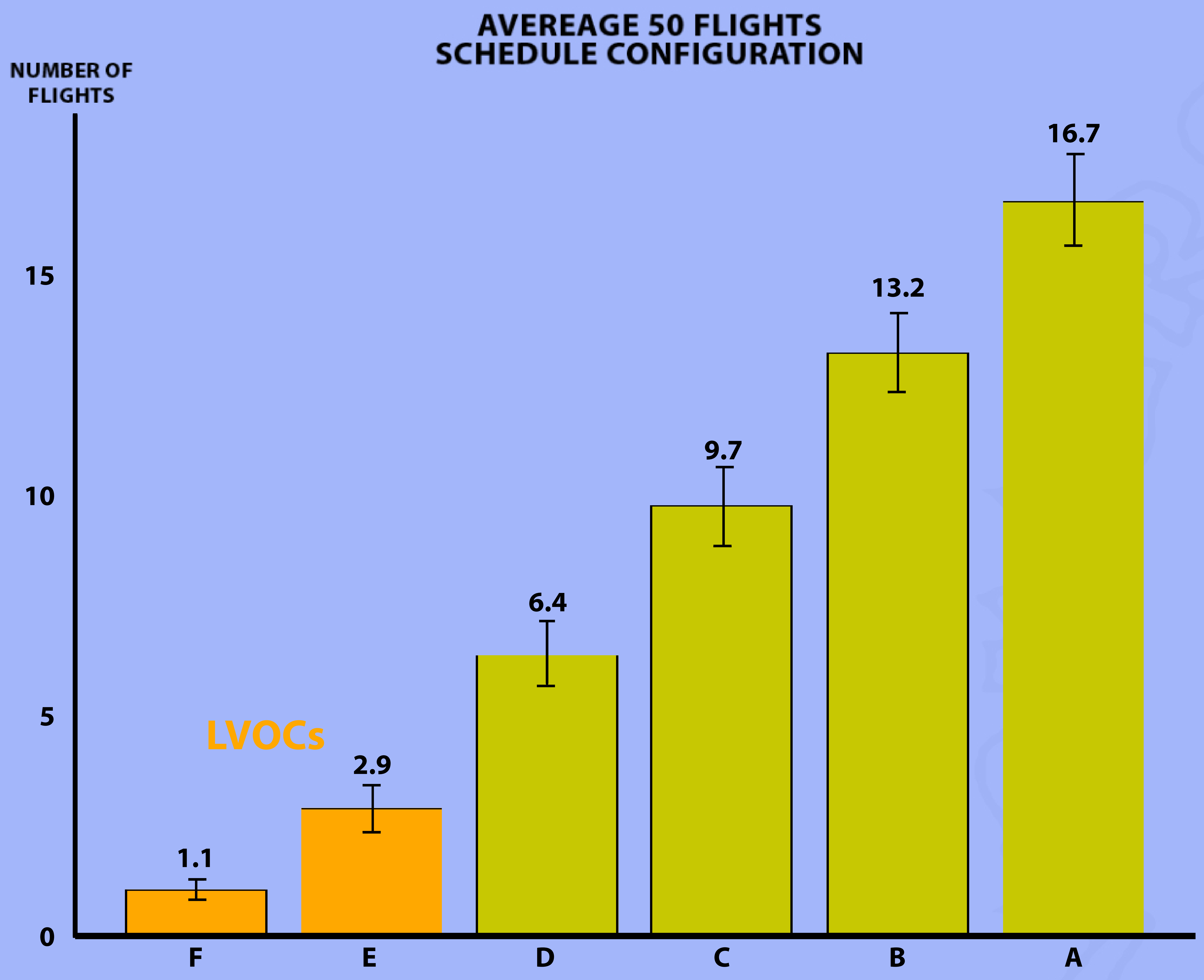
- offers: 2 airlines, 2 flights per airlines
- 50 flights, 5 airlines
- 100 runs

