

Delayed On The Ground ...

(Part 2 ... *airlines*)

ASEN 6519 – Guest Lecture

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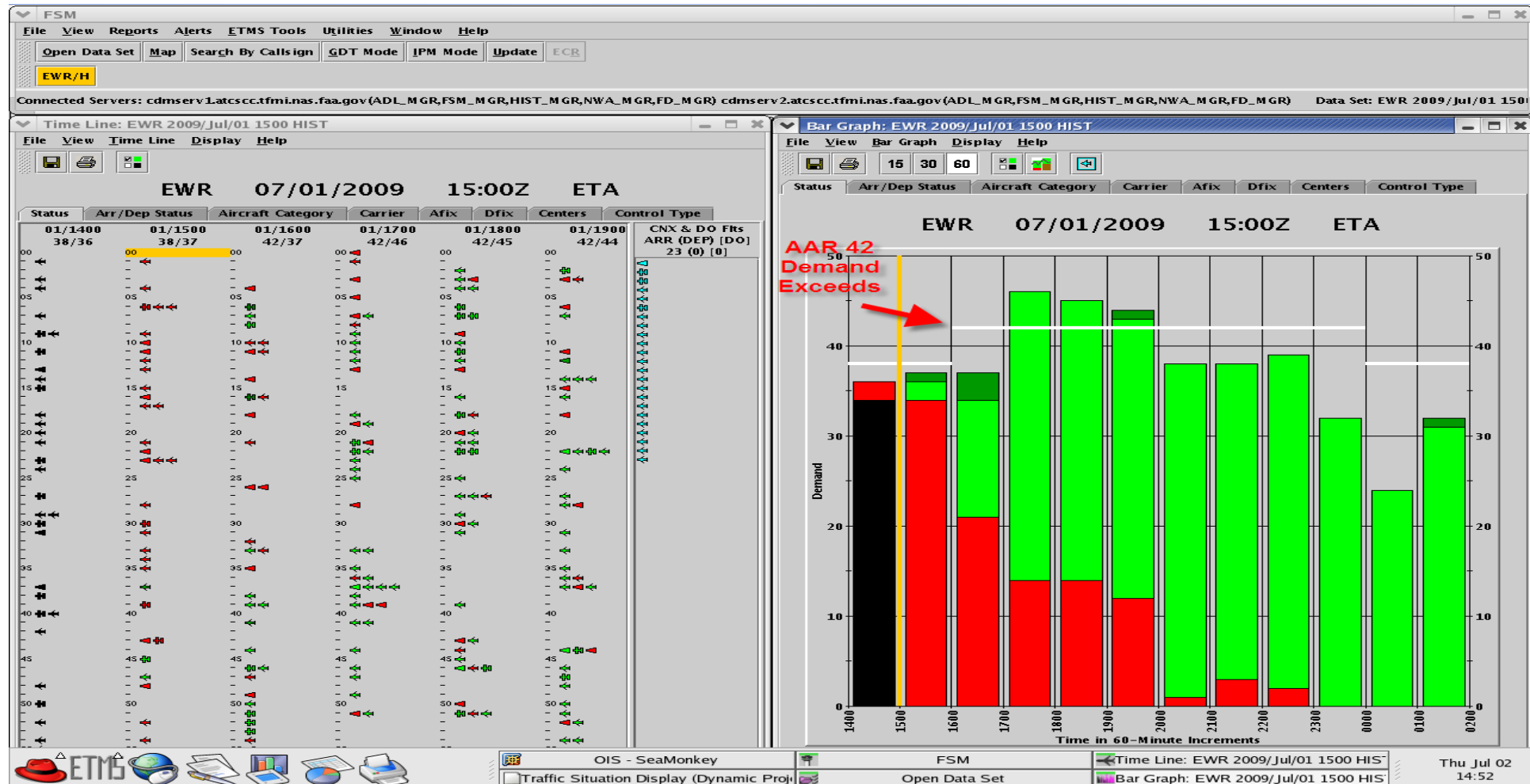
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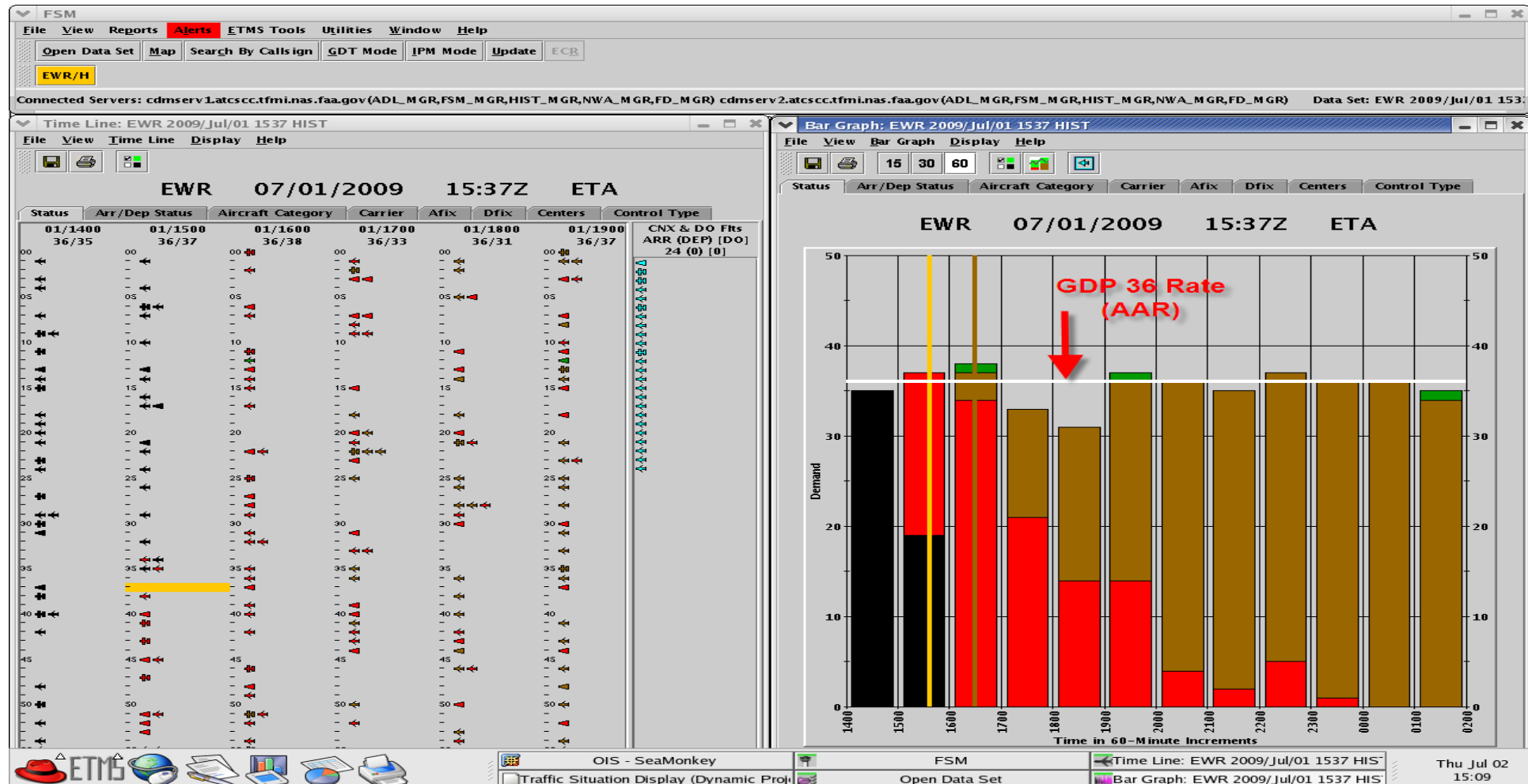
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Ever been delayed in EWR?



Ever been delayed in EWR?



Distributionally Robust Integer Programs

Mathematically encode “how to delay aircraft better”

(with *distributional airport capacity uncertainty*)

$$\min_{x,y,\alpha,\beta} \sum_{z \in Z} \sum_{f \in F(z)} C_f \left(\sum_{t \in T_f(z)} tx_{tf} - r_f \right) + \epsilon \sum_{z \in Z} \alpha_z + \sum_{z \in Z} \sum_{s=1}^N \hat{p}_{z,s} \beta_{z,s} \quad (24a)$$

$$\text{s.t. } \alpha_z \left\| \hat{\xi}_{z,s} - \xi \right\|_2 + \beta_{z,s} \geq \sum_{t \in T} C_h y_{s,t}(\xi), \quad \forall \xi \in \Xi_k, \forall z \in Z, s = 1, 2, \dots, N, \quad (24b)$$

$$\sum_{t \in T_f(z)} x_{ft} = 1, \quad \forall f \in F, z \in Z, \quad (24c)$$

$$\sum_{f \in F(z)} x_{f,t} \leq K_z(\xi) - y_{z,t-1}(\xi) + y_{z,t}(\xi), \quad \forall t \in T, \xi \in \Xi_k, z \in Z, \quad (24d)$$

$$\sum_{t \in T_{f_1}} tx_{f_1,t} - r_{f_1} - s_{f_1,f_2} \leq \sum_{t \in T_{f_2}} tx_{f_2,t} - r_{f_2}, \quad x_{ft} \in \{0, 1\}, f_1, f_2 \in C, \quad (24e)$$

$$y_{z,0}(\xi) = 0, y_{z,t}(\xi) \geq 0, \alpha_z \geq 0, \quad \forall t \in T, \xi \in \Xi_k, z \in Z. \quad (24f)$$

GDPs ... in the wild ... let's study 'em!

Mathematically encode “how to delay aircraft better”

(with *distributional airport capacity uncertainty*)

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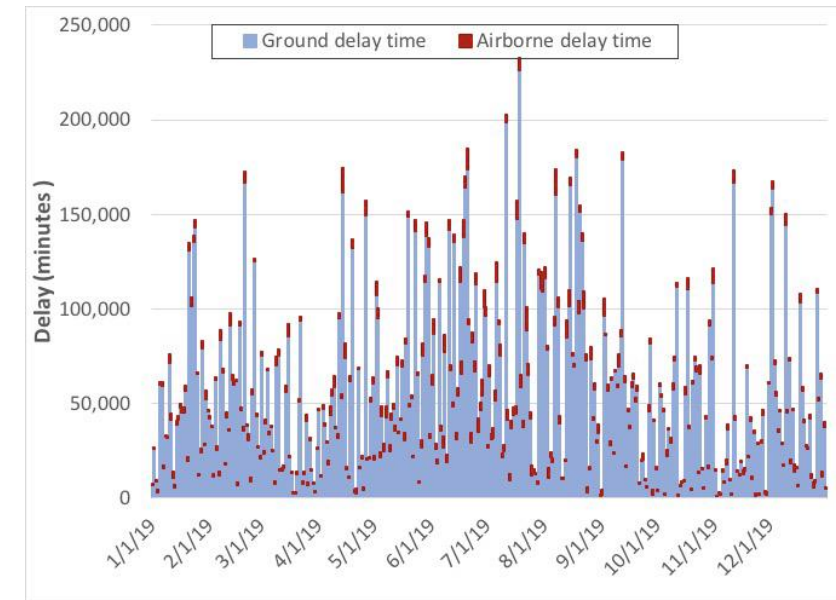
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GOAL:

