ISTOP

INTER AIRLINE SLOT TRADING OFFER PROVIDER

Andrea Gasparin

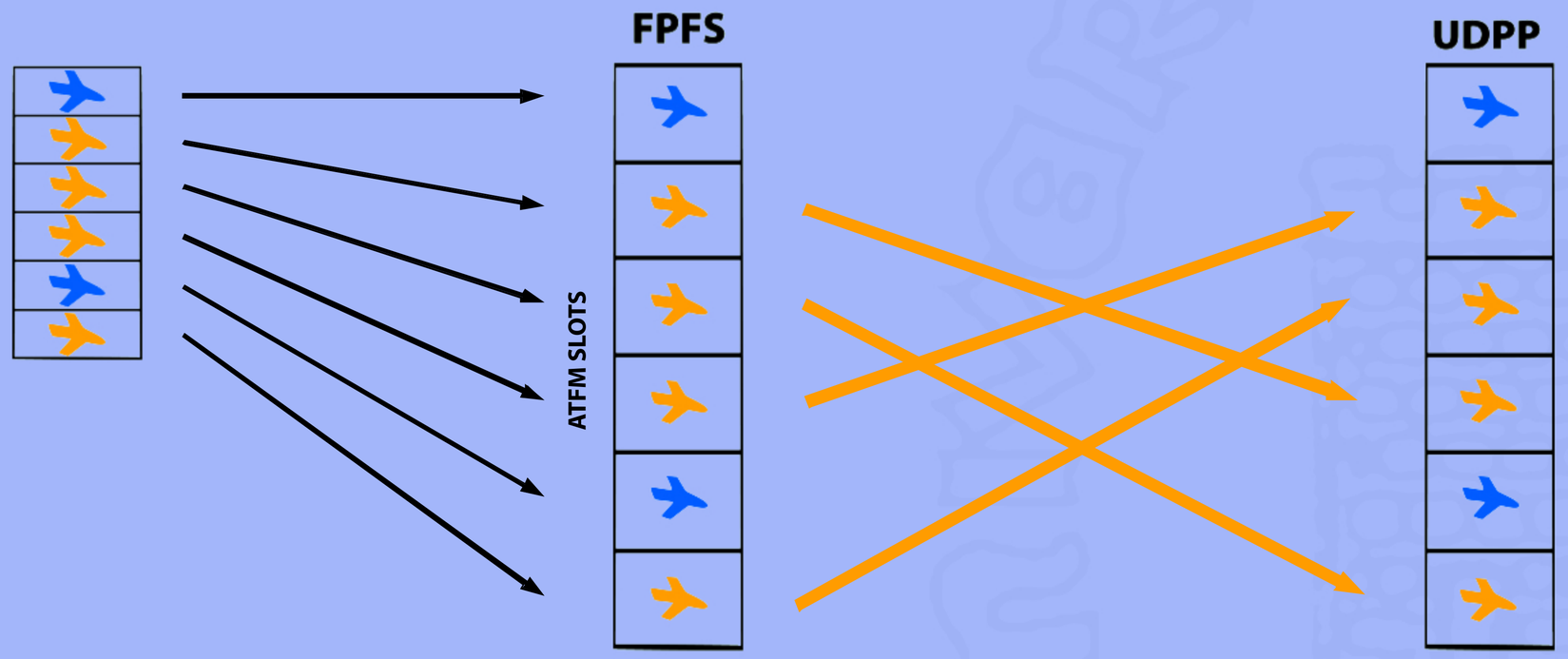
UNIVERSITÀ
DEGLI STUDI
DI TRIESTE

OBJECTIVE: REDUCE DELAY COST IMPACT

SCENARIO:

SINGLE HOTSPOT

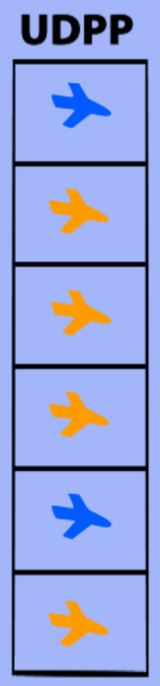
SINGLE AIRPORT



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



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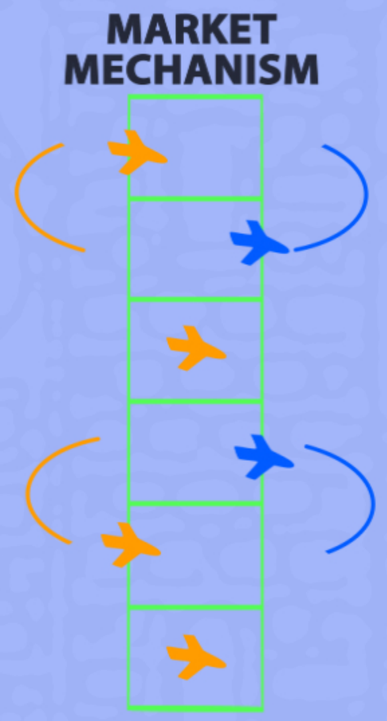

HOW MUCH CAN WE IMPROVE?

Assumption

For any flight f its true cost function 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***

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B12	11	12
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?

