



Domino – Novel tools to evaluate ATM systems coupling

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<https://domino-eu.com/>

<https://cordis.europa.eu/project/id/783206>



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Exploring the Boundaries of ATM



Project overview



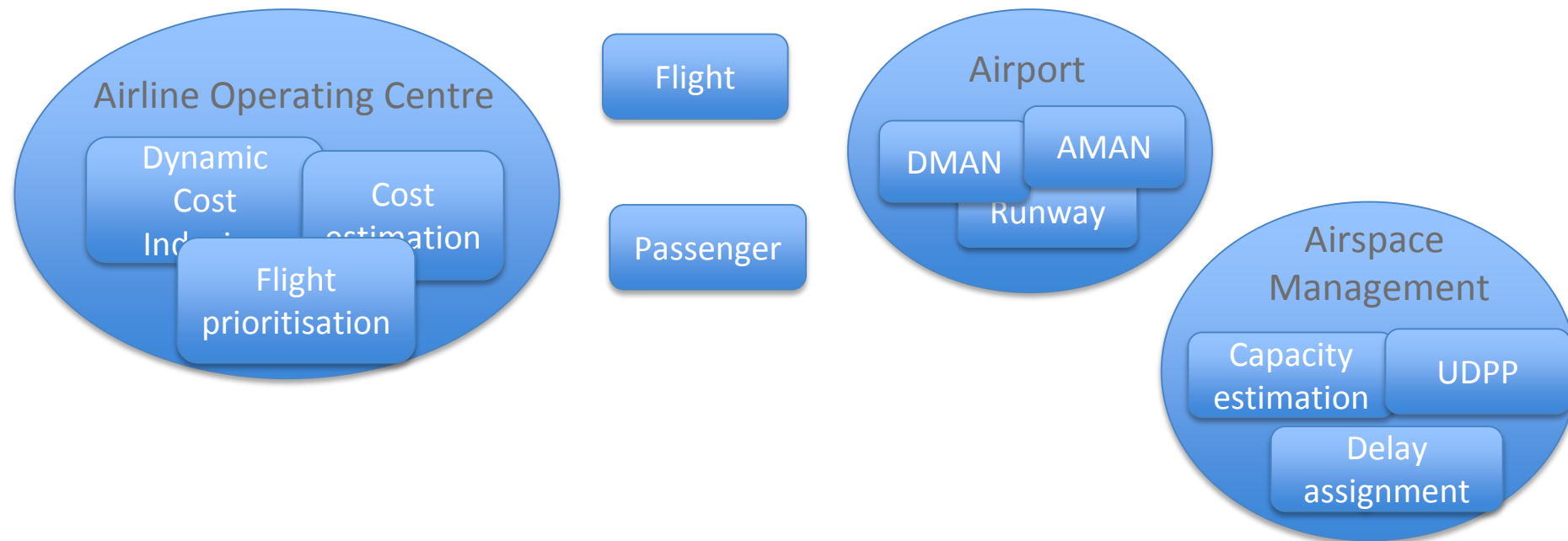
Project goals and objectives

- Develop a set of **tools**, a **methodology** and a **platform** to assess the coupling of ATM systems from a **flight** and **passenger** perspective