Less **red** stuff (airborne delays)

Less **blue** stuff (unnecessary ground holds)



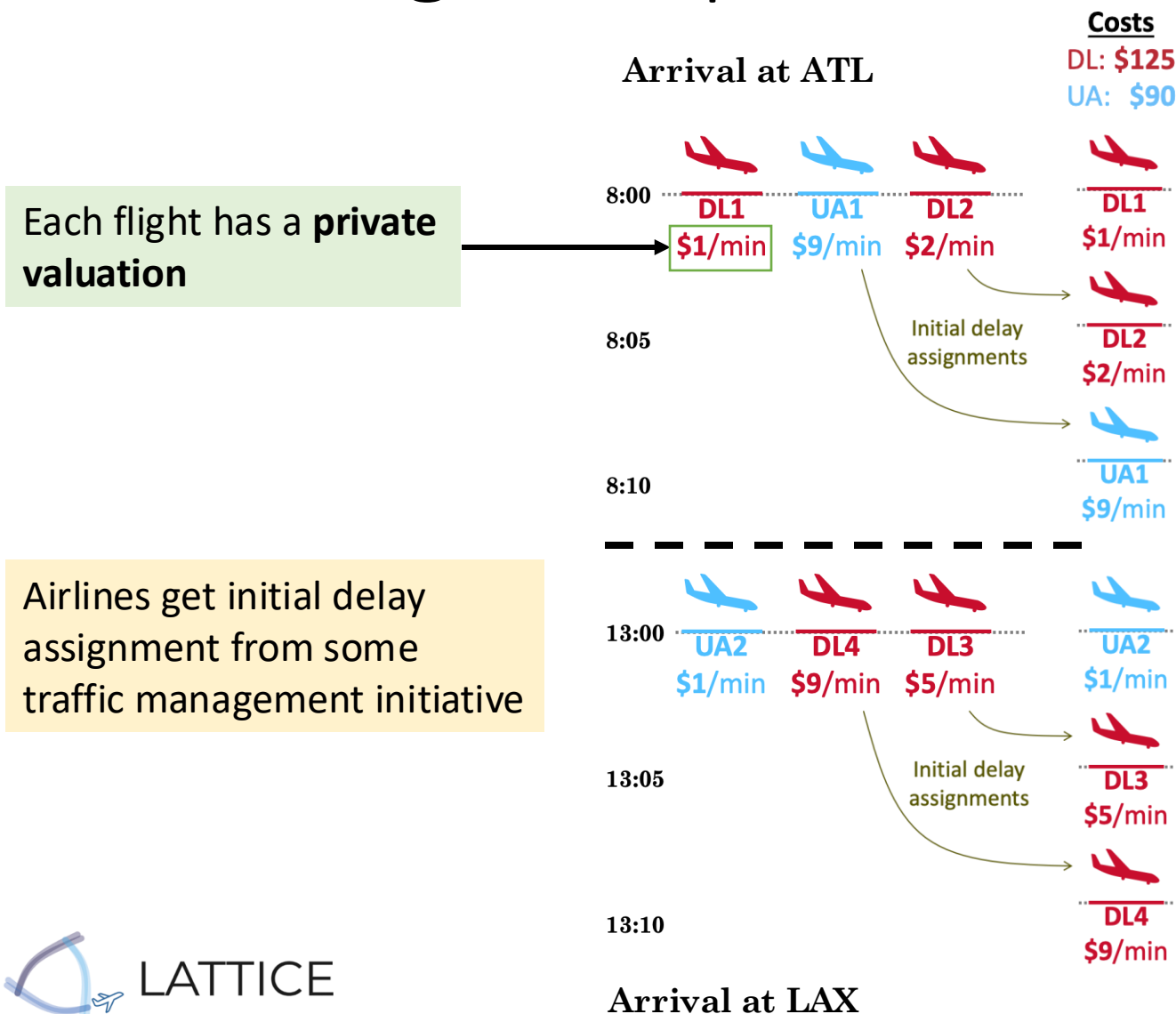


We're Forgetting Something ...

Outline

- Motivating Example
- DeLed Framework and Setup
- DeLed Flowchart and Formulation
- Experimental Results

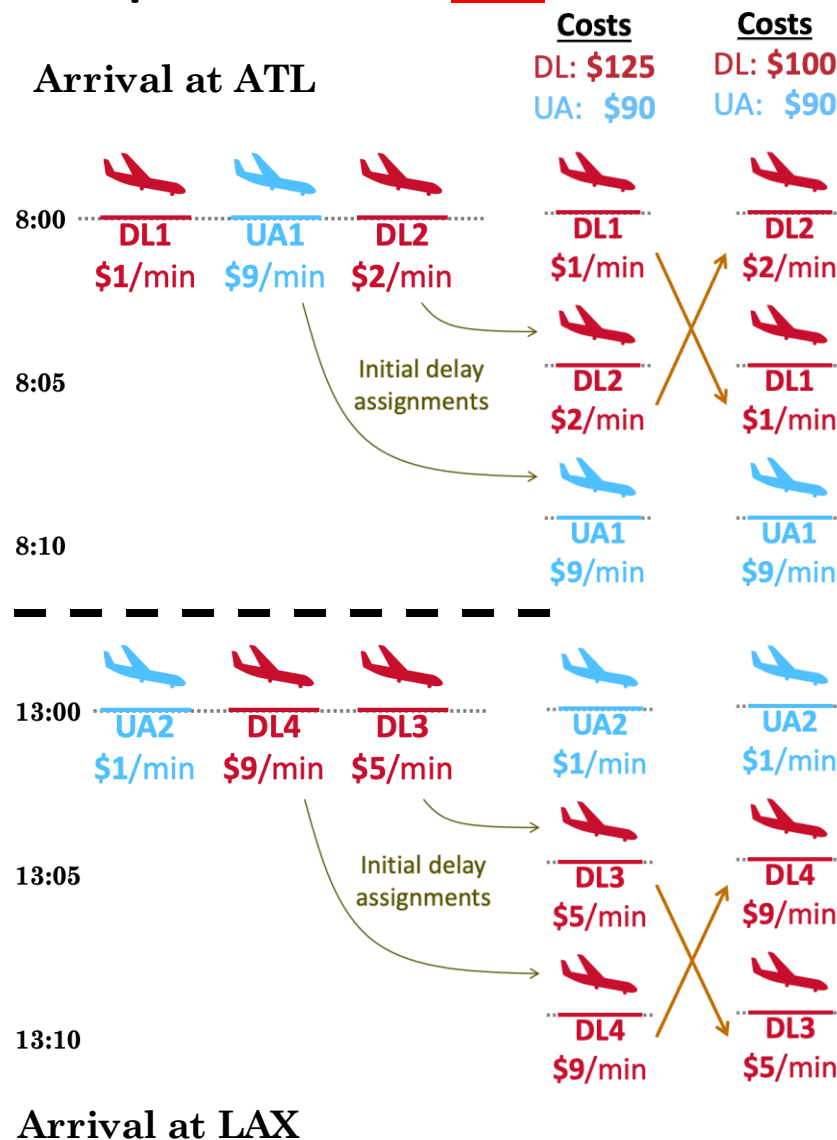
Motivating Example: Initial Delay Assignment



Motivating Example: Intra-Airline Substitution

Airline can perform *intra-airline substitution* to reduce delay costs

Airlines swap departure/arrival slots within their own flights

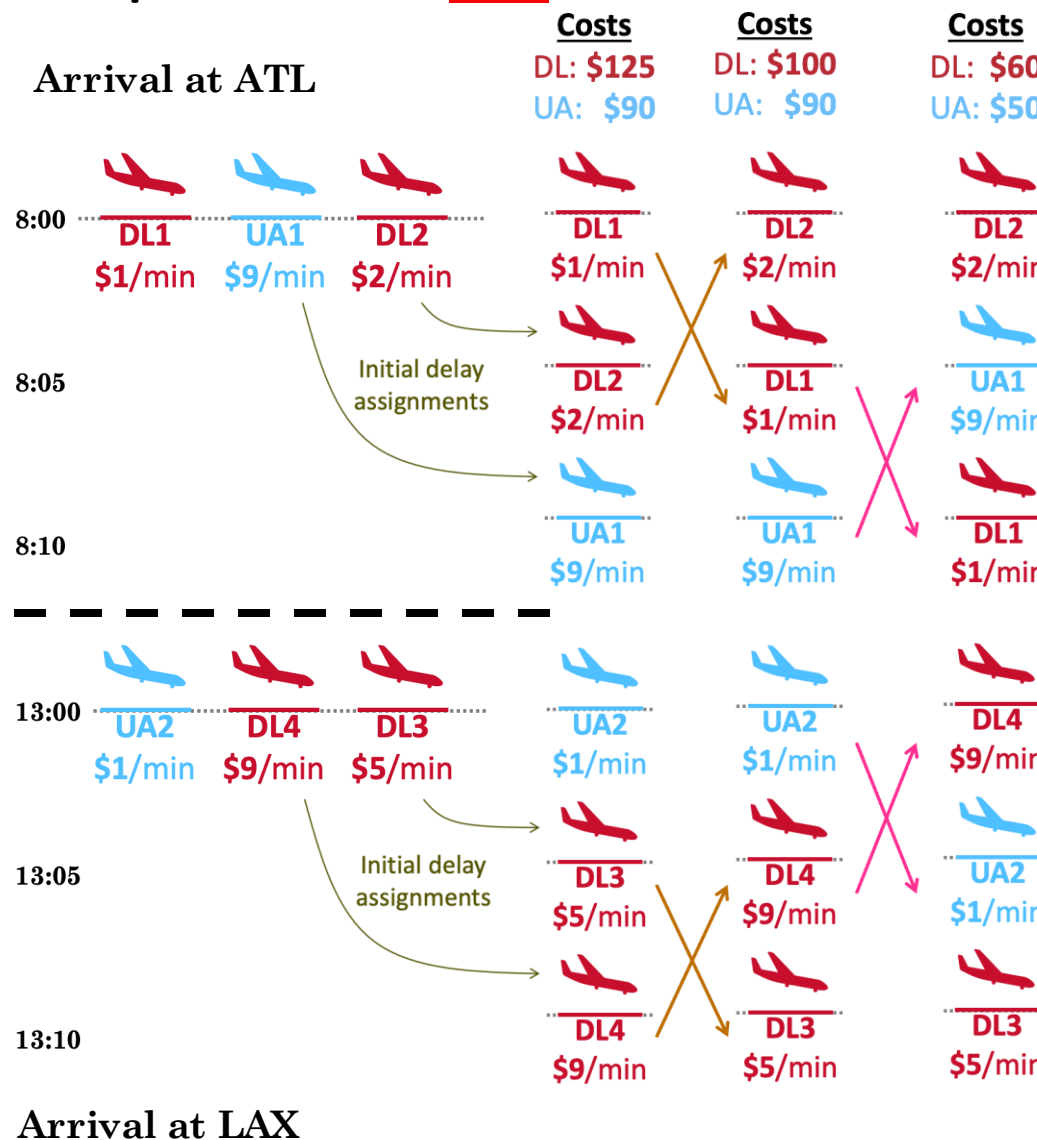


Total delay remains unchanged, but delay costs decrease

Motivating Example: Inter-Airline Swaps

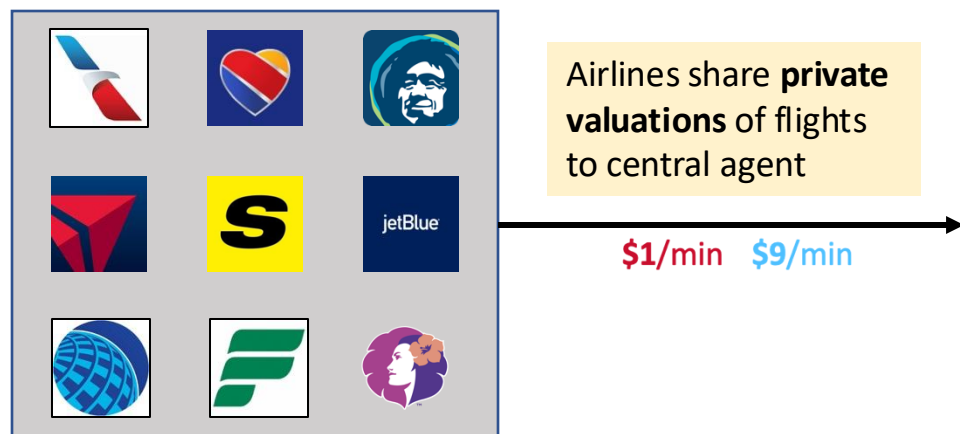
Airline can also swap slots with each other to further reduce costs