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FLIGHT	COST PER MINUTE	DELAY
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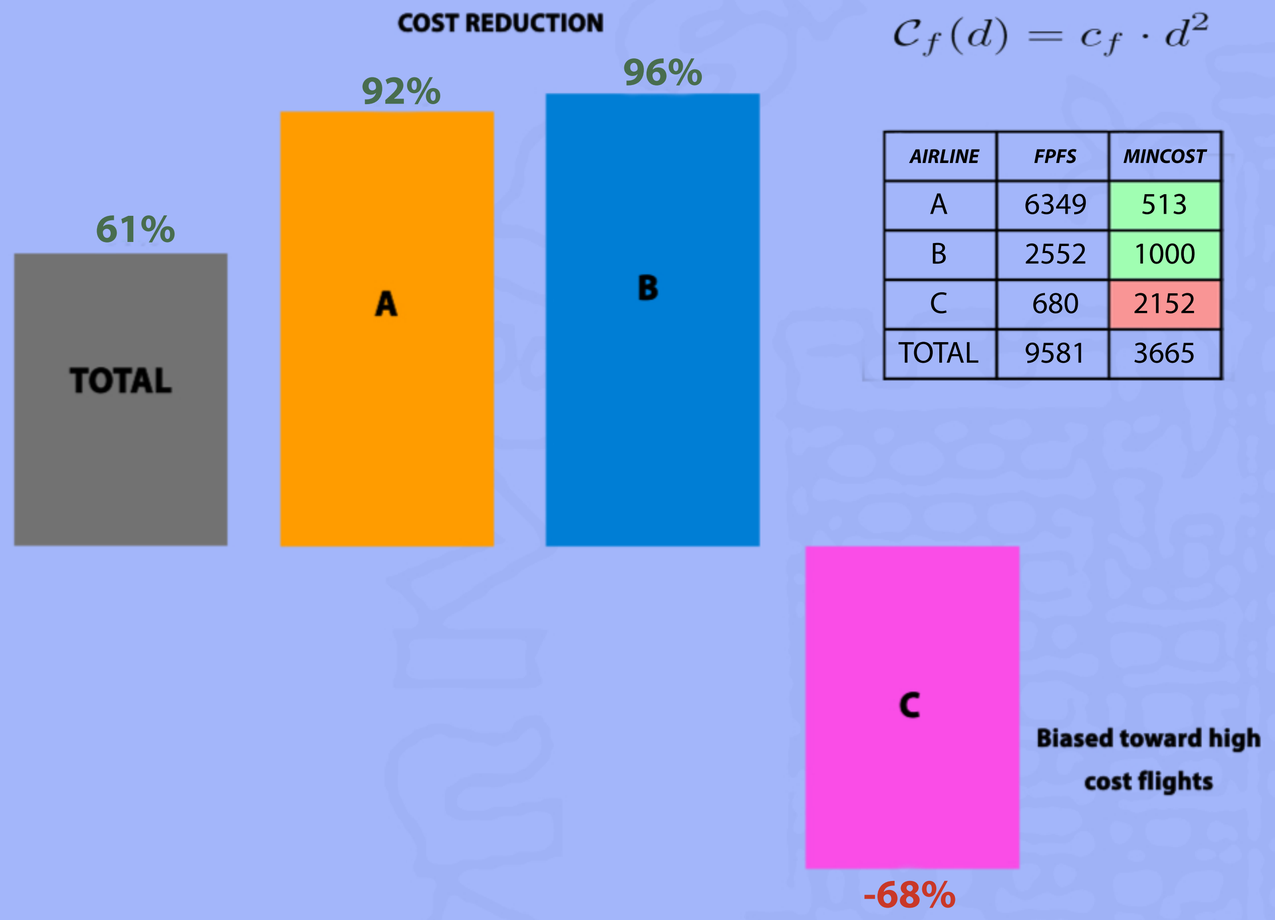

$$\mathcal{C}_f(d) = c_f \cdot d^2$$

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
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HOW MUCH CAN WE IMPROVE?

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B8	10	8
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
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C13	2	13
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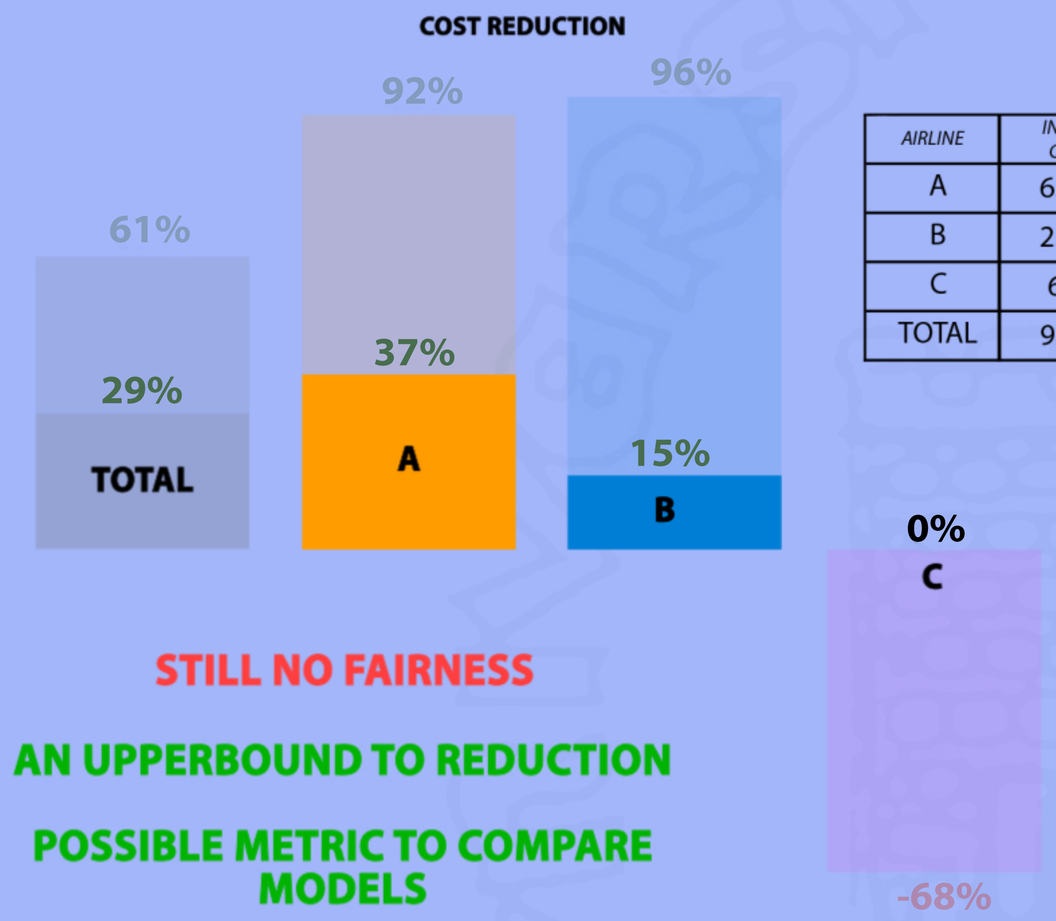

AIRLINE	INITIAL COST	FINAL COST
A	6349	3981
B	2552	2152
C	680	680
TOTAL	9581	6813

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

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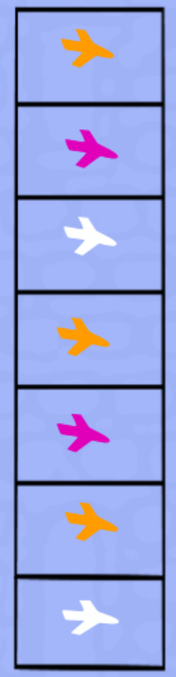
UDPP