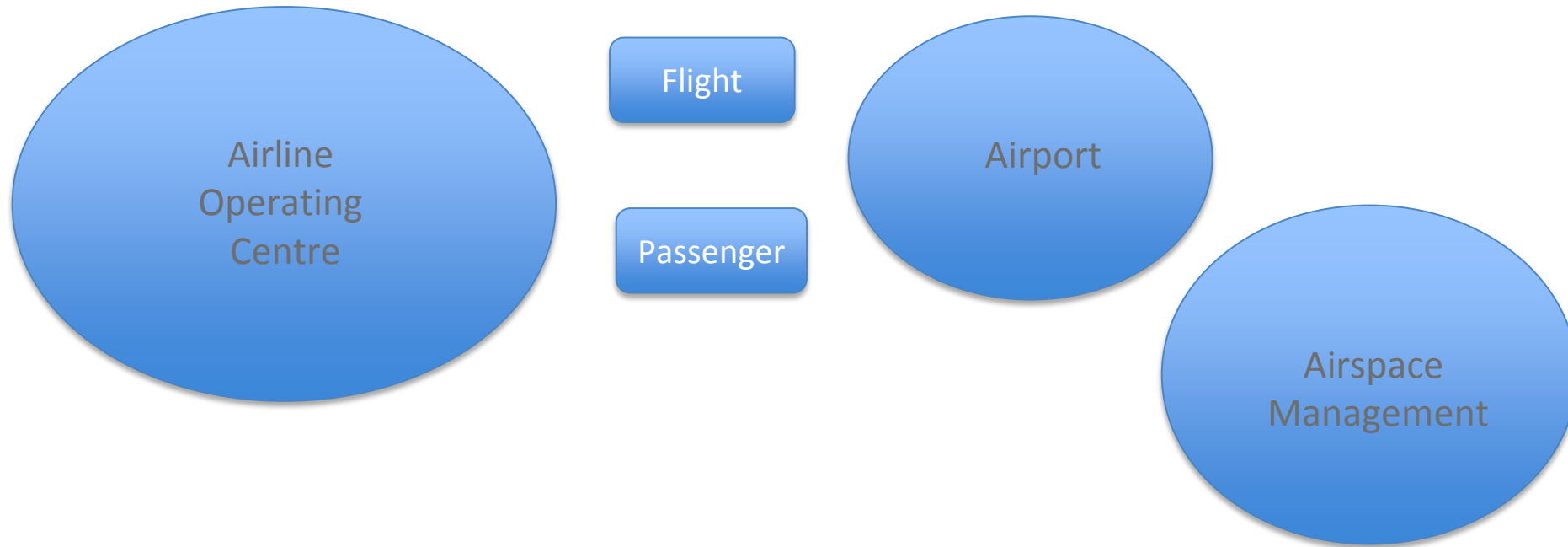
Project goals and objectives

Specific challenge

- Architecture of ATM system is complex



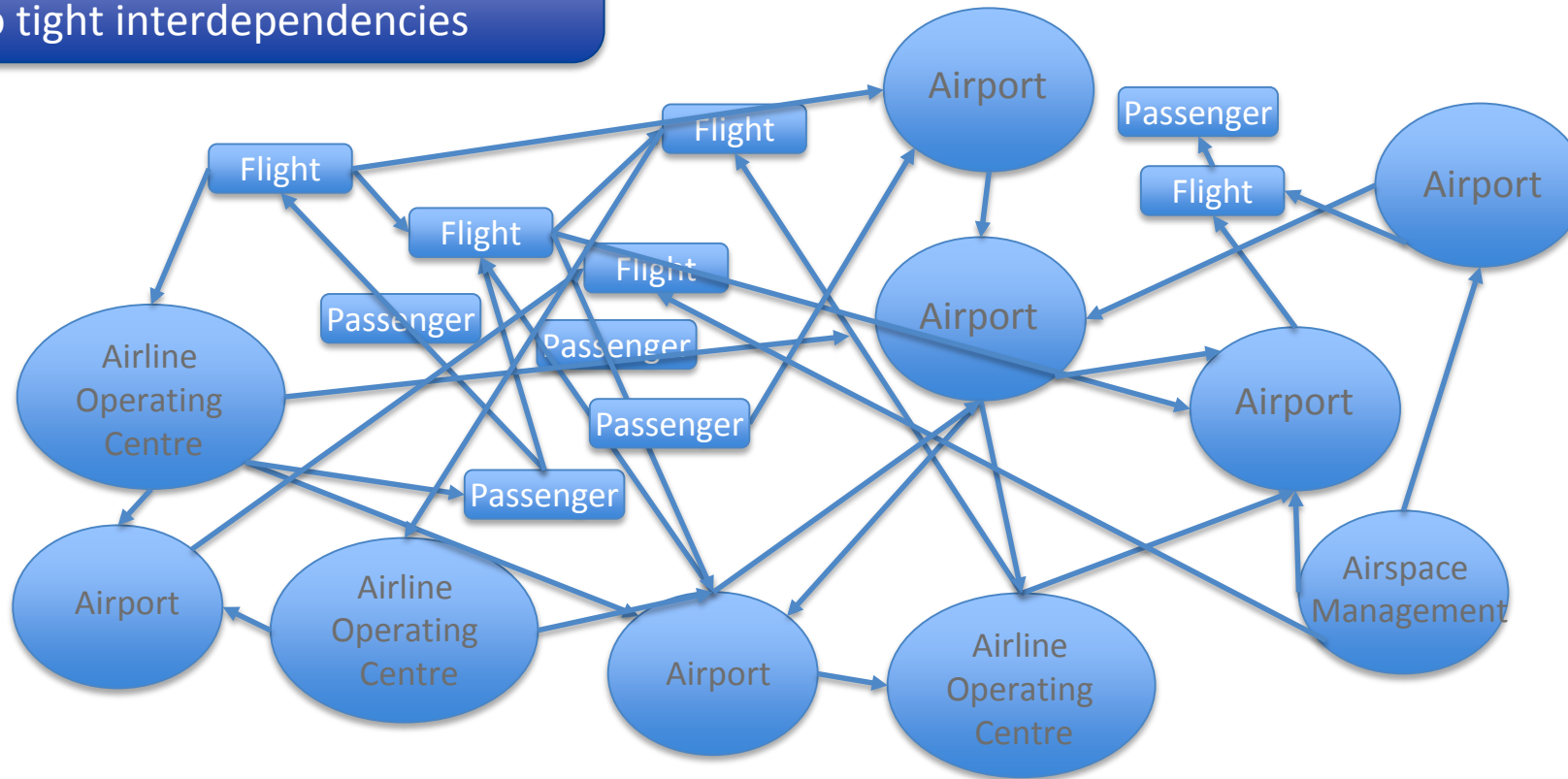
Project goals and objectives



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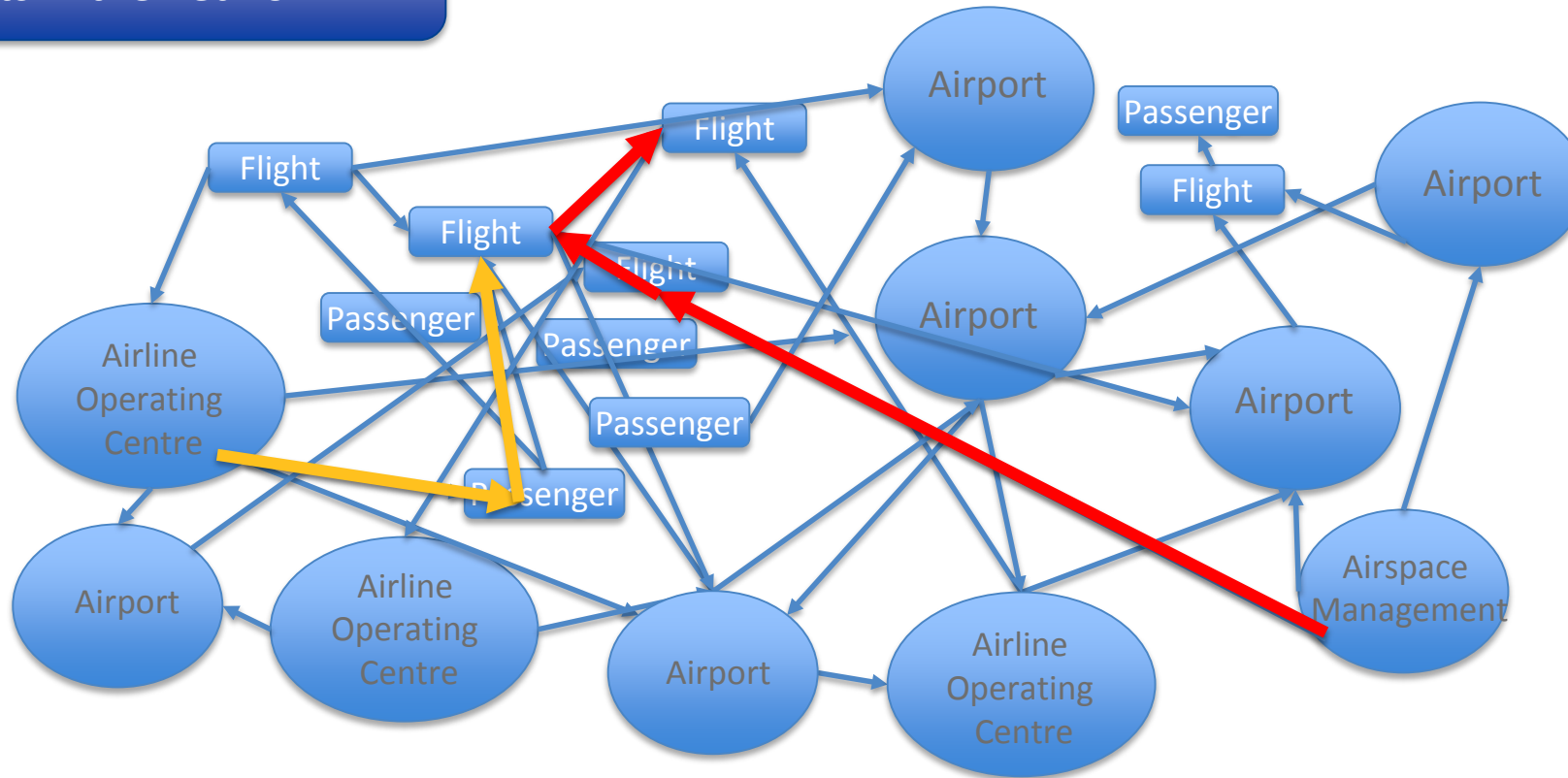
Specific challenge

- Introducing change into this system is often difficult due to tight interdependencies

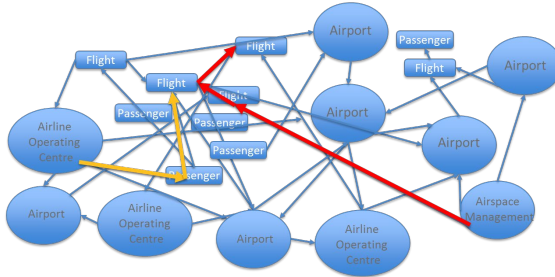


Project goals and objectives

Propagation of delay/cost through
the elements in the network

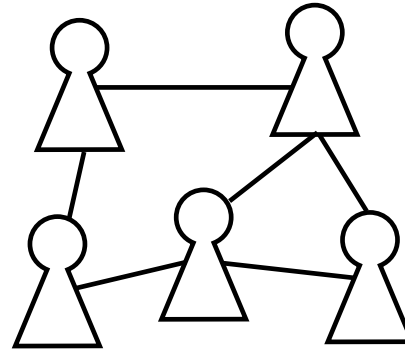


Project goals and objectives



Different actors

- Interacting (cooperation/competition)
- With rules defined by system
- Considering own utility functions (cost/delay)



Changes in the system

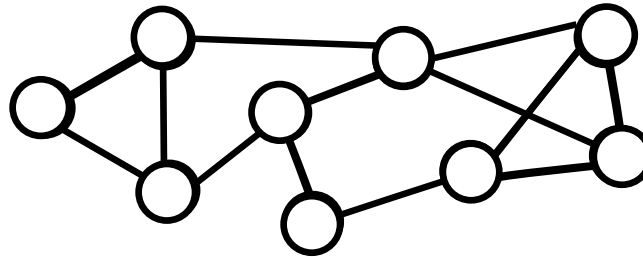
- Modify the rules by which the actors operate
- Change the degree of uncertainty
- Modify the degree of competition/cooperation