Both airlines reduce their delay costs



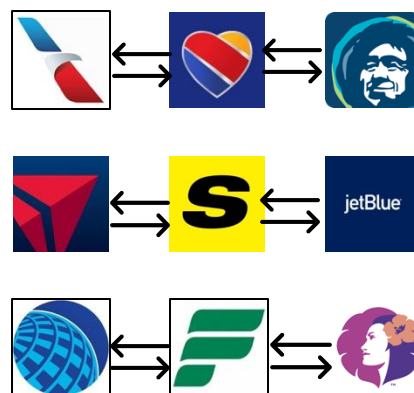
Challenge: Inter-airline swaps are difficult to facilitate

Centralized Approach



May reveal sensitive business practices and exposes system to gaming behavior

Decentralized Approach



Airlines negotiate with each other

Difficult for an airline to propose acceptable swaps; computational tractability concerns

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Problem Setup: Delays and Ledgers

- **Scheduling Round:** time duration for which network of flights is scheduled
- **Public Delay:** schedule delay measured with respect to original arrival times—*observable* by all airlines
- **Private Delay Cost:** public delay scaled by private flight valuation—*unobservable* to other airlines

Inter-airline swaps may cause some airlines to incur public delay



Delay ledger tracks cumulative increase in public delay relative to input solution

Problem Setup: Coordinator and Participants

- **Coordinator:** Coordinating airline adjusts participants' schedules as well as its own
 - Utilizes its own private valuations
 - Accounts for *flight priorities* of participants
- **Participants:**
 - Provide flight priorities to coordinator
 - High/medium-priority: flight cannot be delayed further
 - Low-priority: flight can be delayed further
 - Provide private valuation ranges of high, medium, low priority flights

Coordinator role
given to airline with
highest value in delay
ledger

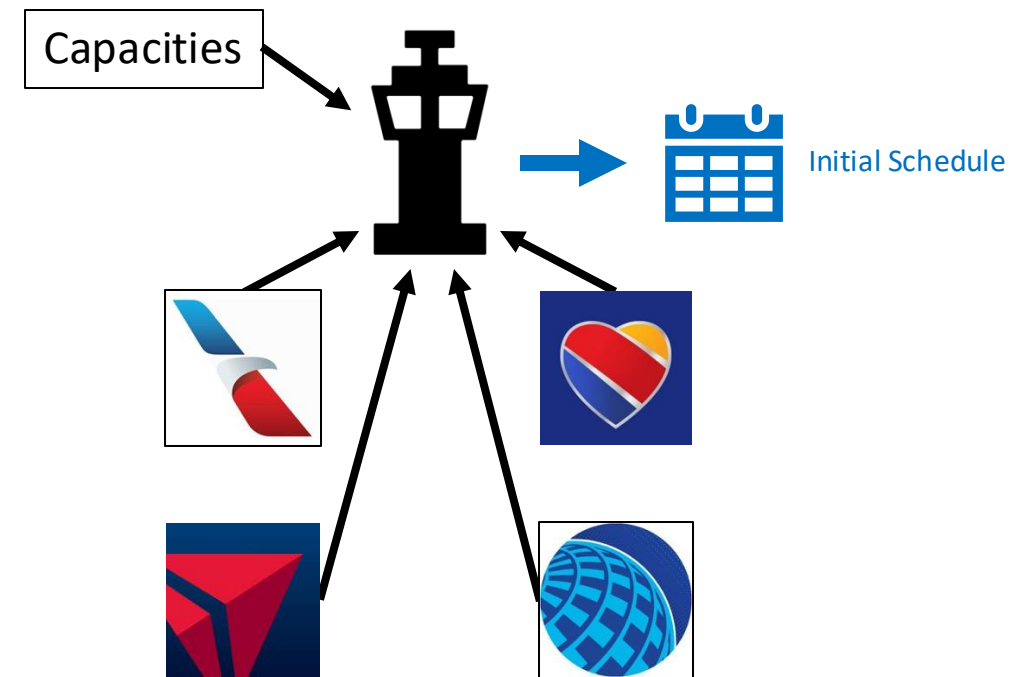
Participants are guaranteed to not
see increase in private delay costs

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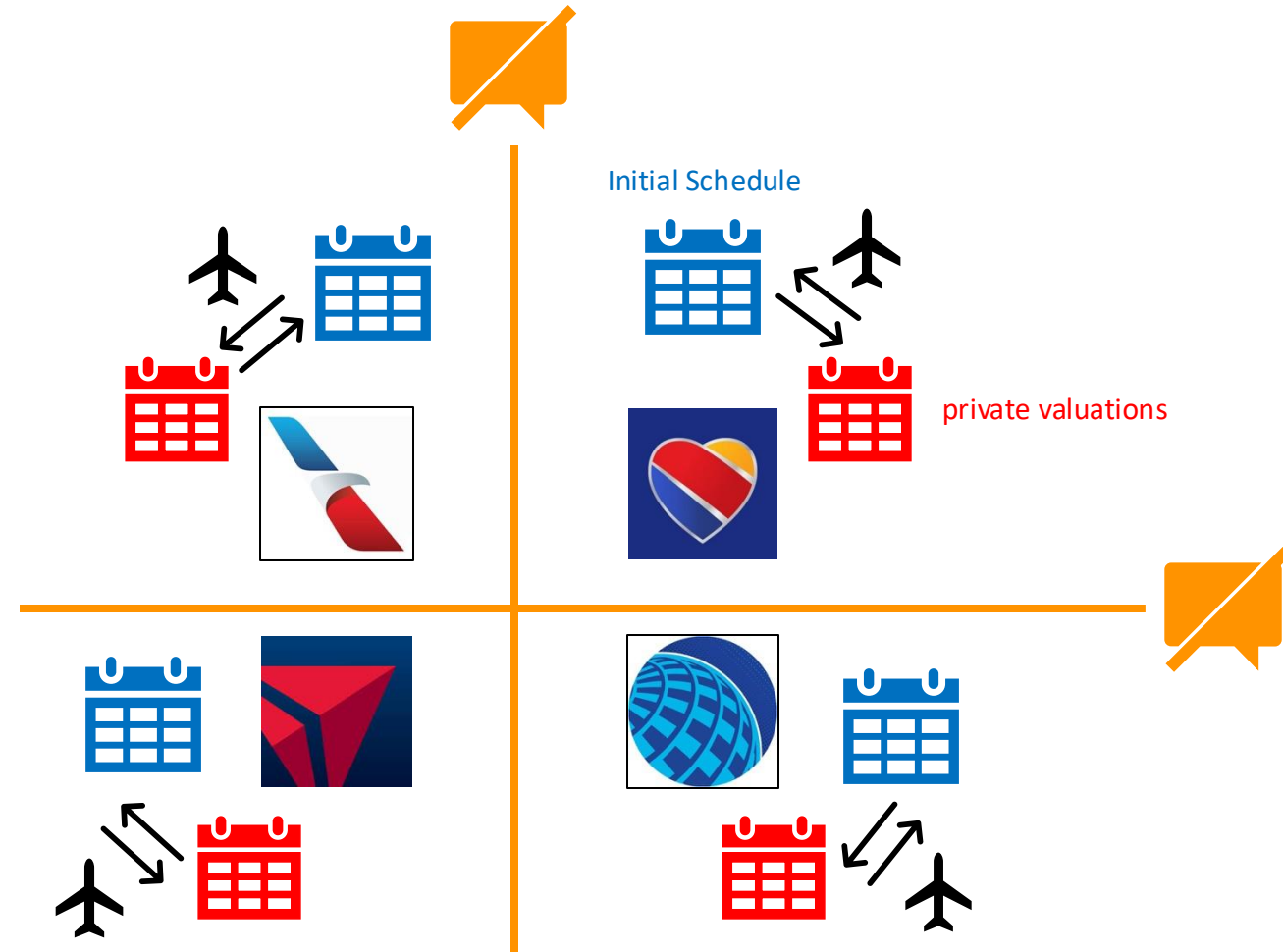
Step 1: Create initial schedule

- Airlines submit feasible departure and arrival times to central agent, which creates the **Initial Schedule**



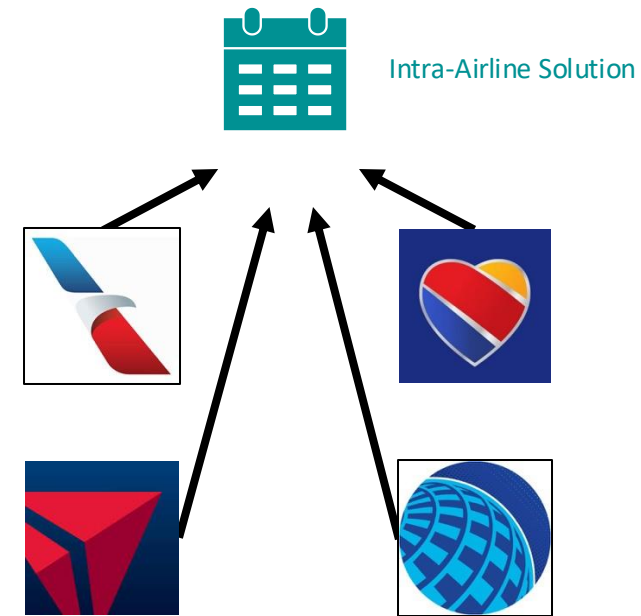
Step 2: Intra-Airline Substitution

- With **Initial Schedule**, airlines individually swap within their own flight slots
- Within an airline, swaps are determined based on **private valuations**