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

NETWORK MANAGER



AIRLINE

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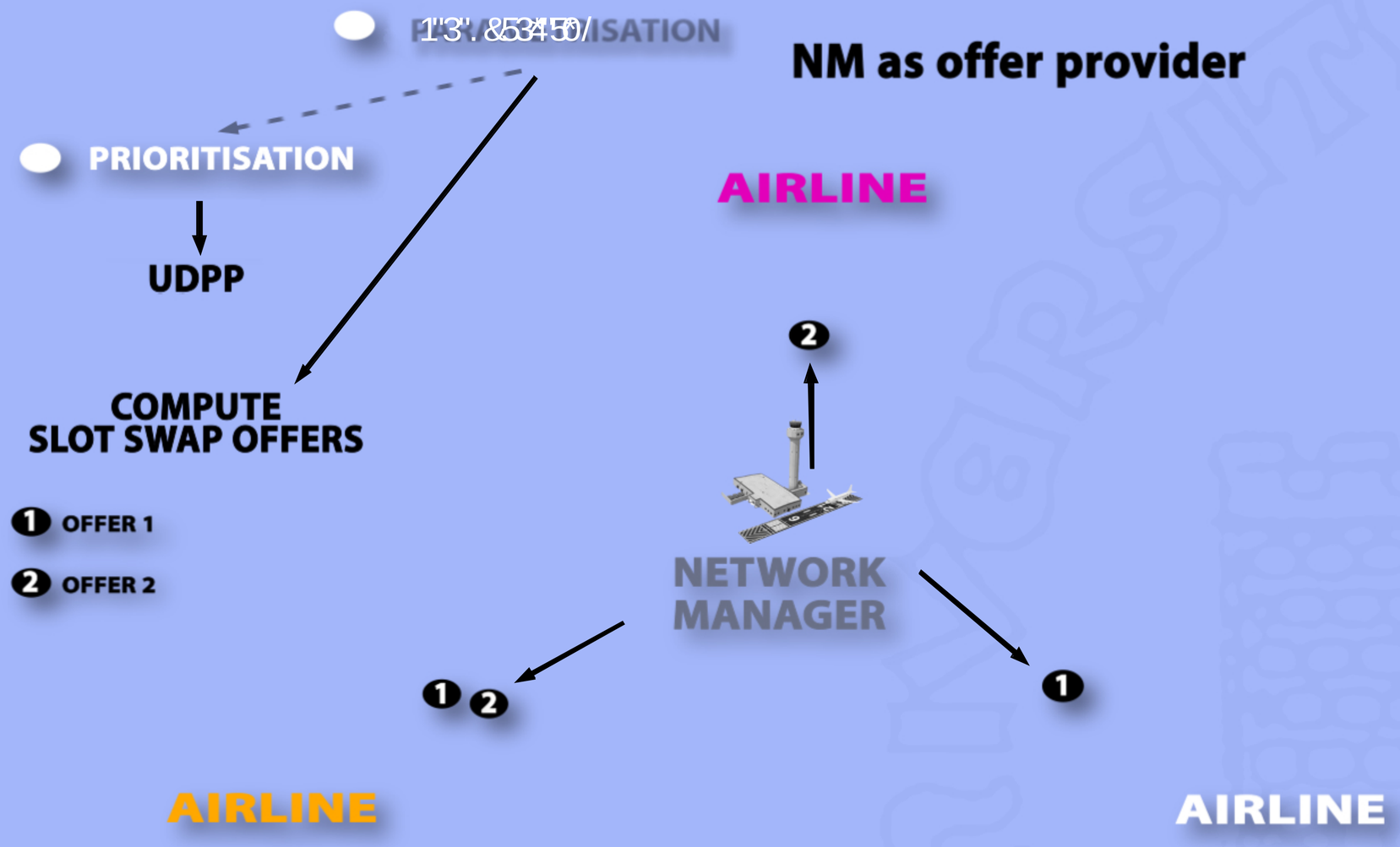

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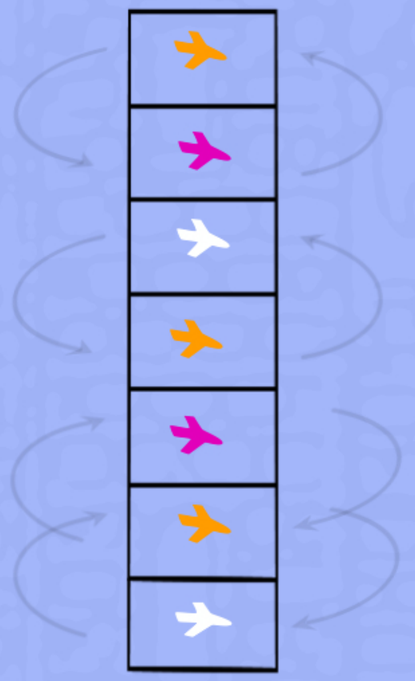

NM as offer provider

PRIORITISATION

UDPP

PRIORITISATION

COMPUTE
SLOT SWAP OFFERS

1 OFFER 1

2 OFFER 2

AIRLINE

2

NETWORK
MANAGER

1 2

AIRLINE

1

AIRLINE

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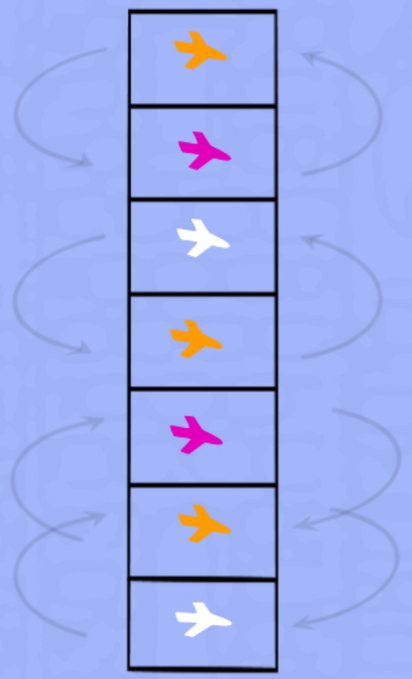