Project goals and objectives

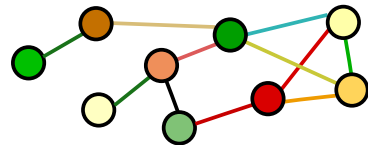
- Contrasting stakeholder perspectives

Flight 

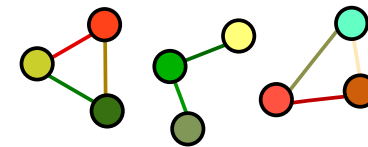
Passenger 



Flight network analysis

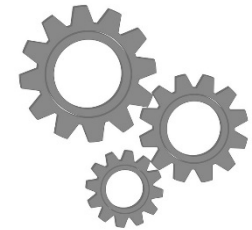


Passenger network analysis



Project goals and objectives

- Create a **toolbox**
 - To analyse coupling of system
 - Identifying, testing, validating metrics based on complexity science
- Provide a **methodology**
 - Defining case studies based on selected mechanisms
 - Describe how methodology & toolbox can be applied to historical data
- Create detailed **agent-based model**
 - Capturing interactions between stakeholders & ATM elements
 - working in close cooperation with stakeholders
 - generating behavioural and cost functions



Work performed



- **Definition of network metrics**

- Review and evaluation of existing **complexity network metrics**
- Definition and evaluation of newly specialised network metrics for **centrality** and **causality** considering stakeholders and system particularities
- Assessing relationship between newly defined network metrics and current operational indicators



- **Methodology to evaluate mechanism on platform with network metrics**

- **Broad case studies** to evaluate platform and metrics
- Validation of platform and metrics with **targeted case studies**



- **Development of testing platform**

- Design and implementation of **agent-based model**
- Definition of **behaviour models** and complex cost functions
- Validation of model with interaction with **stakeholders** and historical datasets



Results overview



Metrics



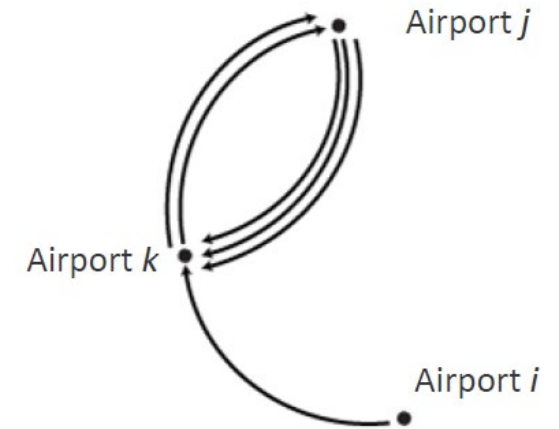
- Literature review on classical and advanced metrics
 - Need for **cost-driven** and **passenger-centric** metrics
 - Definition of metrics capturing **network effects** in the entire system:
centrality and **causality**



Metrics

- Centrality

- Assess the importance of a node in a network
- Number paths coming from or going to a given node to estimate this importance
- New metrics that take into account the temporal aspect of a path on the airport-flight network, i.e., **feasible connection**
- Measure the **loss of connectivity** (between **scheduled** and **actual** itineraries) of an airport, in terms of broken itineraries
- Two versions of this metric:
 - **Trip-centrality**: potential connectivity of an airport, based on flight schedules
 - **Passenger-centrality**: realised connectivity of an airport, based on planned passenger itineraries



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Captures loss of connectivity experienced by passengers

Easy to highlight airports impacted

Possibility of layered analysis (e.g., by airline)

Metrics

- (Granger) causality
 - Granger causality answer the question: “Can we predict the state (e.g., congestion) of node A knowing the state of node B?”
 - If this is the case → **casual link** between A and B (‘B causes A’)
 - How? Use an autoregressive model
 - Different choice for the ‘state’
 - Classical (**Granger in mean**): x and y are departure delays, averaged for instance over 1 hour
 - New in Domino (**Granger in tail**): use of ‘extreme’ states, i.e., x=1 if delay over a threshold, 0 otherwise

Metrics

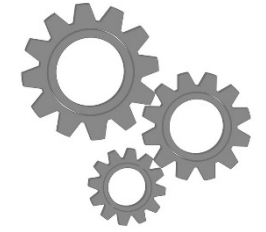
Complex but valuable
Intuitive metrics even if their quantitative values
are difficult to interpret
Represent truly network-based metrics

- (Granger) causality
 - Granger causality answer the question: “Does the knowledge of the state of node B (e.g., congestion) of node A knowing the state of node B?”
 - If this is the case → **casual link** between A and B (‘B causes A’)
 - How? Use an autoregressive model
 - Different choice for the ‘state’
 - Classical (**Granger in mean**): x and y are departure delays, averaged for instance over 1 hour
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Metrics

- Application of metrics
 - Methods can be applied to any **network of subsystem** having links between them (beyond airport-flight)
 - Opens the way to estimation of the degree of '**tightness**' of the air transportation system at different levels
 - Metrics applied to **historical data** and to output of the model
 - Some degree of overlap with other existing metrics, but they capture other aspects of **systemic disruptions**