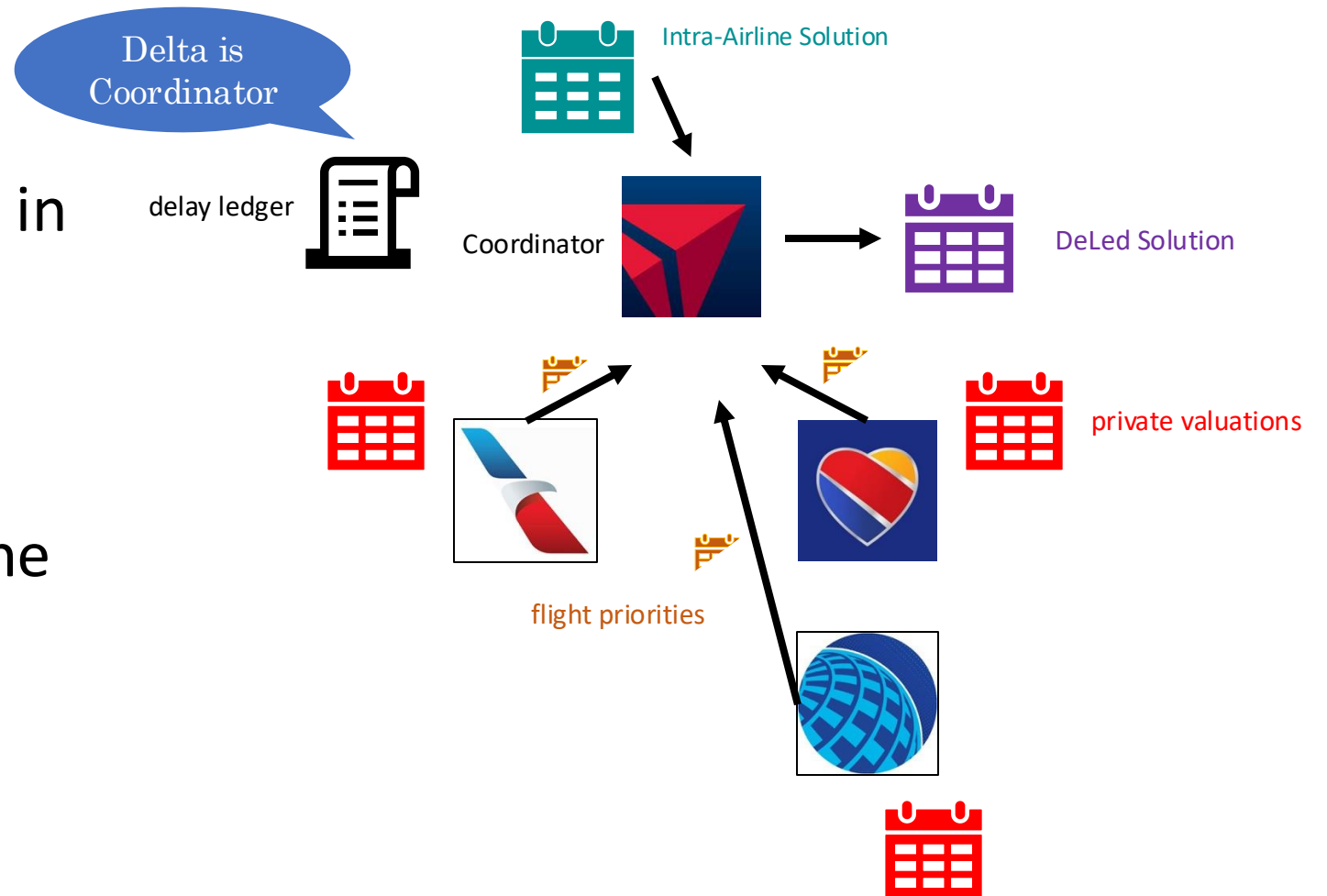
Step 3: Assimilation of intra-airline swaps

- Airlines submit post Intra-Airline swapped schedule to create the **Intra-Airline Solution**



Step 4: Delay Ledger Mechanism

- Coordinator role given to airline with highest value in delay ledger
- Participants submit **flight priorities** to Coordinator
- Coordinator constructs the **DeLed Solution**

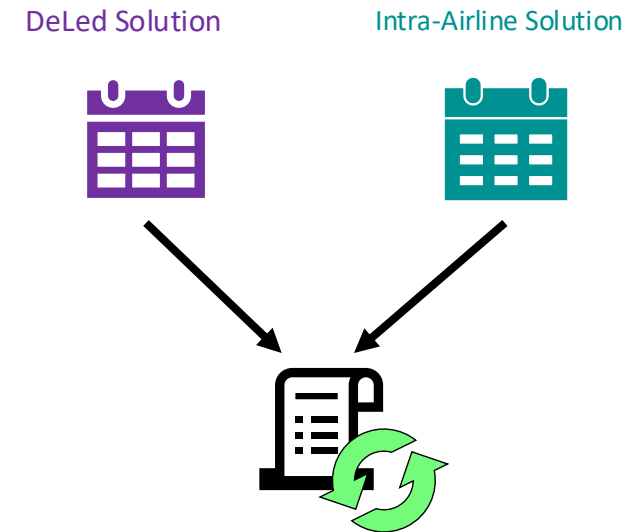


Step 5: Update delay ledger

- For each airline, change in mean delay between the **Intra-Airline Solution** and the **DeLed Solution** is recorded
- Ledger is **cumulative** across scheduling rounds

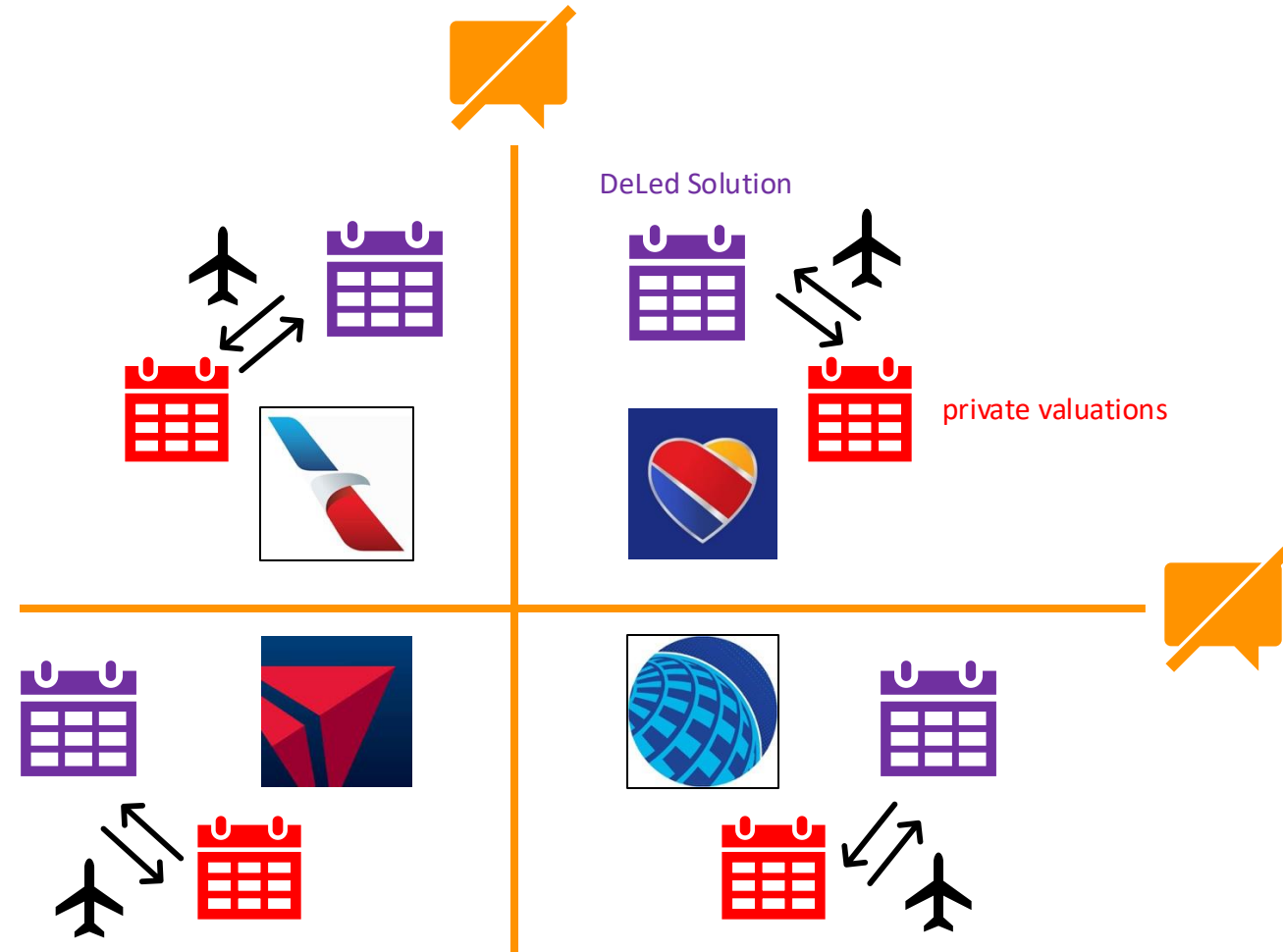
Round	Delay Change	Delay Ledger
1	+3	+3
2	-1	+2

DeLed Solution reduced airline's mean delay by 1 unit, relative to Intra-Airline Solution

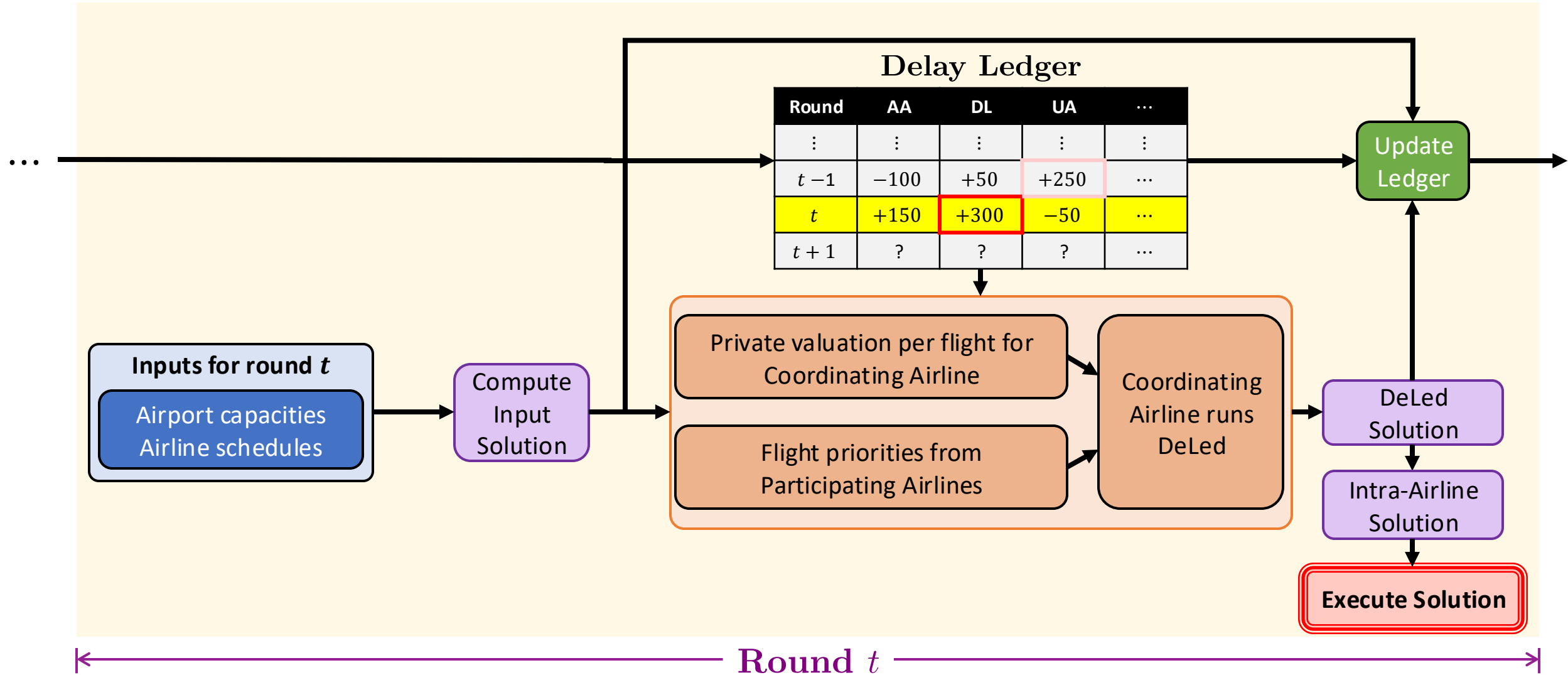


Step 6: Intra-Airline Substitution

- With **DeLed Solution**, airlines individually swap within their own flight slots
- Within an airline, swaps are determined based on **private valuations**