NM as offer provider

PRIORITISATION

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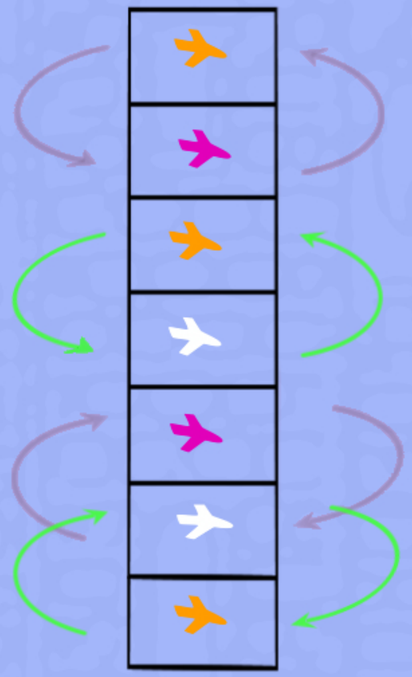
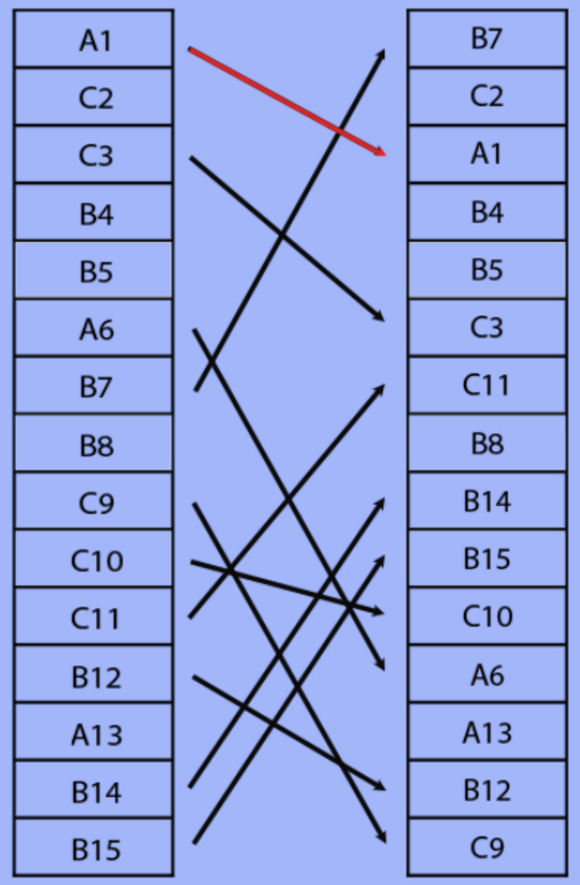
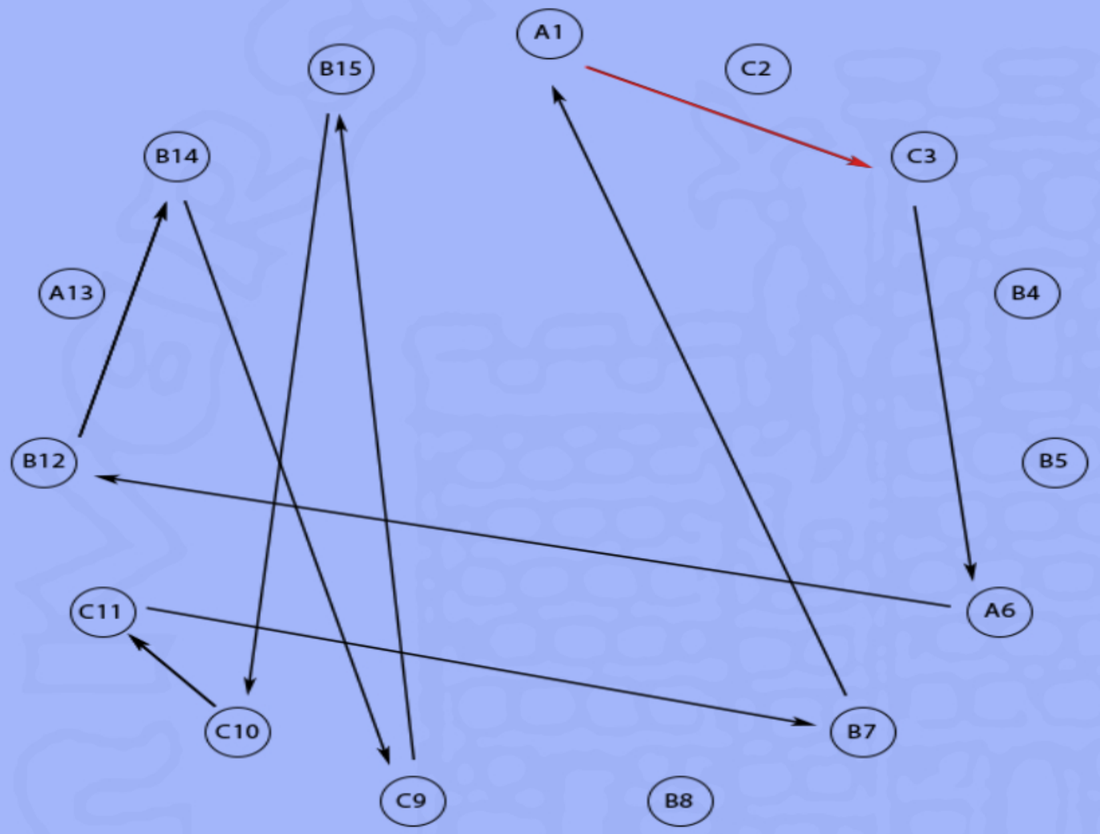
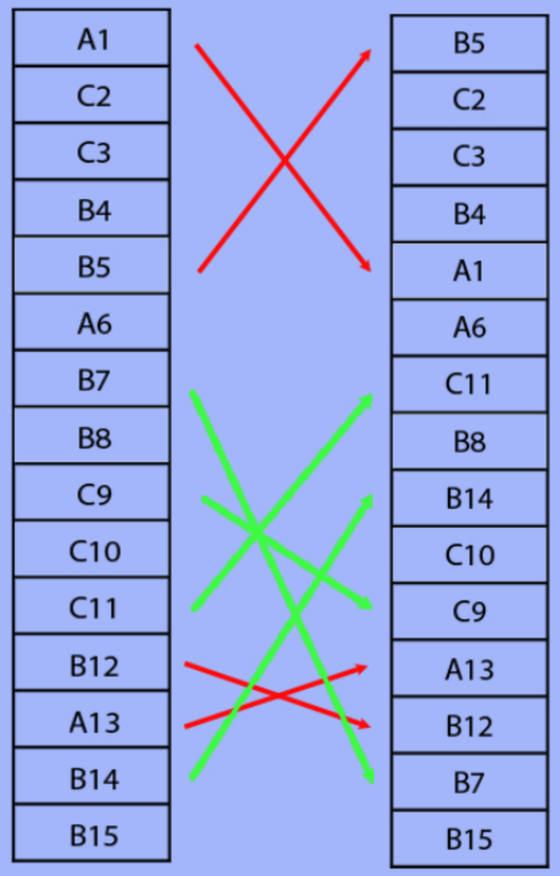