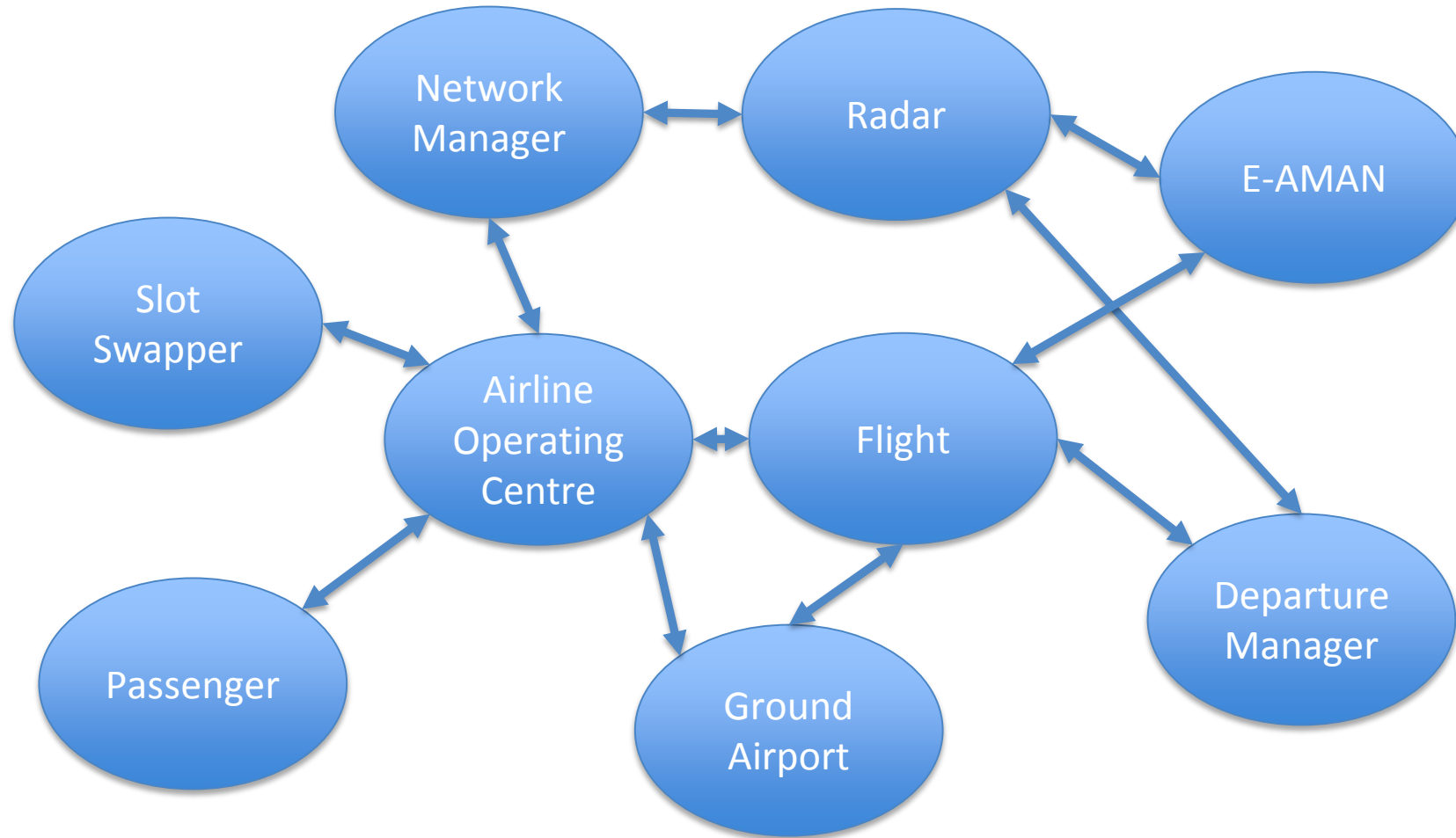
Platform – Mercury ABM



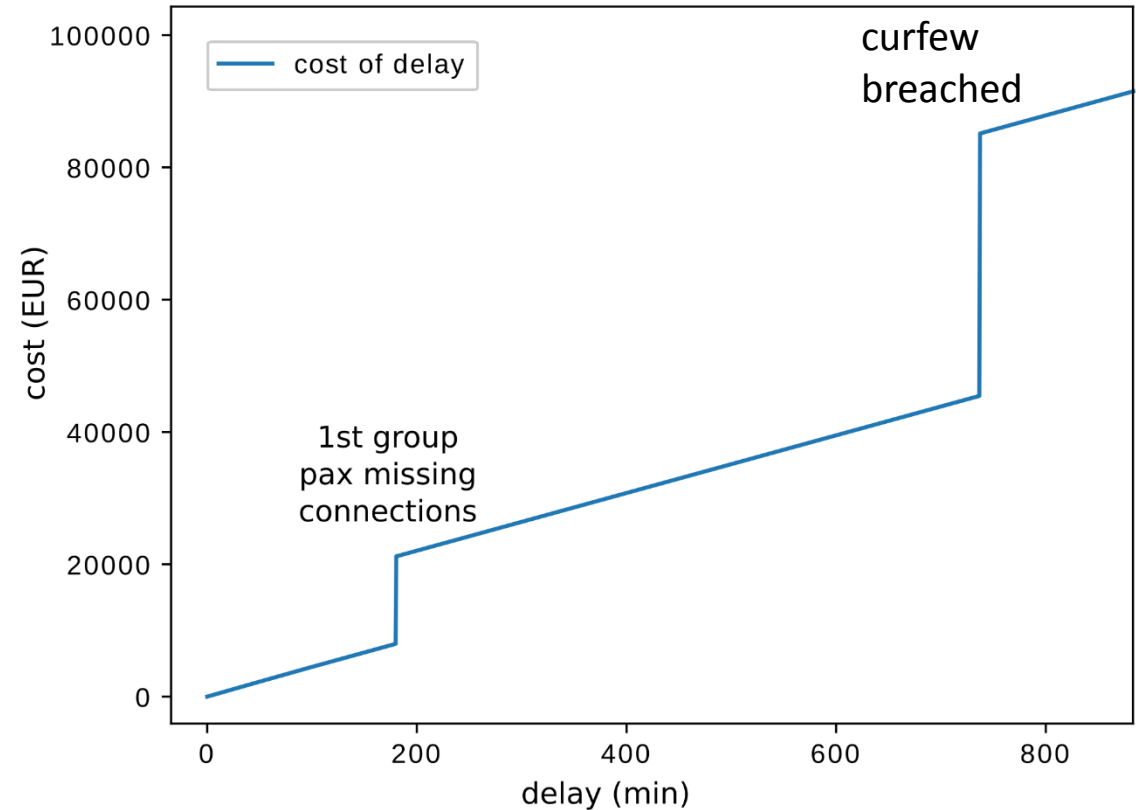
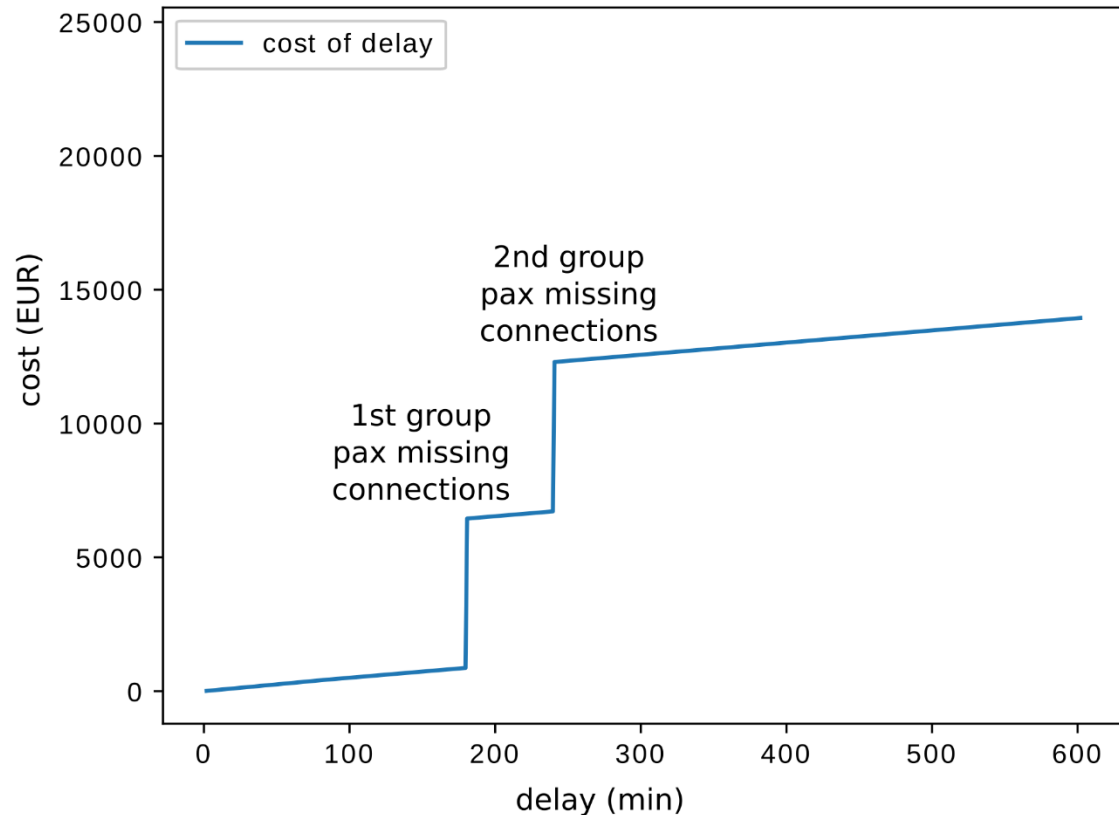
- Mercury is an European-scale simulator developed over nearly a decade
 - Detailed description of a day of operations (**pre-tactical/tactical**)
 - Individual **passenger tracking** (including connections)
 - European-scale: 800 airports, 30K flights, 3.4M pax
 - Monte-Carlo simulation with tailored distributions
 - Agent-based paradigm