Flowchart



DeLed Formulation (in words)

Objective

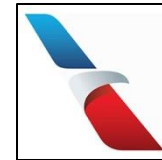
Minimize **coordinator's** private delay costs



Constraints

Total public delay does not exceed that of input solution

Increase in total public delay of each **participant** is bounded



High and medium priority flights cannot be delayed further

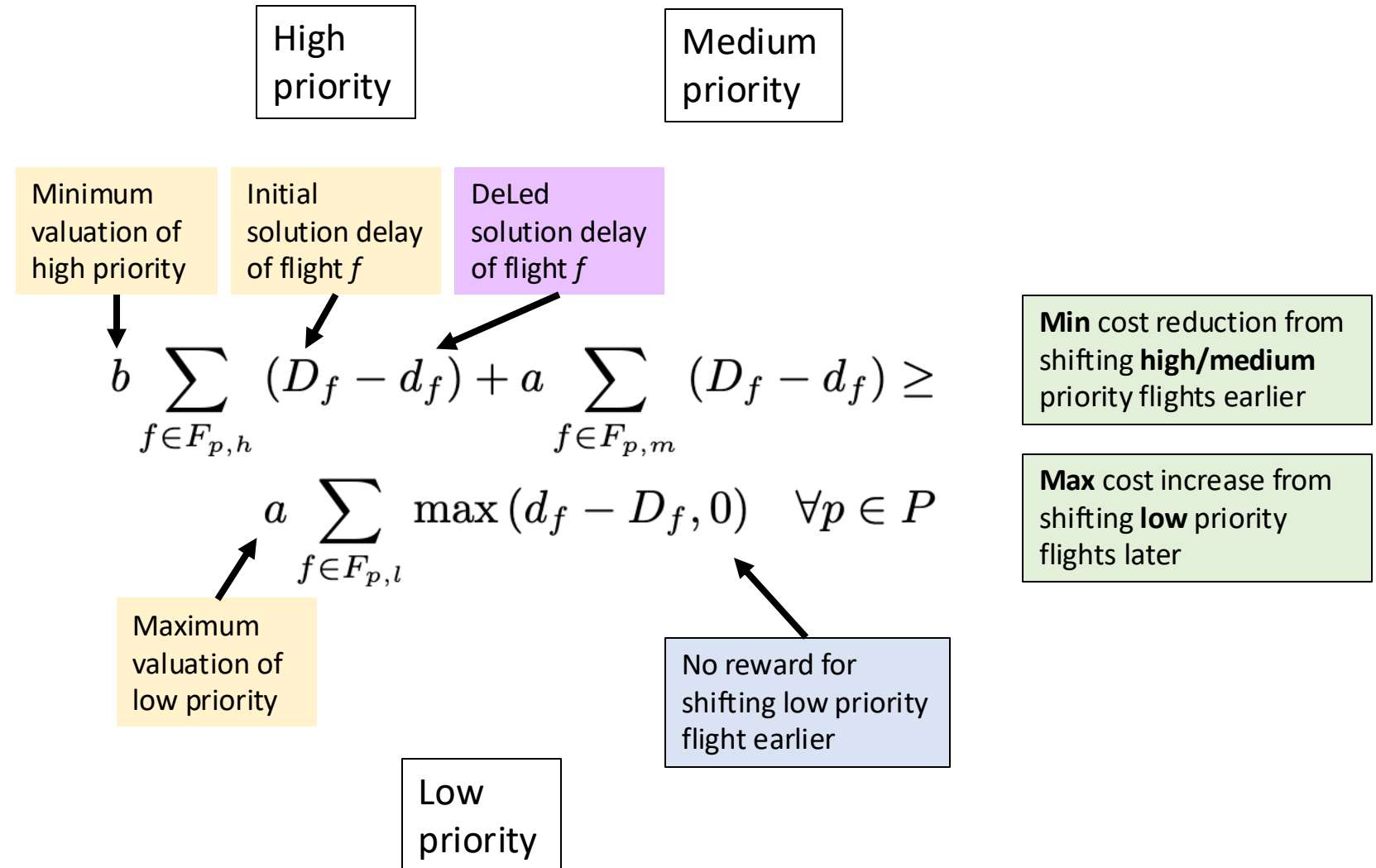


Participant private delay costs do not increase

Constraint: Participants' private delay costs

Flight Priority to Flight Valuation Mapping

Priority	Flight Valuation
High	$[b, \text{inf})$
Medium	$[a, b)$