COST MODEL

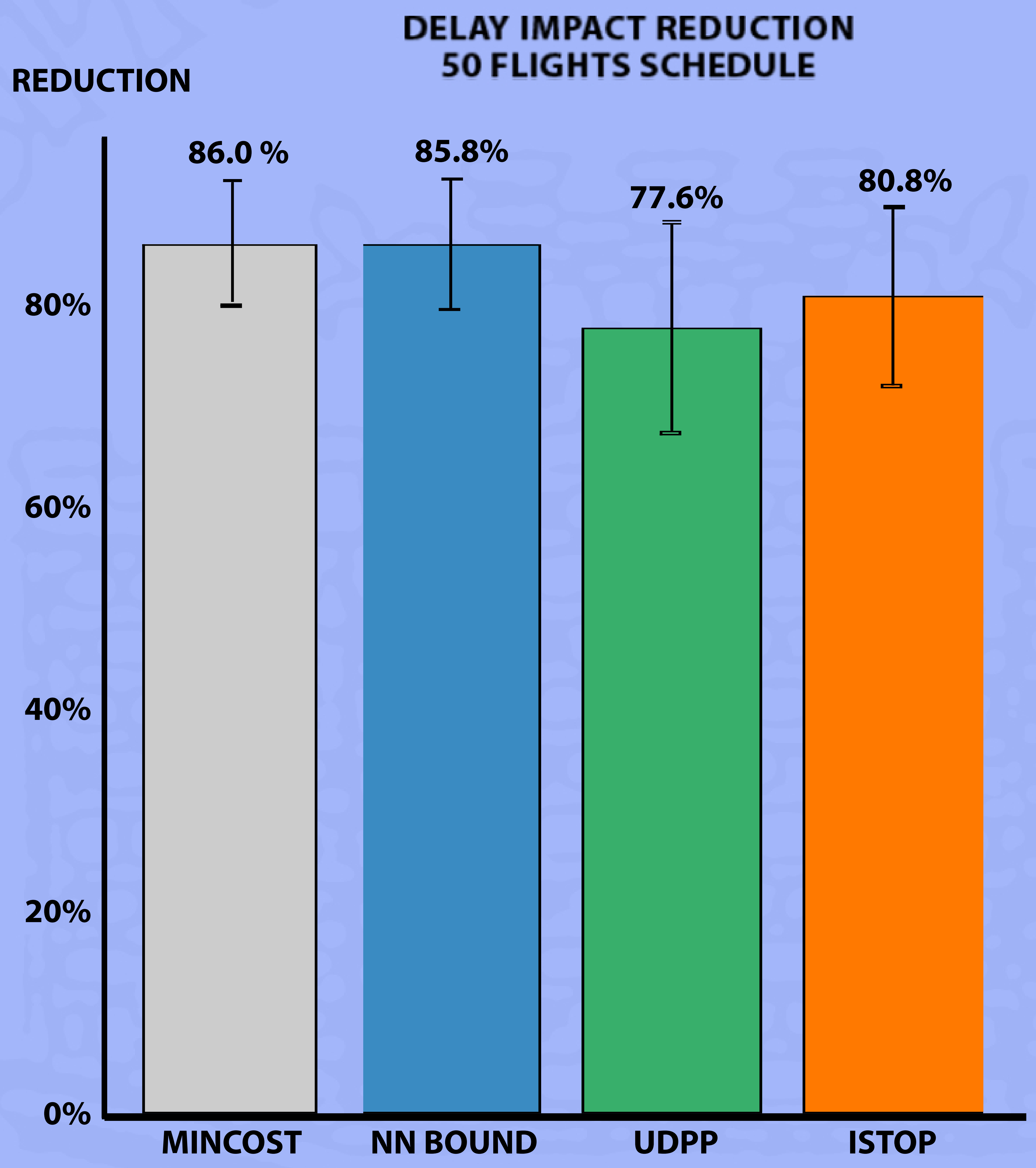
European airline delay cost reference values (2015)

- passengers
    * duty of care
    * compensation
    * soft costs
- turnaround
- maintenance
- crew
- connecting passengers
- on ground maintenance