TRADING GRAPH INTERPRETATION





SOLUTION


A1
C2
C3
B4
B5
A6
B7
B8
C9
C10
C11
B12
A13
B14
B15
B5
C2
C3
B4
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B14
C10
C9
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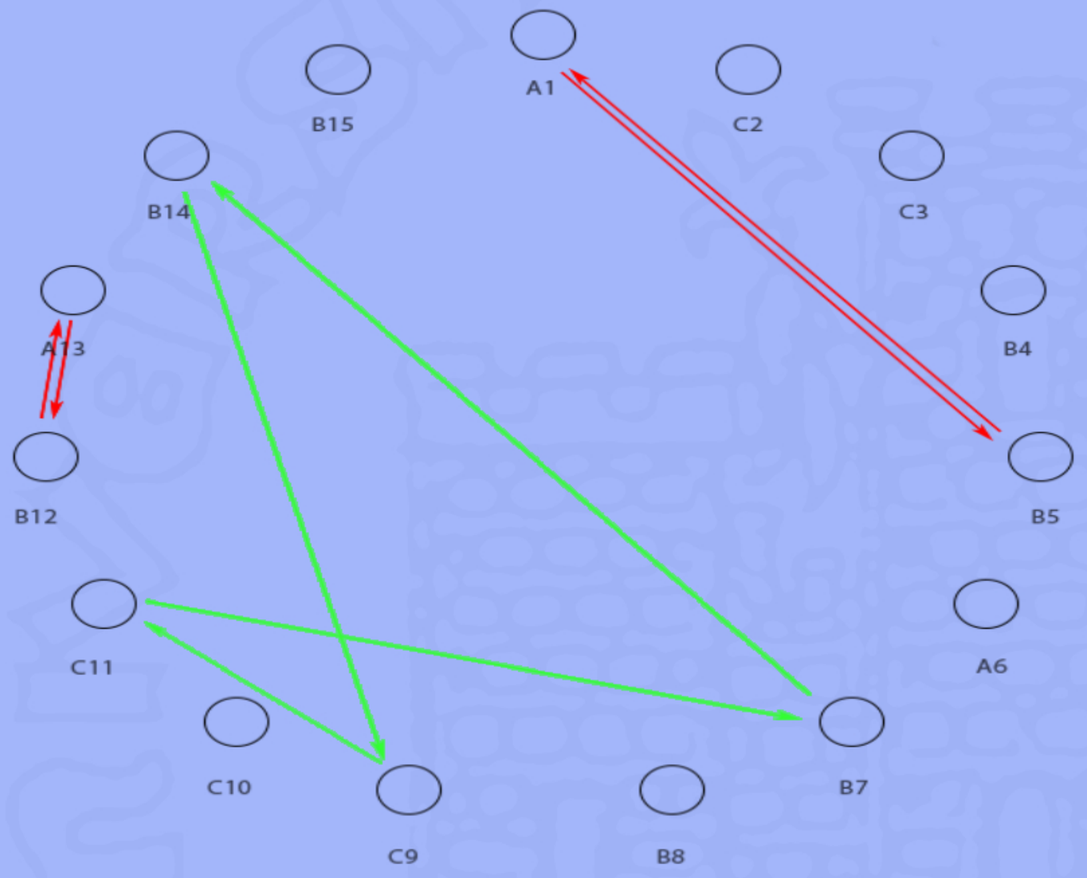
B12
B7
B15


A1
C2
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B5
A6
B7
B8
C9
C10
C11
B12
A13
B14
B15