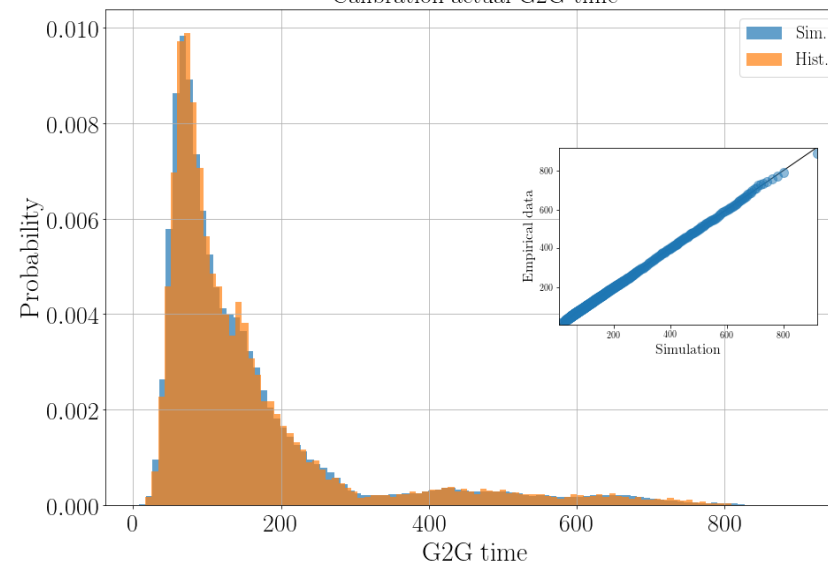
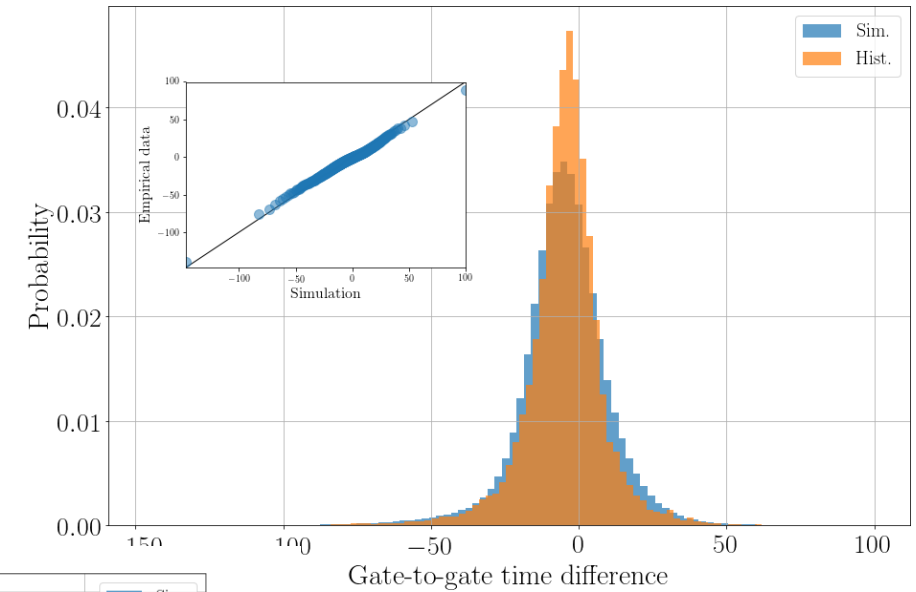
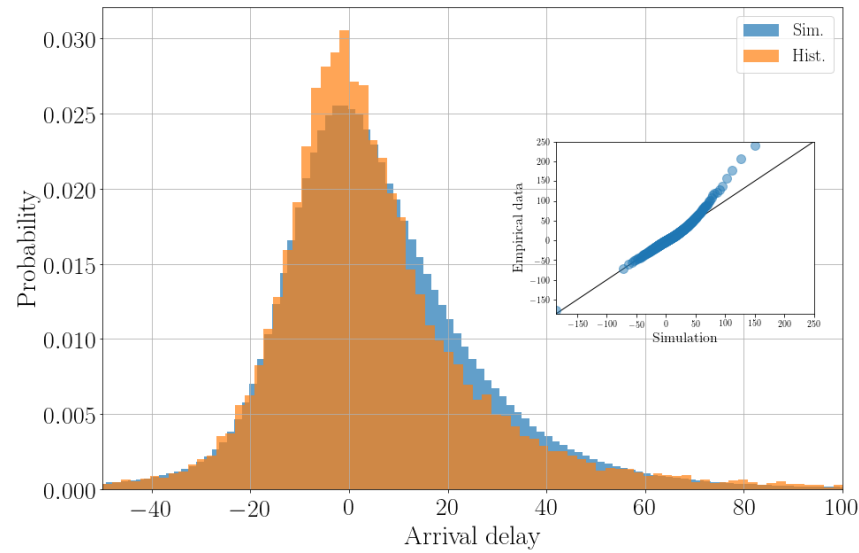
Platform – Mercury ABM – Agents



Platform – Mercury ABM – Cost functions



Platform – Mercury ABM – Calibration



Methodology to evaluate mechanisms



1. Define mechanism as

- **relationships** (or modifications thereof) between agents and/or;
- the introduction (or modification) of an **agent** and/or;
- modifications of **parameters** and/or;
- additional **events** and/or;
- additional options in the agents' **behaviours**



Methodology to evaluate mechanisms

1. Define mechanism

2. Implementation of the mechanism in the model

3. Defining scenarios

- Schedules for flights and planned itineraries for passengers (12/09/2014)
- Other parameters can be fine-tuned: level of turnaround delay, ATFM regulations, simulation scale (e.g., European-wide, focusing on a subset of flights or airports)
- Level of stress in the system: level of delay
- Focused scenarios (e.g., local disruptions at some airports) to answer operational questions

Methodology to evaluate mechanisms

1. Define mechanism

2. Implementation of the mechanism in the model

3. Defining scenarios

4. Different realisations of each scenario are then produced

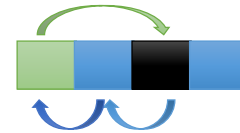
- Low-level observables (delay for each flight, cruise distance, fuel, etc.)
- Advanced metrics can then be computed from the output

Mechanisms

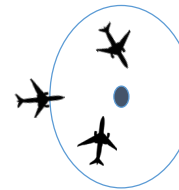
- 4D Trajectory Adjustment (4DTA)



- Flight Prioritisation (FP)



- Flight Arrival Coordination (FAC)



Implementation Level

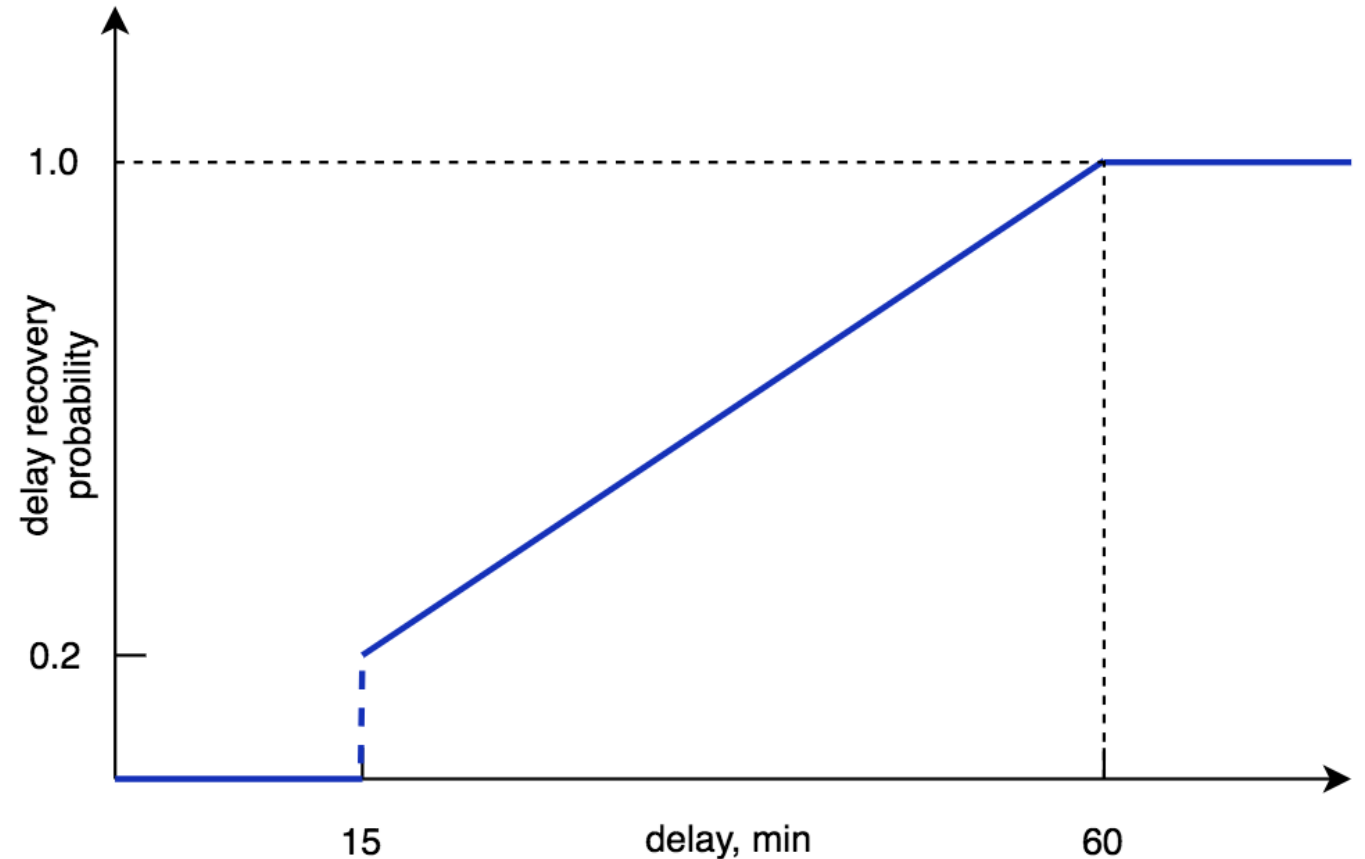
Level 0
Current

Level 1
Improved

Level 2
Futuristic

Example mechanism (4DTA)