RESULTS

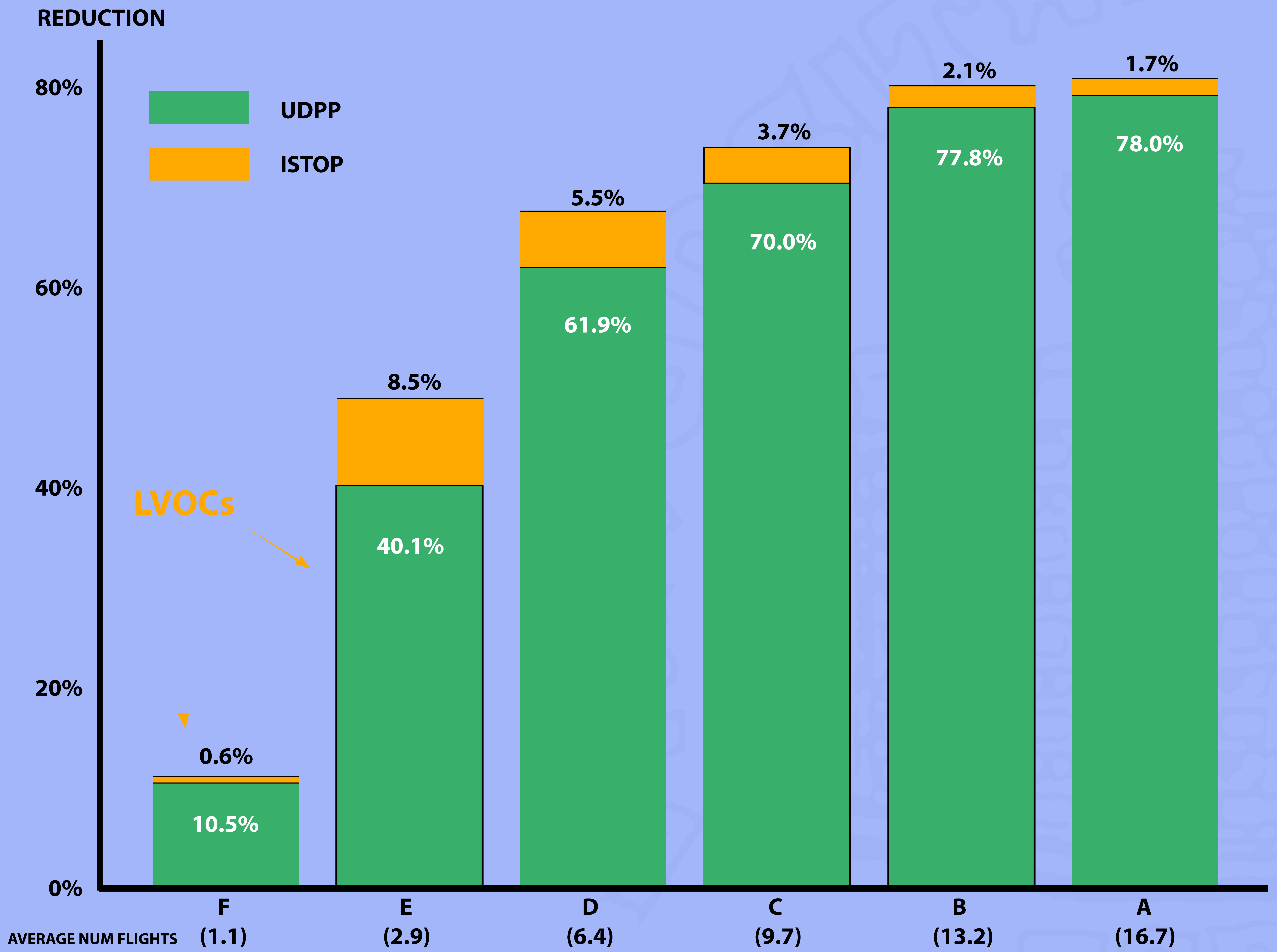


AVEREAGE 50 FLIGHTS
SCHEDULE CONFIGURATION
NUMBER OF
FLIGHTS
15
10
5
0
LVOCs
1.1
2.9
6.4
9.7
13.2
16.7
F
E
D
C
B
A



DELAY IMPACT REDUCTION
50 FLIGHTS SCHEDULE
REDUCTION
80%
60%
40%
20%
0%
86.0 %
85.8%
77.6%
80.8%
MINCOST
NN BOUND
UDPP
ISTOP

RESULTS


REDUCTION
80%
60%
40%
20%
0%
UDPP
ISTOP
LVOCs
0.6%
10.5%
8.5%
40.1%
5.5%
61.9%
3.7%
70.0%
2.1%
77.8%
1.7%
78.0%
F
E
D
C
B
A
AVERAGE NUM FLIGHTS
(1.1)
(2.9)
(6.4)
(9.7)
(13.2)
(16.7)

CONCLUSIONS

PROS

- Preserves UDPP equity concept
- Improves cost reduction
- Improves LVOCs impact
- High level of control from the airlines
- Hides real costs information

LIMITATIONS

- No benefit for 1 flight airlines
- Requires an accurate cost function approximation

THANK YOU FOR THE ATTENTION