HOW TO COMPUTE OFFERS part 1

AT DISPOSAL

Cost function PARAMETRISATION

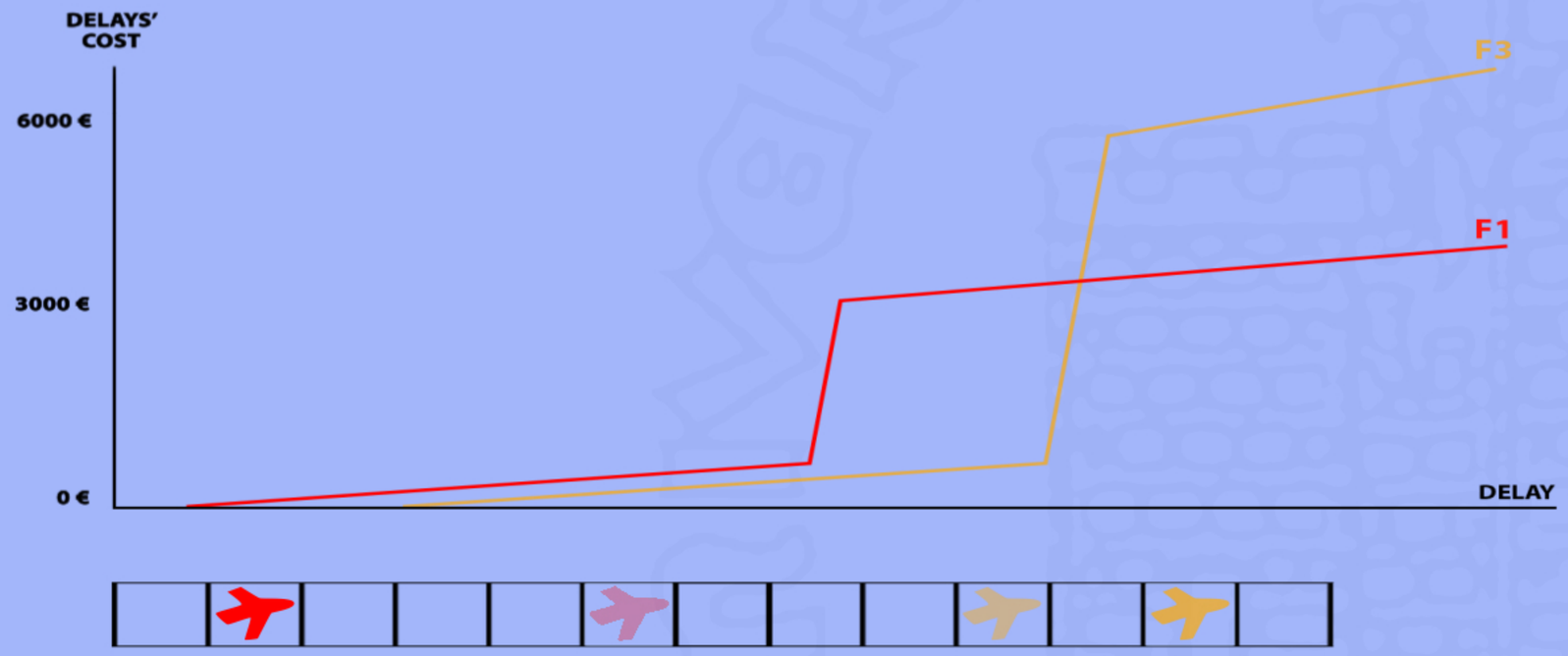
→

Reproduce the **SHAPE** of the cost function

→

GOAL

Extimate the **relative** importance of flights within the airlines



$PTU
CFGPSF

$PTU
BGJFS

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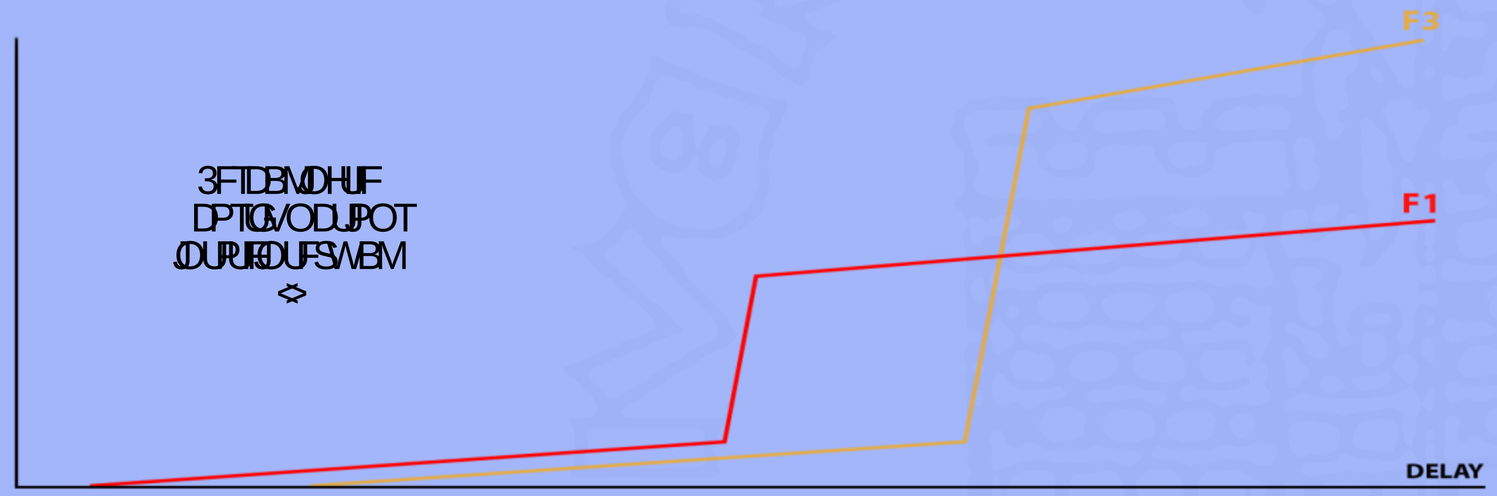


HOW TO SELECT OFFERS

Minimise the *Penalty score function*

Objective

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

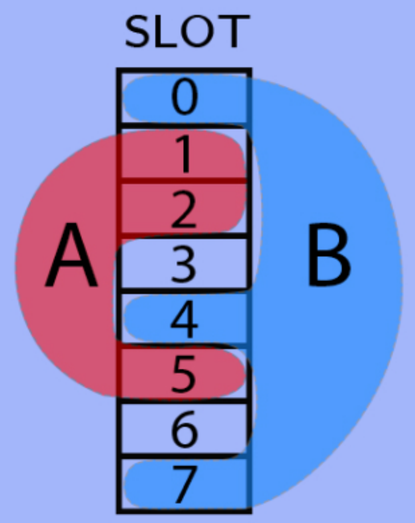
The model is NOT anymore biased to favour high cost flights

HOW TO COMPUTE OFFERS part 2

Definition

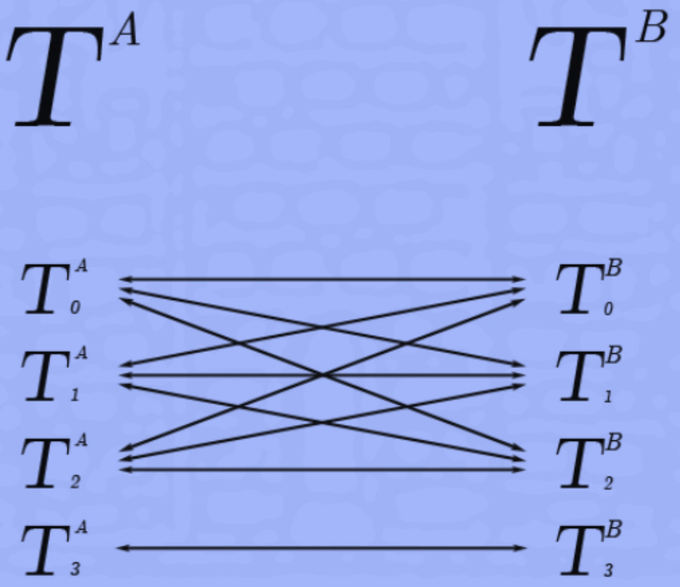
An **offer** consists of an exchange of tuples of slots of the same size, between two airlines; so if T_s^k belongs to A_k and $T_{s'}^w$ belongs to A_w, the offer of exchanging T_s^k and $T_{s'}^w$ can be represented as:

$$T_s^k \sim T_{s'}^w \quad \longleftrightarrow \quad o_{ss'}^{kw} \in \{0,1\} \text{ offer variables}$$