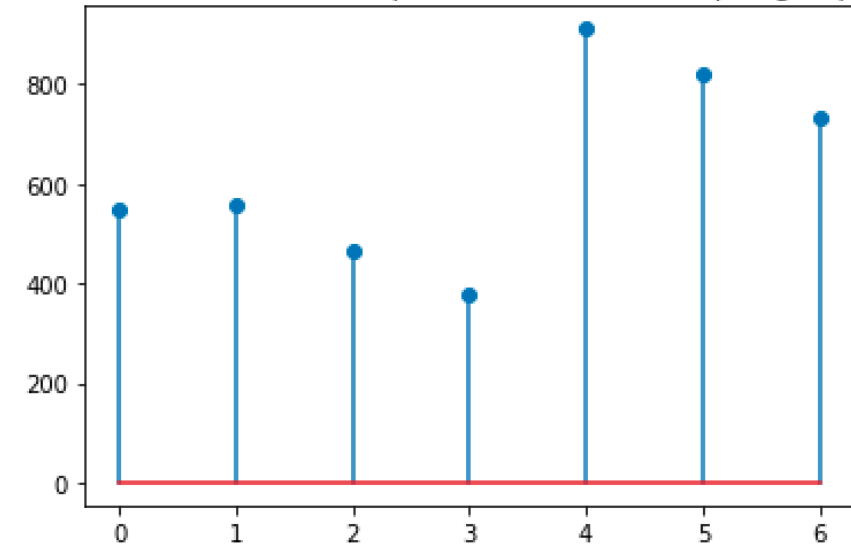
- Level 0 – Rule of thumb
 - Wait for premium passengers up to 15 minutes (WfP)
 - Probability of speeding up based on expected delay (DCI)



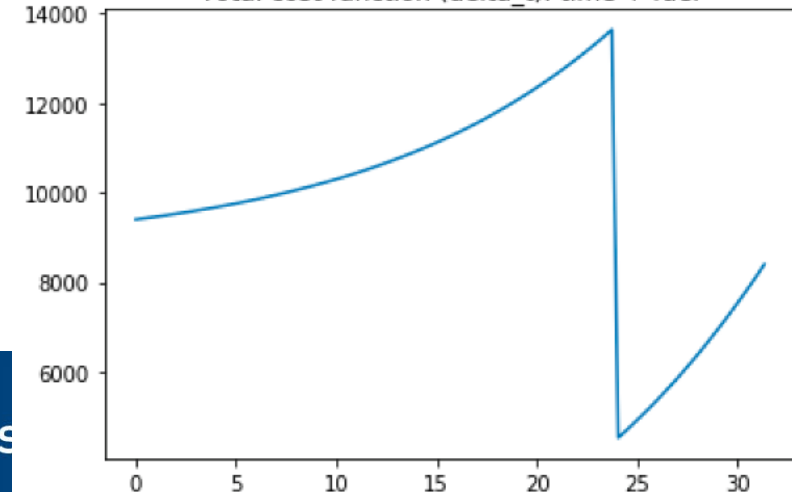
Example mechanism (4DTA)

- Level 1
 - Wait for passengers balances
 - Cost of delaying passengers ready to board
 - Cost of rebooking connecting passengers missing connection
 - Cost index decided at Top of Climb (TOC) considering
 - Cost of fuel
 - Cost of delay

Total cost of wait/no-wait options: no-wait + each pax group wait



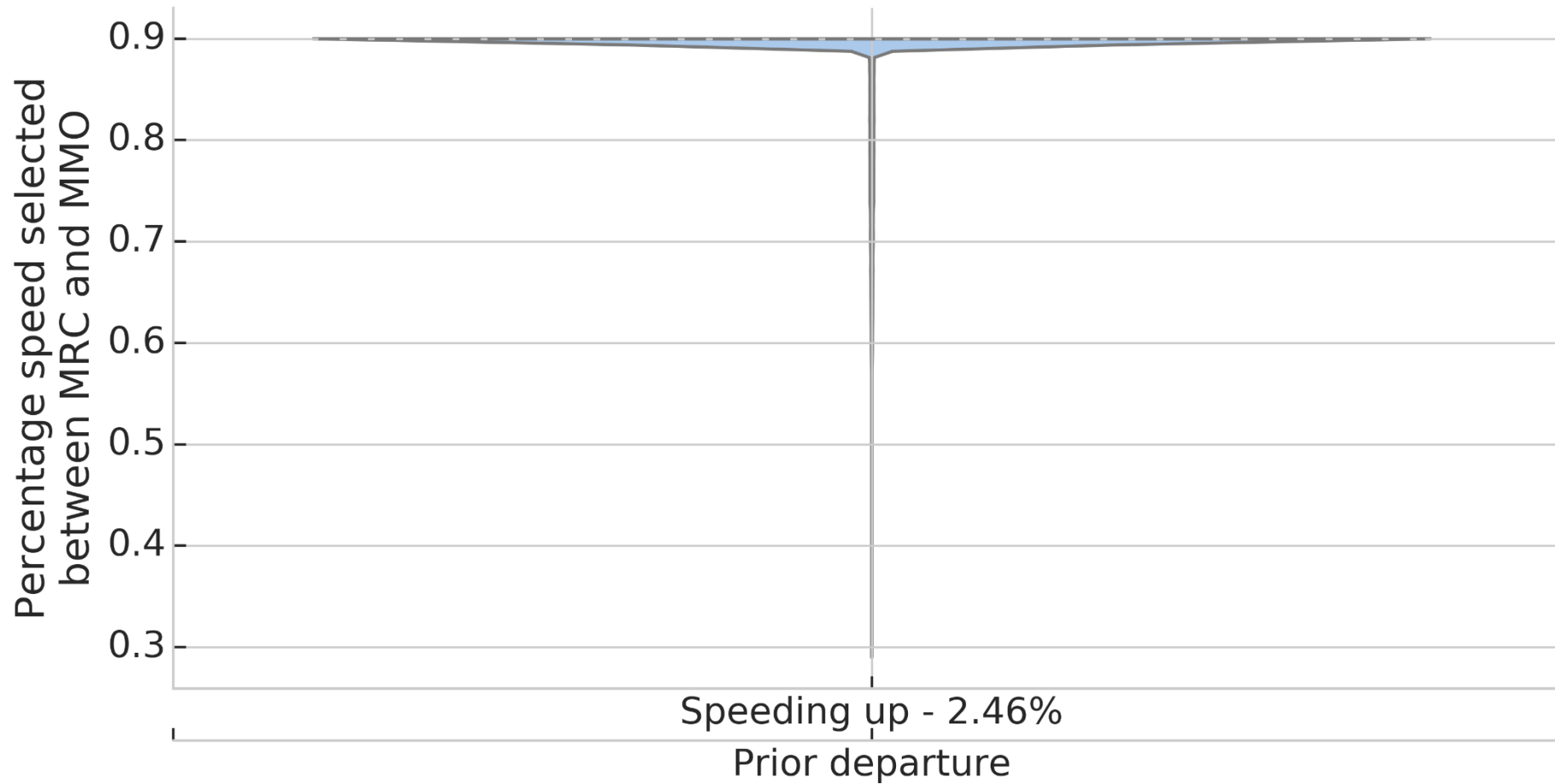
Total cost function (delta_t): time + fuel