Low	$[0, a)$

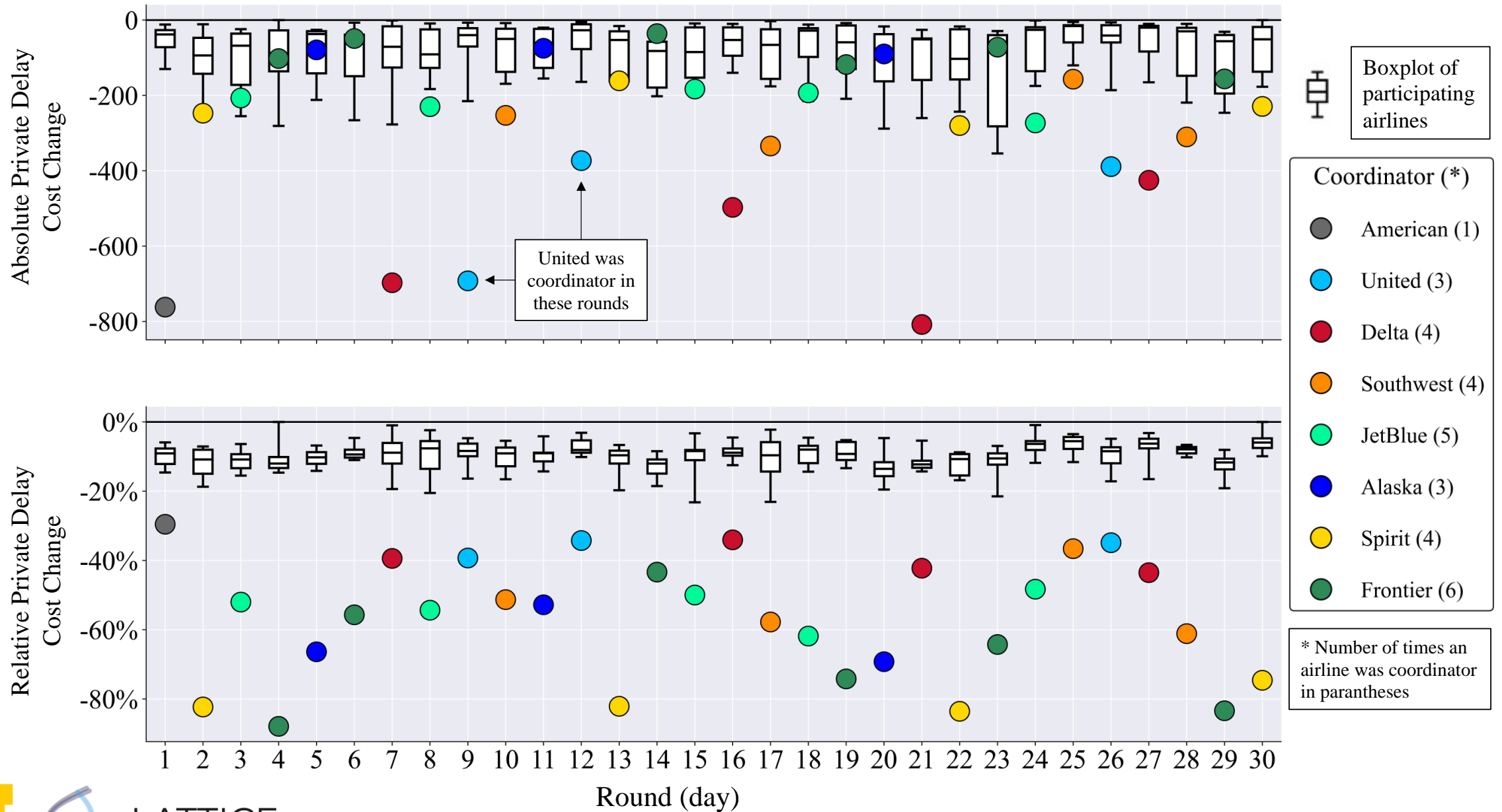


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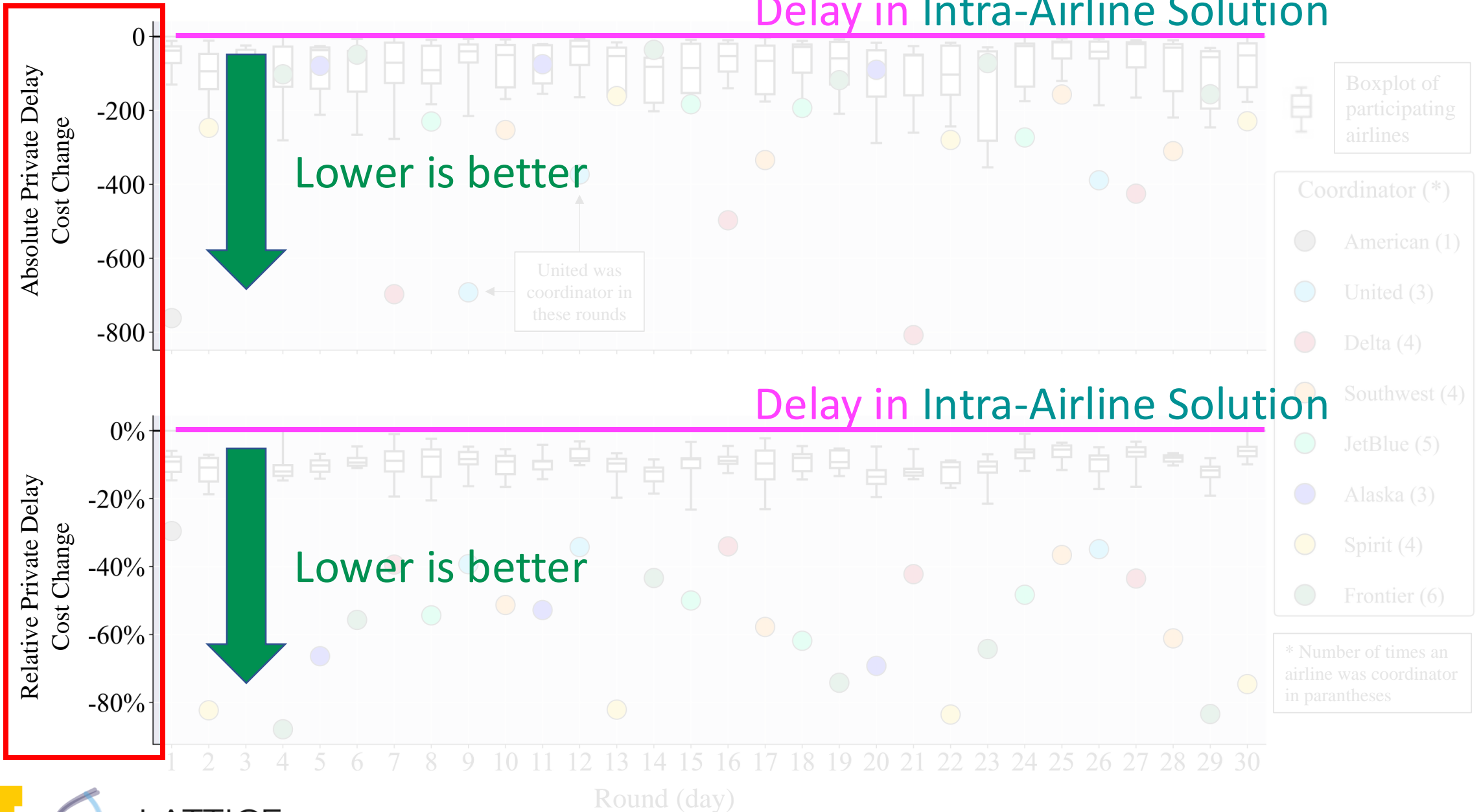
Experimental Setup

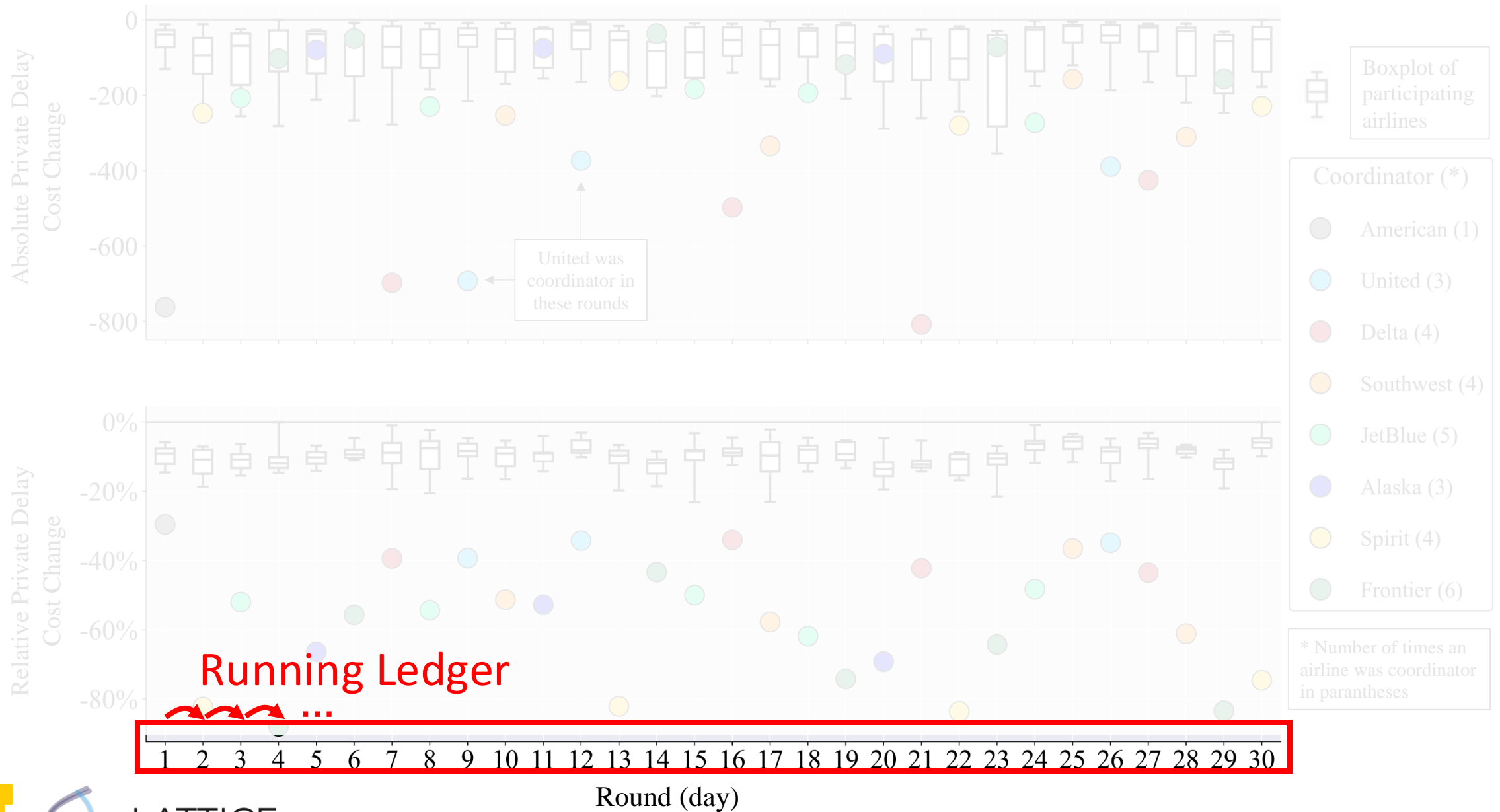
- Bureau of Transportation Statistics (BTS) On-Time Performance data for May 2019
 - Scheduled/actual departure and arrival times
 - Omit flights between non “Core 30 airports” and on small carriers that operate less than 1.1% of flights
- Round duration is 1 day, and capacity is estimated from throughput
- Random private valuations drawn from uniform distribution