T^A	
{0,4}	T_0^A
{0,7}	T_1^A
{4,7}	T_2^A
{0,4,7}	T_3^A

T^B	
{1,2}	T_0^B
{1,5}	T_1^B
{2,5}	T_2^B
{1,2,5}	T_3^B



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:

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

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

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

$$\sum_{\substack{i \in T_s^k \\ j \in T_{s'}^w}} x_{ij} \cdot \mathcal{PF}(p_i, d_{ij})$$

$$\sum_{\substack{i \in T_s \\ j \in T_{s'}}} x_{ji} \cdot \mathcal{PF}(p_j, d_{ji})$$

Penalty before the swap

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

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

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

RESULTS

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SVOT

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QBTTFOHFST

EVUZPGBSF

DPN QFOTBUPO

TPGUPTUT

UVSOBSPVOE

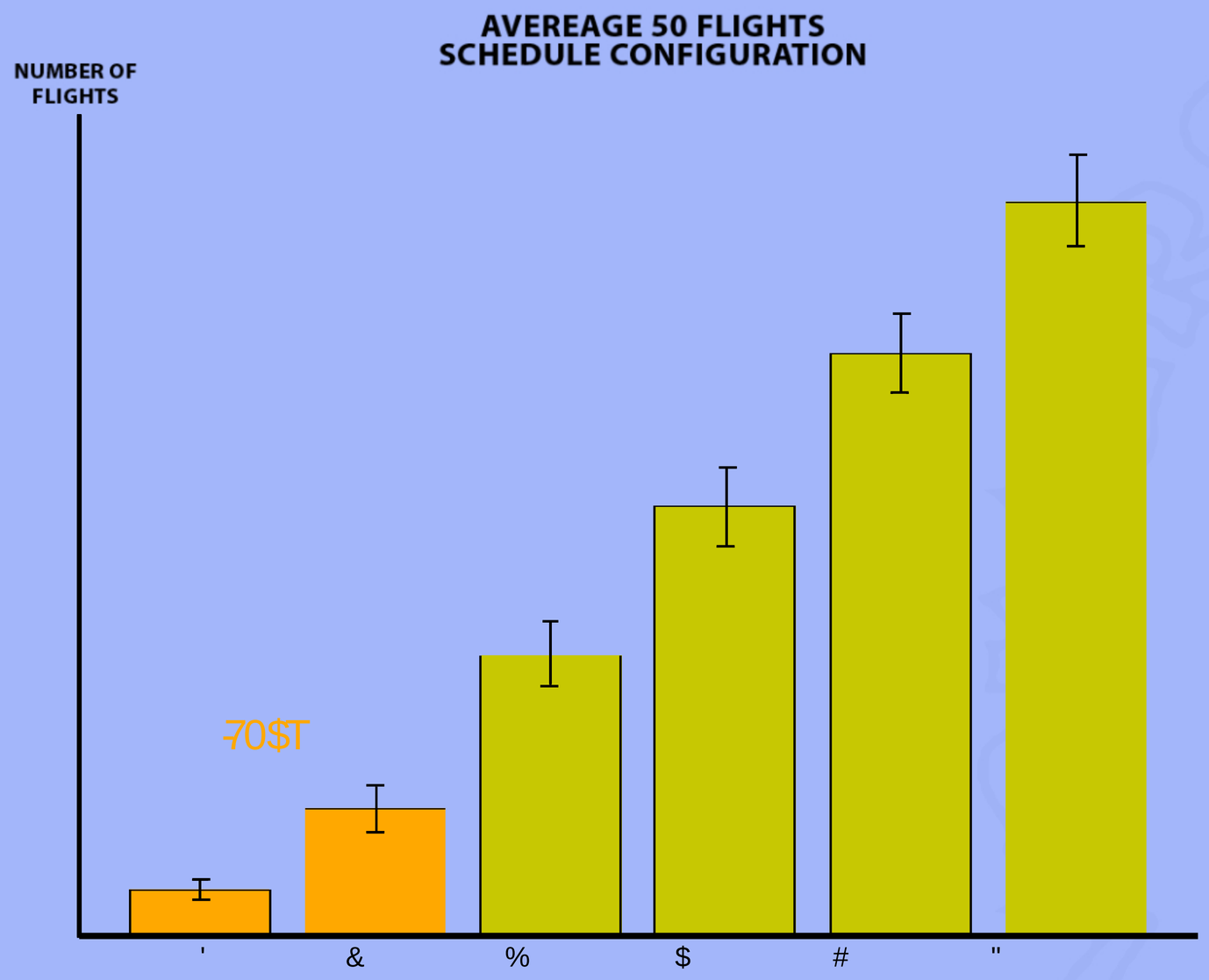
N BOUFOBODF

DSFX

DPOOFDUJOHQBTTFOHFST

POHSPVOEN BOUFOBODF

RESULTS


AVEREAGE 50 FLIGHTS
SCHEDULE CONFIGURATION
NUMBER OF
FLIGHTS
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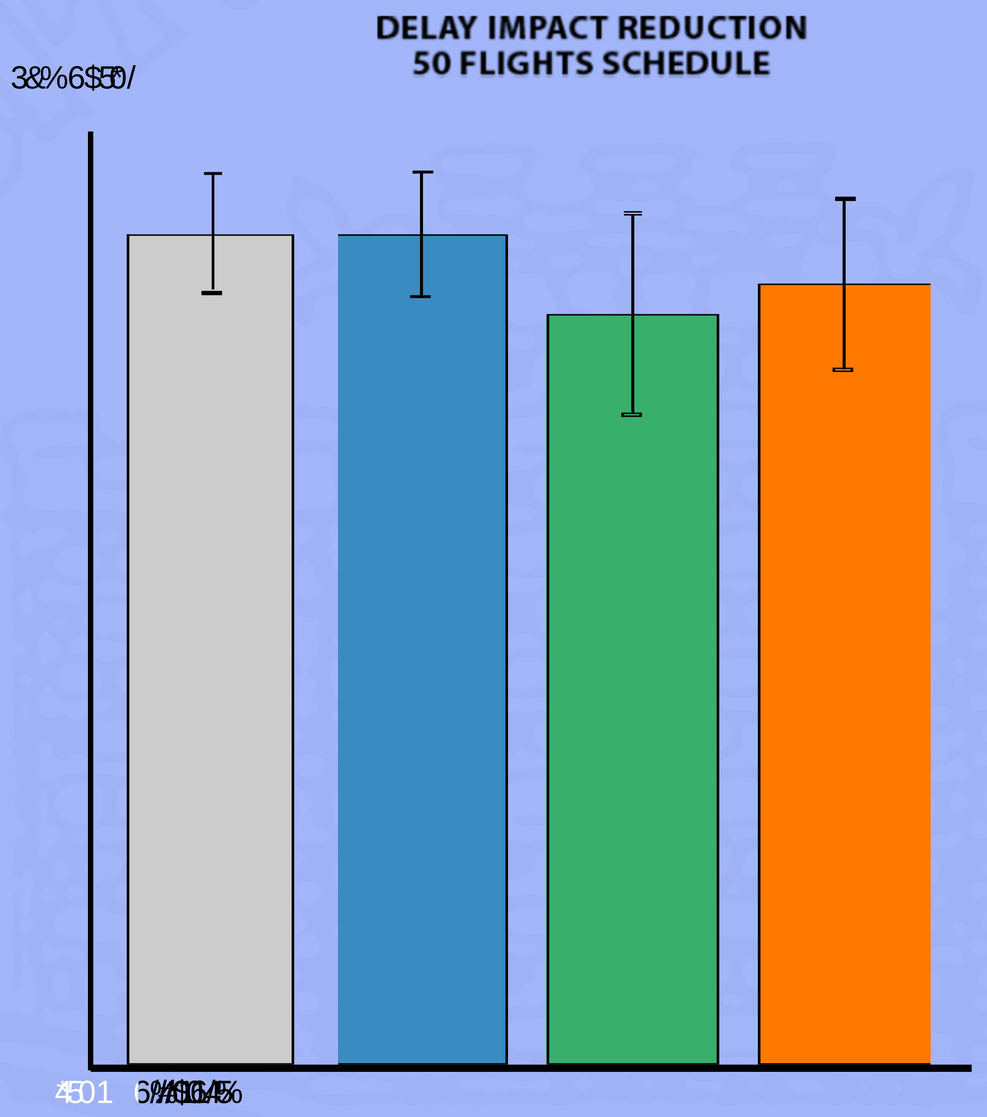
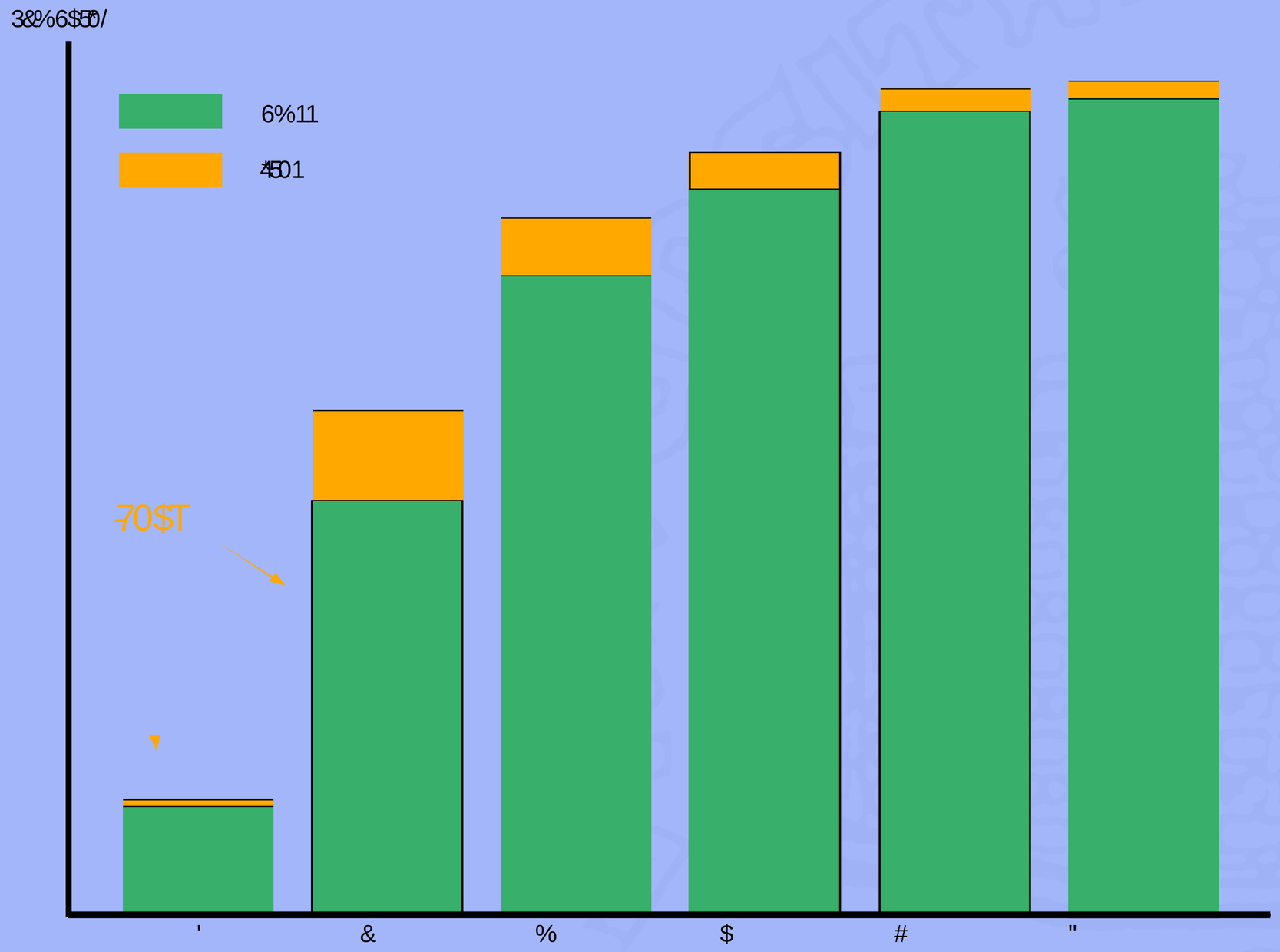

DELAY IMPACT REDUCTION
50 FLIGHTS SCHEDULE

RESULTS



CONCLUSIONS