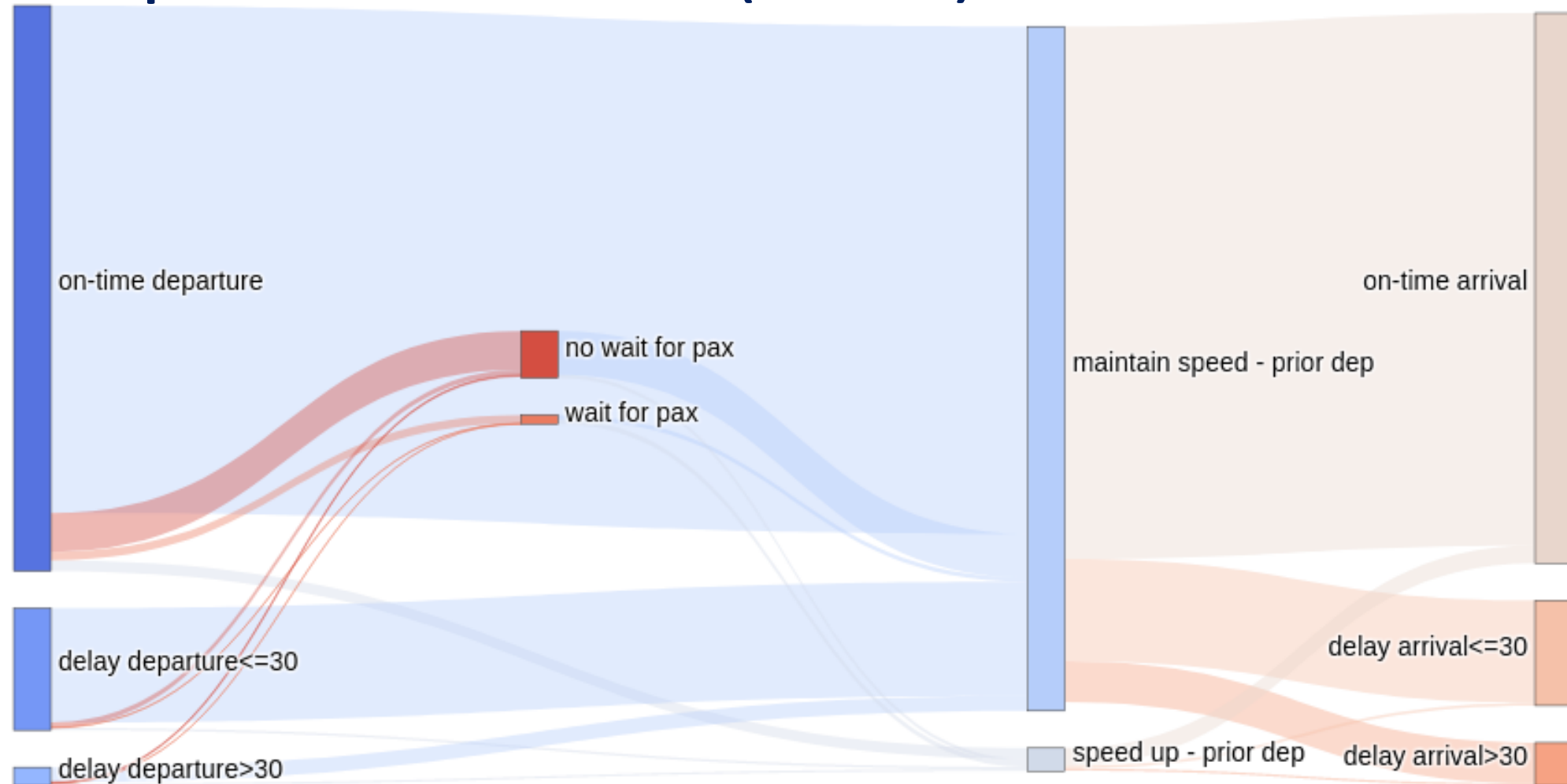
Example mechanism (4DTA)

- Level 2
 - Joint decision WfP and DCI at gate
 - DCI (including slowing down possibility) at TOC

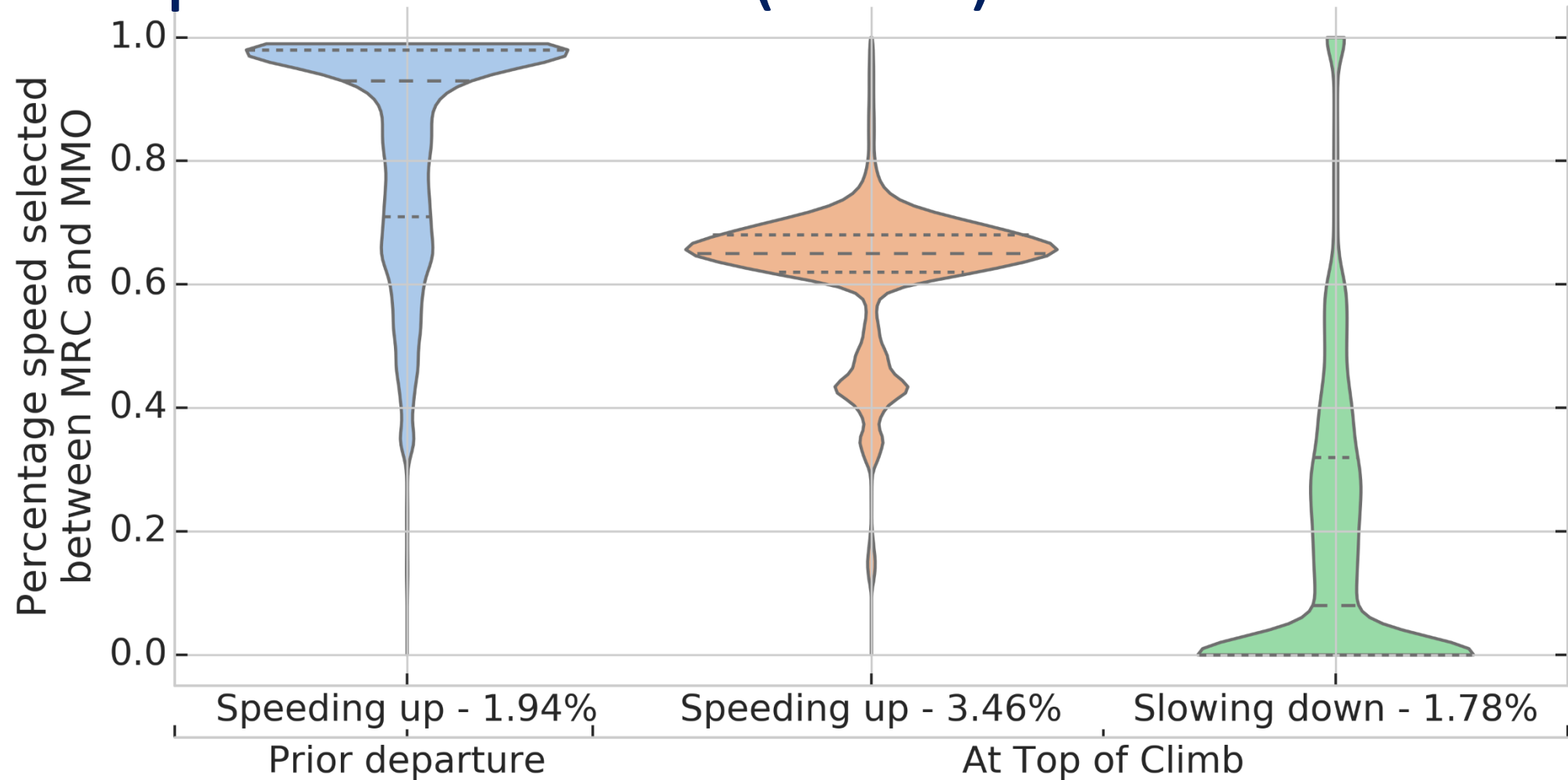
Example mechanism (4DTA) – Level 0 results