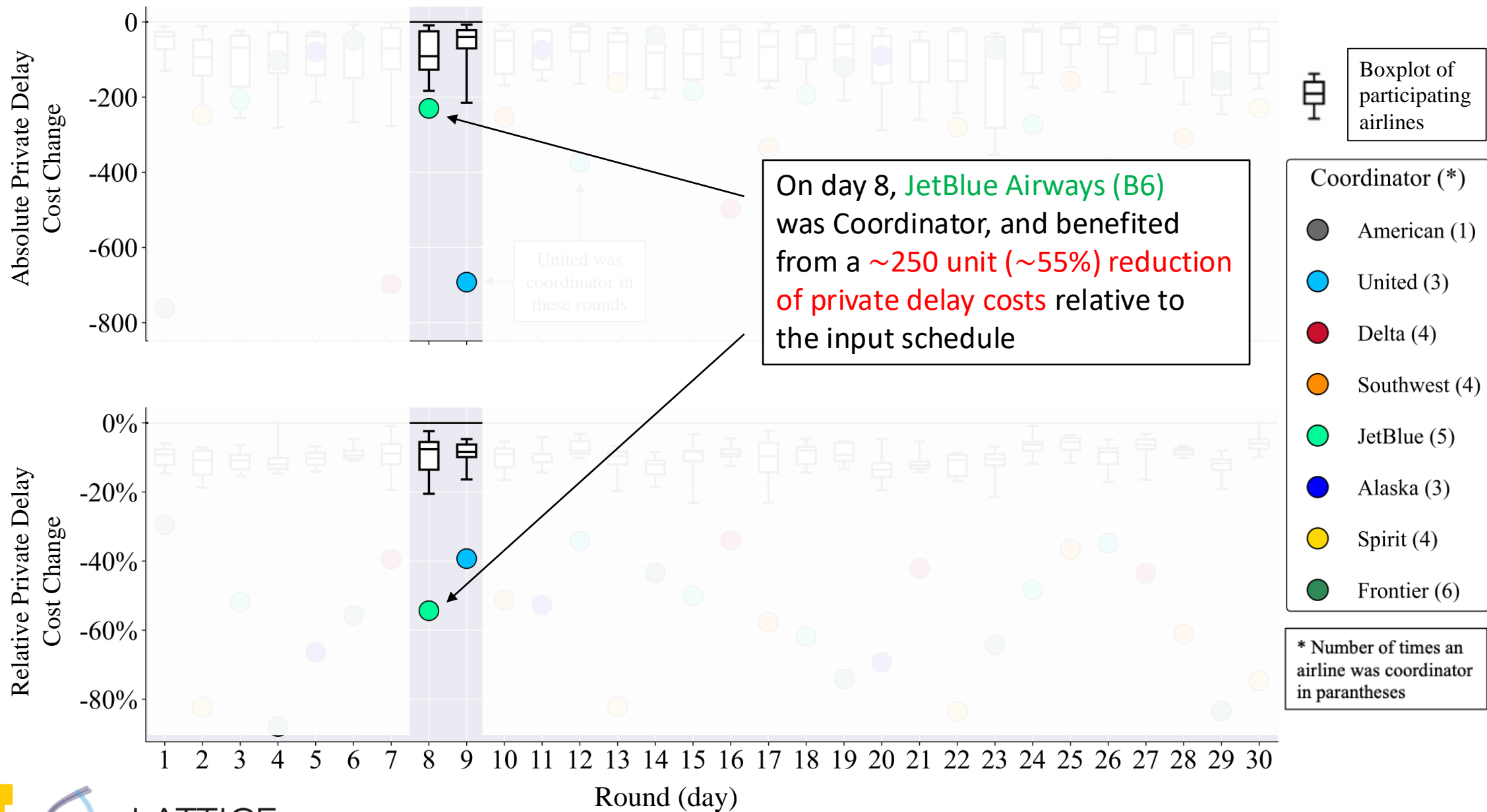


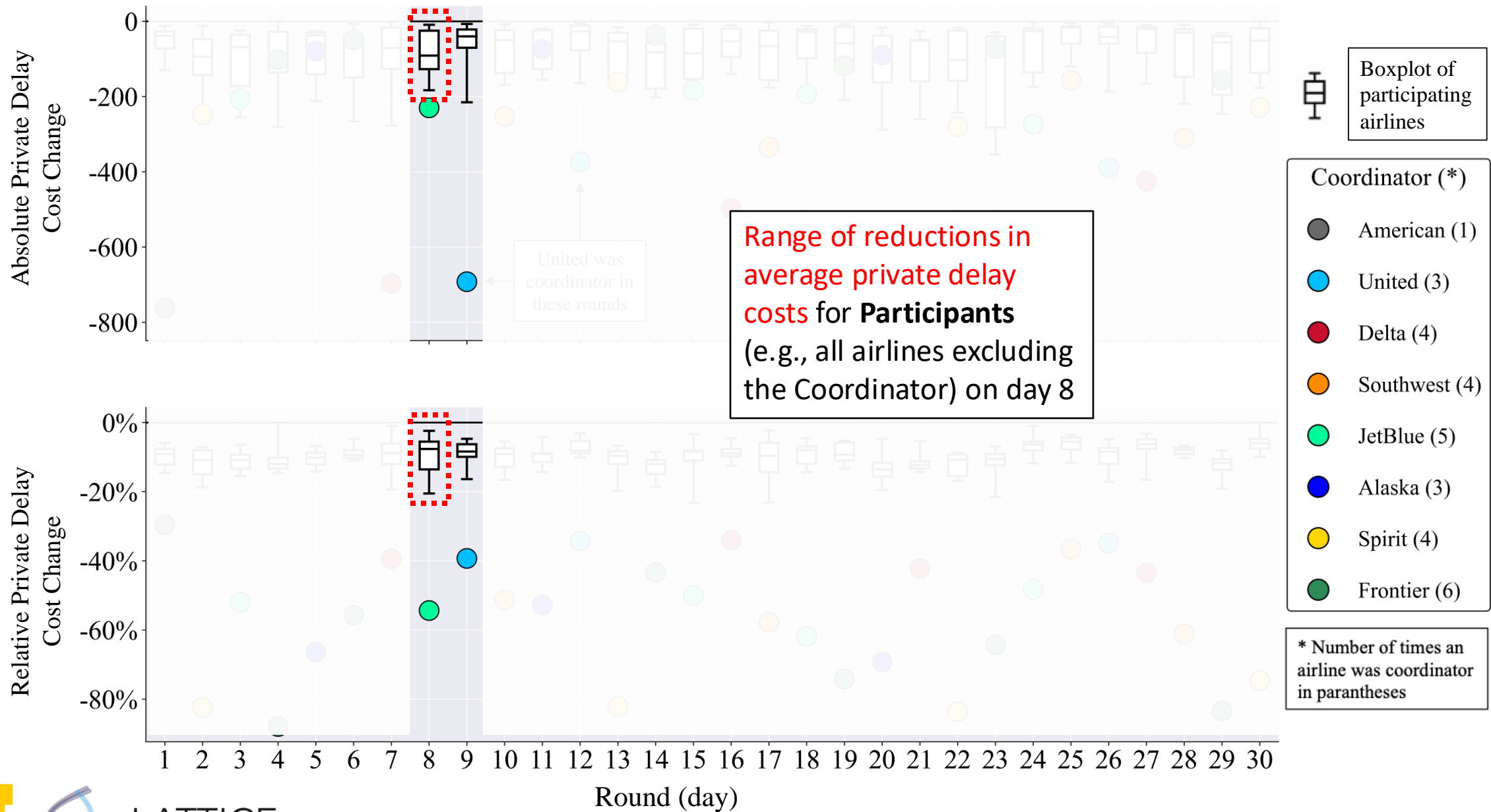
Delay in Intra-Airline Solution

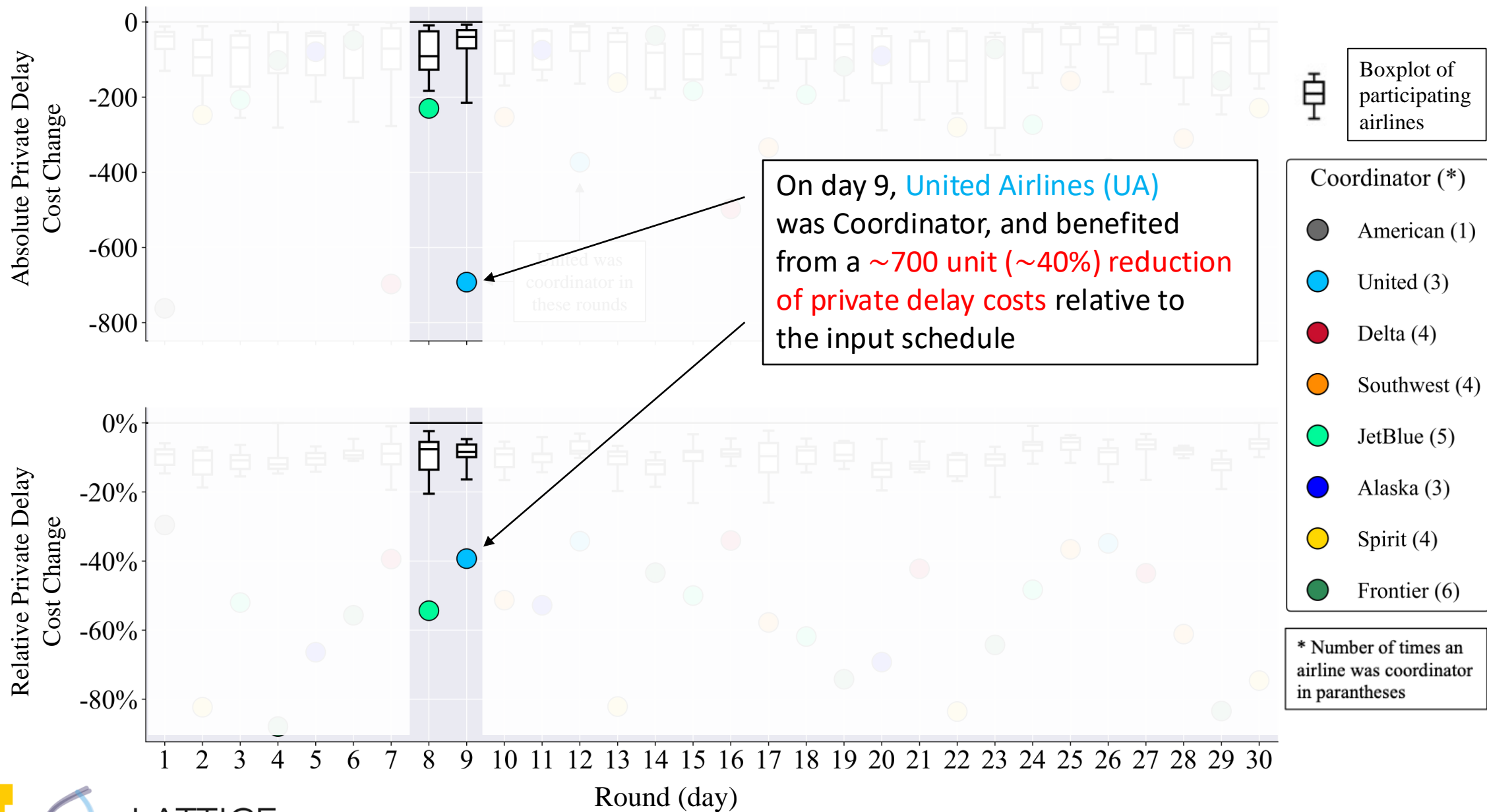
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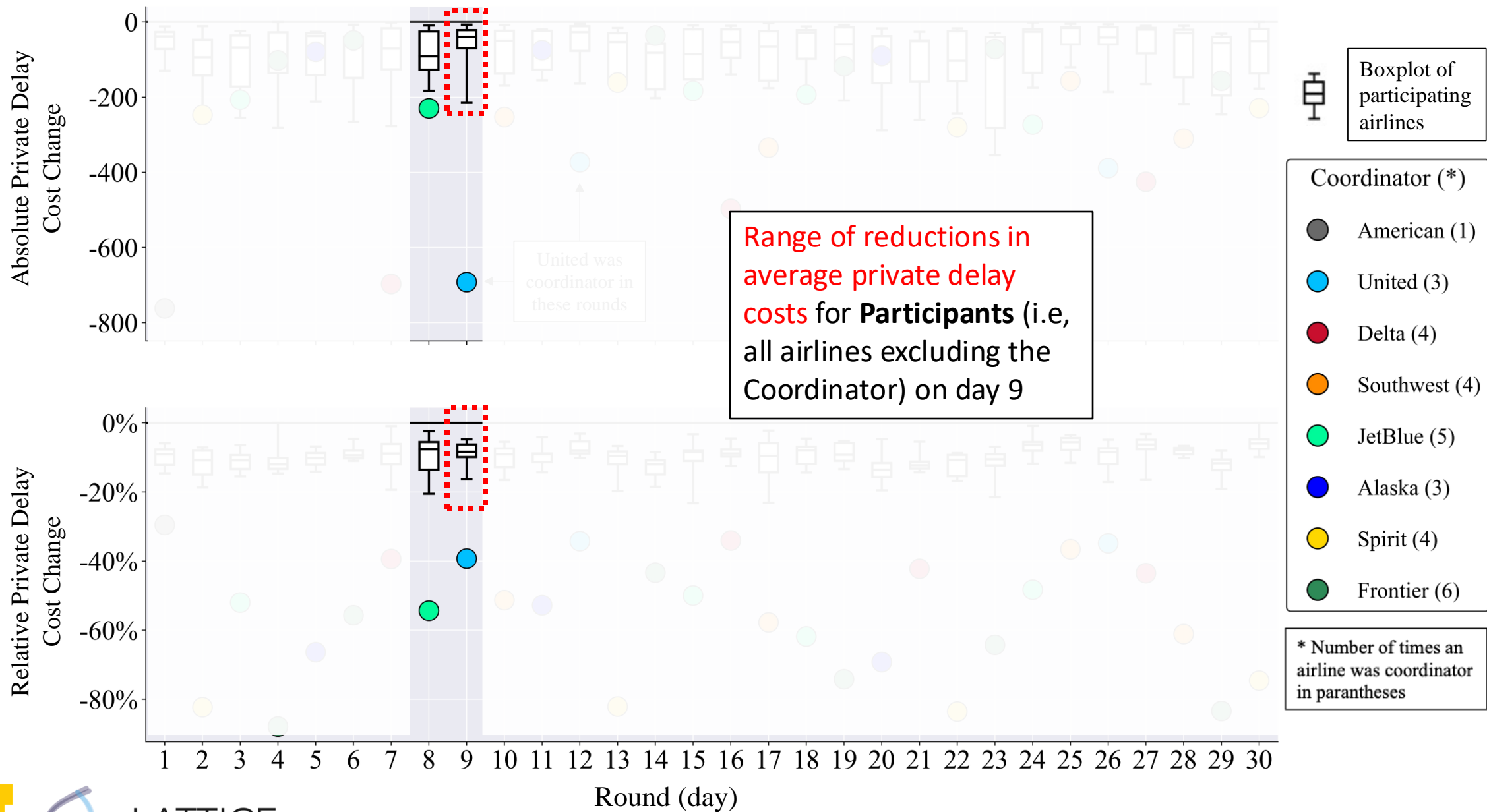


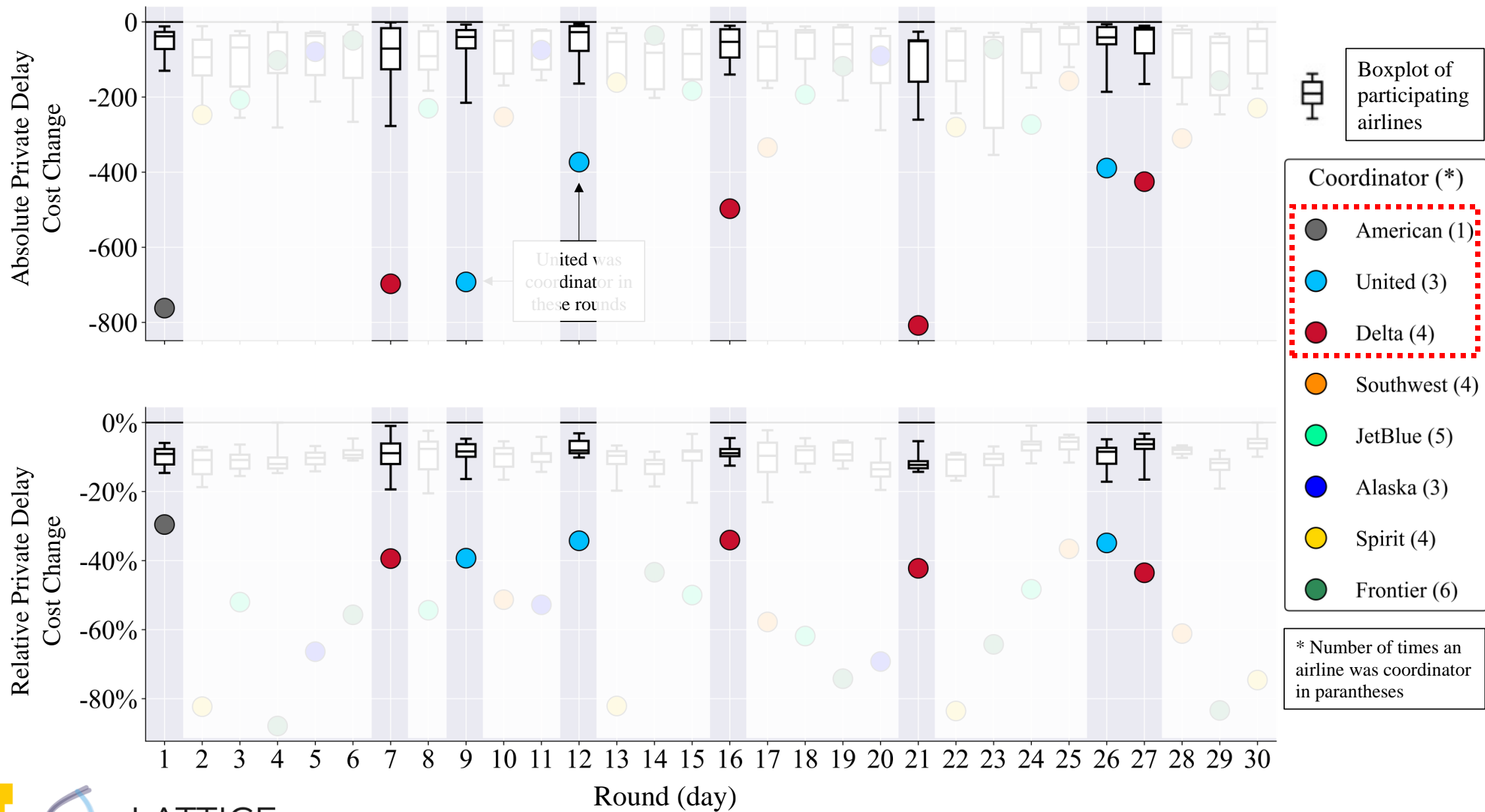












Results: Change in Delay Costs

DeLed Reduction in Private Delay Costs relative to Intra-Airline Solution (%)

	American	United	Delta	Southwest	JetBlue	Alaska	Spirit	Frontier
Overall	-8.3	-12.8	-13.6	-16.3	-16.8	-16.5	-18.6	-22.3
When participant	-7.6	-10.2	-9.5	-10.8	-9.5	-11.4	-9.1	-10.8
When coordinator	-29.6	-36.2	-39.8	-51.7	-53.3	-62.8	-80.7	-68.2

- All airlines see a reduction in private delay costs with DeLed
- Reduction is greater when coordinator (as private valuations can be used), but reduction still present when participant

Challenge: Inter-airline swaps are difficult to facilitate

Delay ledger tracks cumulative increase in public delay relative to input solution

Coordinator role given to airline with highest value in delay ledger

Coordinators use private valuations, and participants provide **flight priorities**

Participants are guaranteed to not see increase in private delay costs

8-22% reduction in private delay costs, relative to just intra-airline substitution

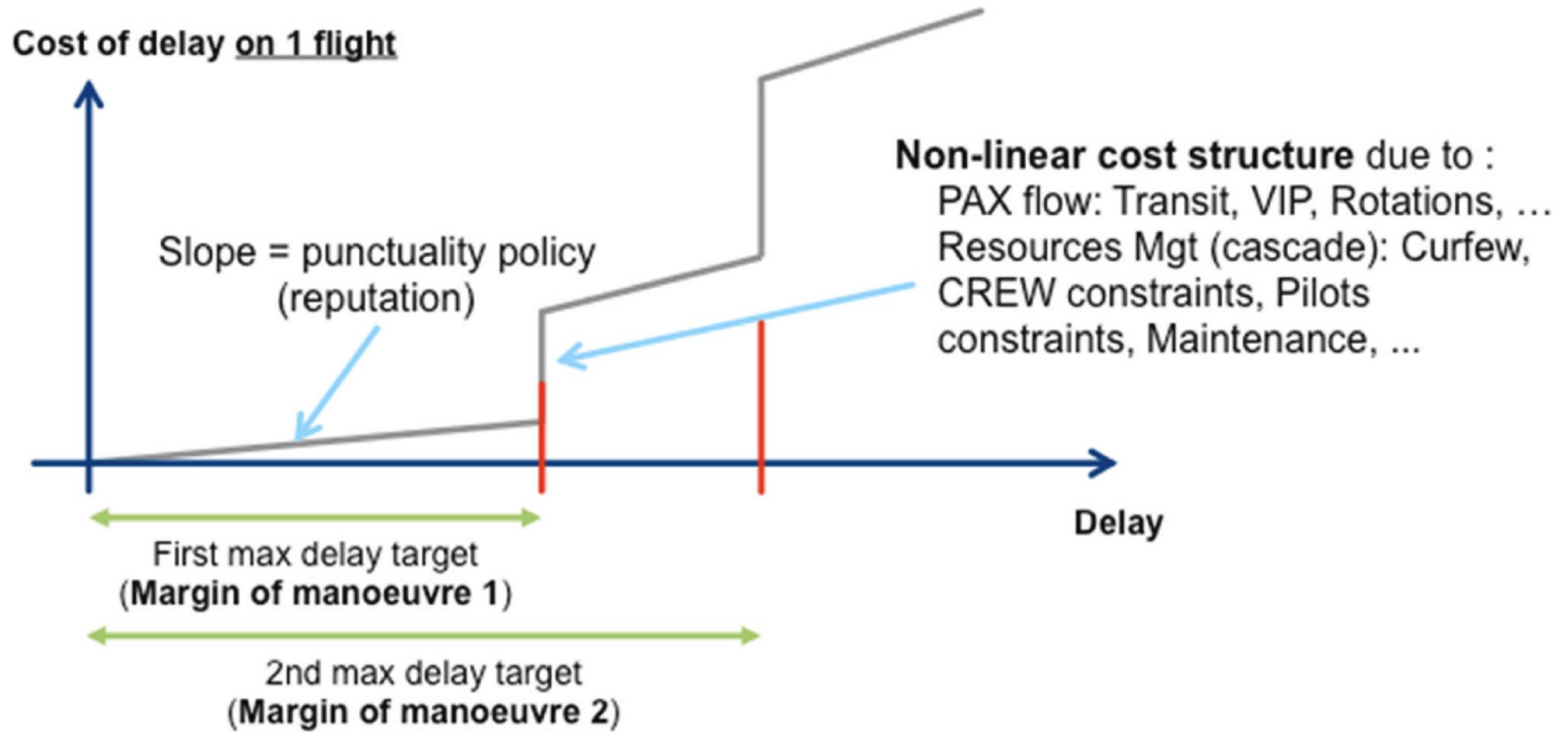


Fig. 1. Typical cost-delay model profile per flight.

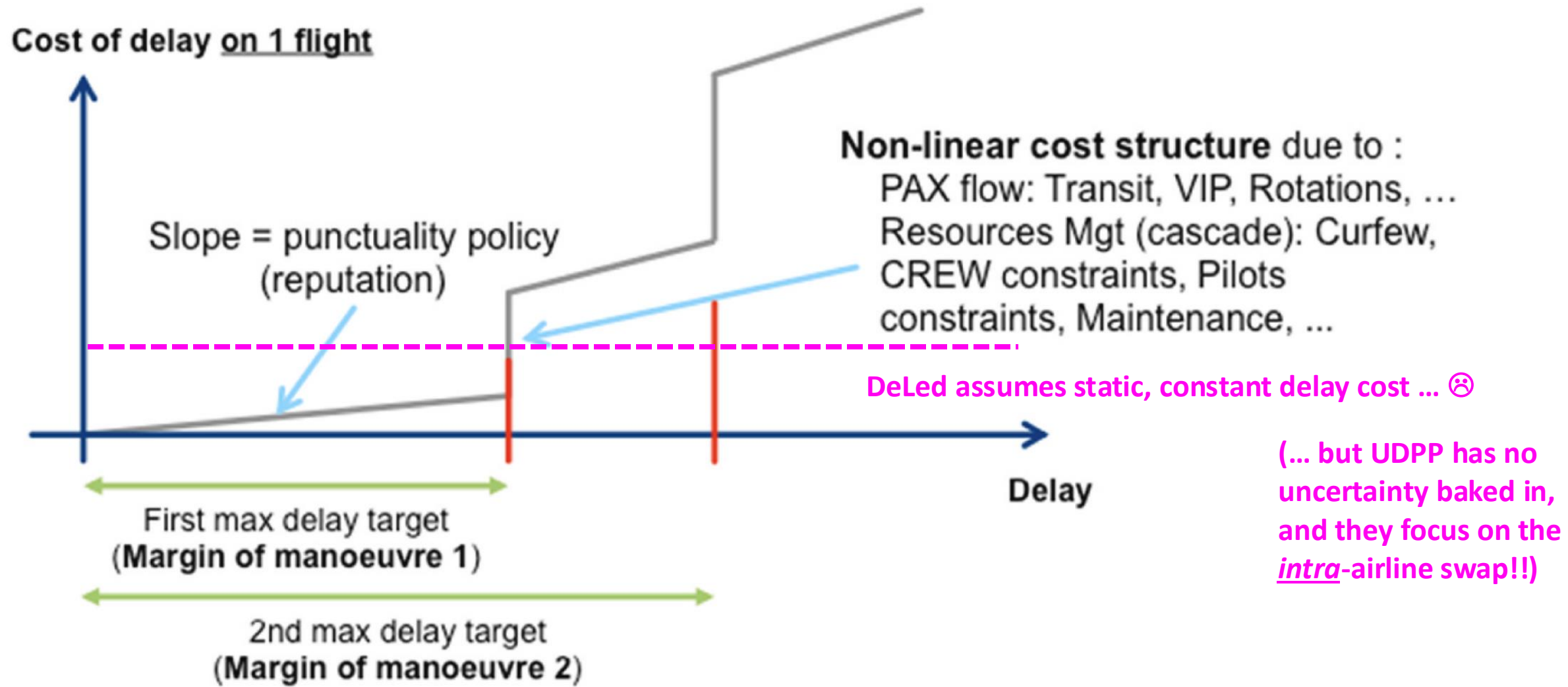


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Thank You!

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