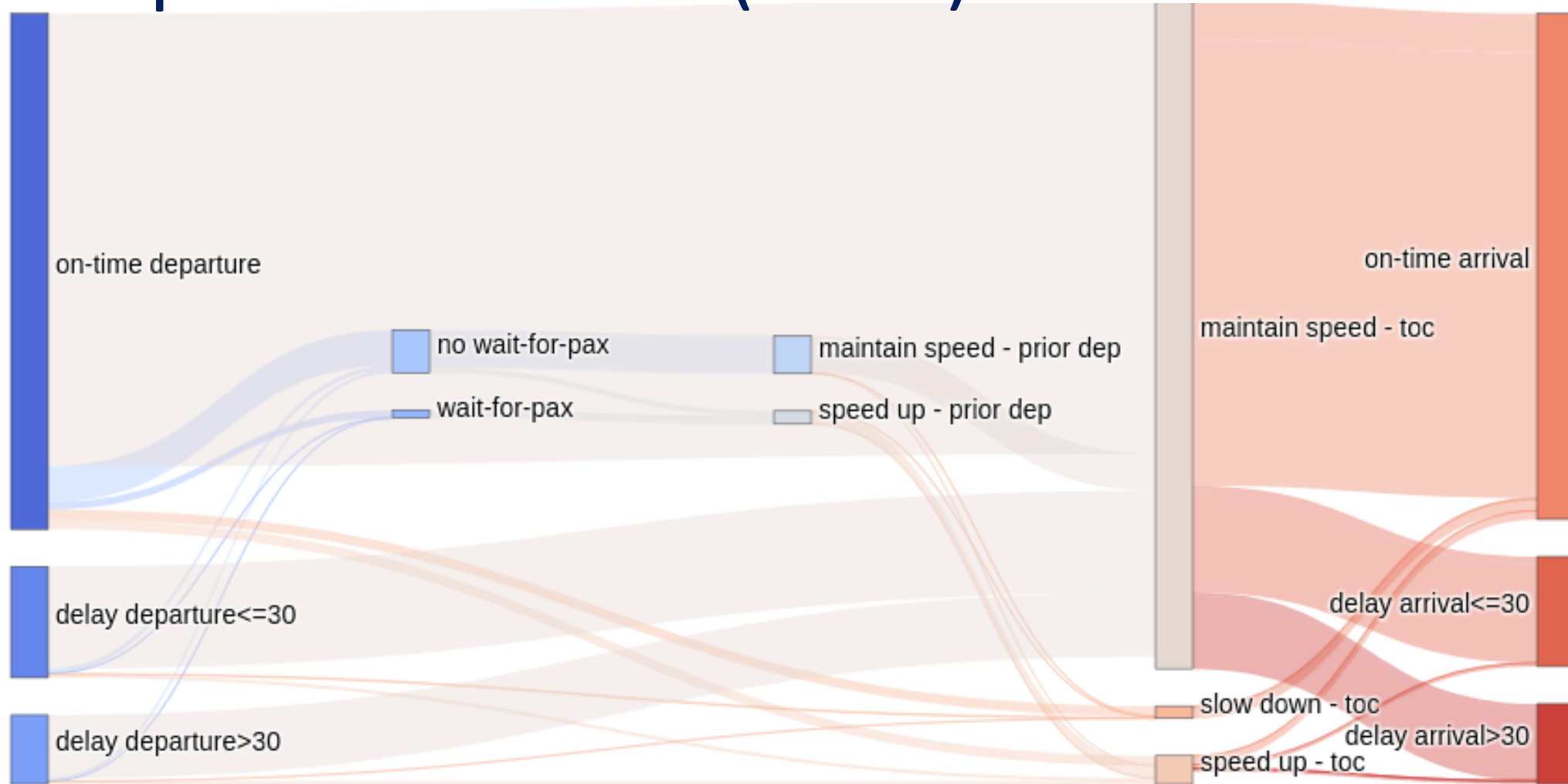
Example mechanism (4DTA) – Level 0 results



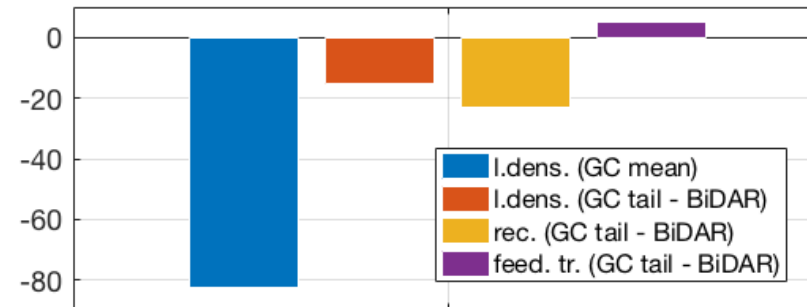
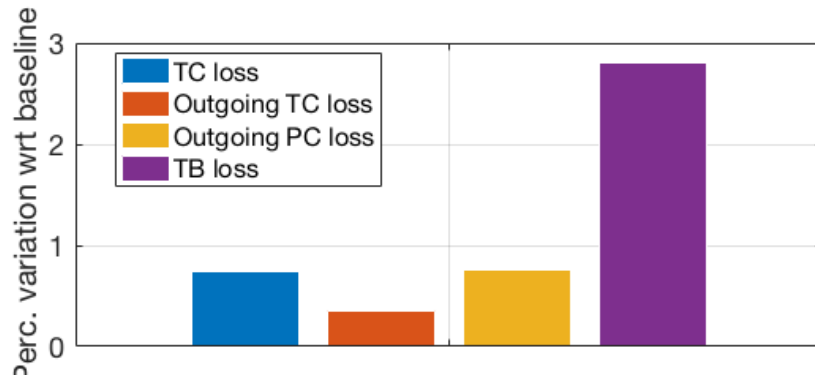
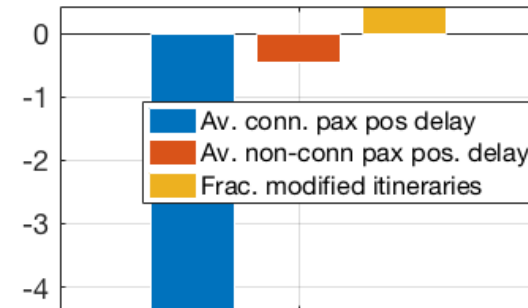
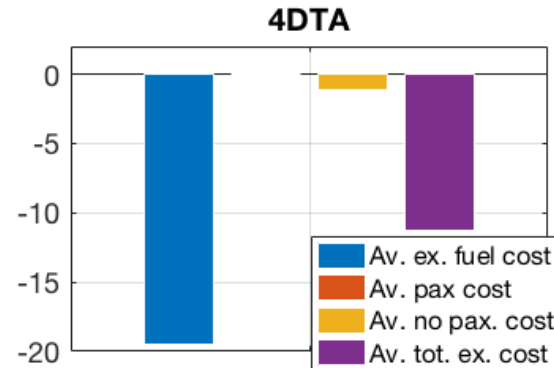
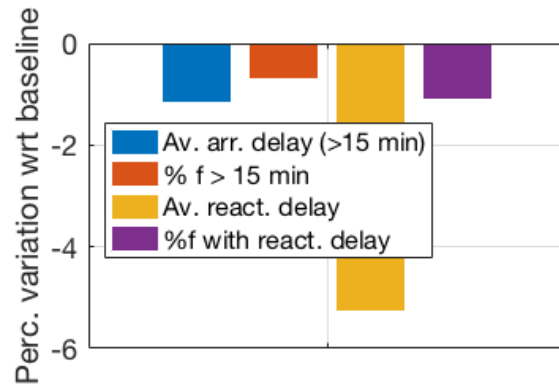
Example mechanism (4DTA) – Level 2 results



Example mechanism (4DTA) – Level 2 results



Key result (4DTA)



- 4DTA has a significant impact on the system, especially in terms of reactionary delay and cost
- Connecting passengers gain more from 4DTA
- System gets some slack from 4DTA

Conclusions



Conclusions

- Domino built an **ABM** able to **model very finely the air transportation system**, on a European scale and down to the **individual passenger**
- Domino defined and tested **new metrics** able to capture **network effects**:
trip & passenger centrality
causality

Future research

- Improving model and metrics
 - **Model calibration and validation**
 - **Database improvement**
 - **Further network metrics analysis**
 - **Detailed modelling of some phases**
 - **Integration with other (data) platforms**
 - **Relationships with other models**



Future research

- Improving model and metrics
- *Future Architecture European Airspace* assessment
- Clean Sky 2
 - Pilot3 (www.pilot3.eu)
 - Dispatcher3 (www.dispatcher3.eu)
- ER4
 - Beacon *BEACON*
 - Modus *Modus*
 - NOSTROMO



Thank you

