Mercury Introduction

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Why?

System performance – Distributed decision making

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- ATM system is complex, with many different actors
  - Airlines
  - Crew (flight)
  - Airports (arrival managers, departure managers)
  - Network Manager
  - …

- Actors make decisions through the day with various objectives in mind
  - Local objectives optimisation
  - Cooperation but also competition

System performance – Distributed decision making

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- Network Manager, ANSPs… try to provide capacity but,
  Airlines making decisions on how to manage their flights, passengers…

System performance – Distributed decision making

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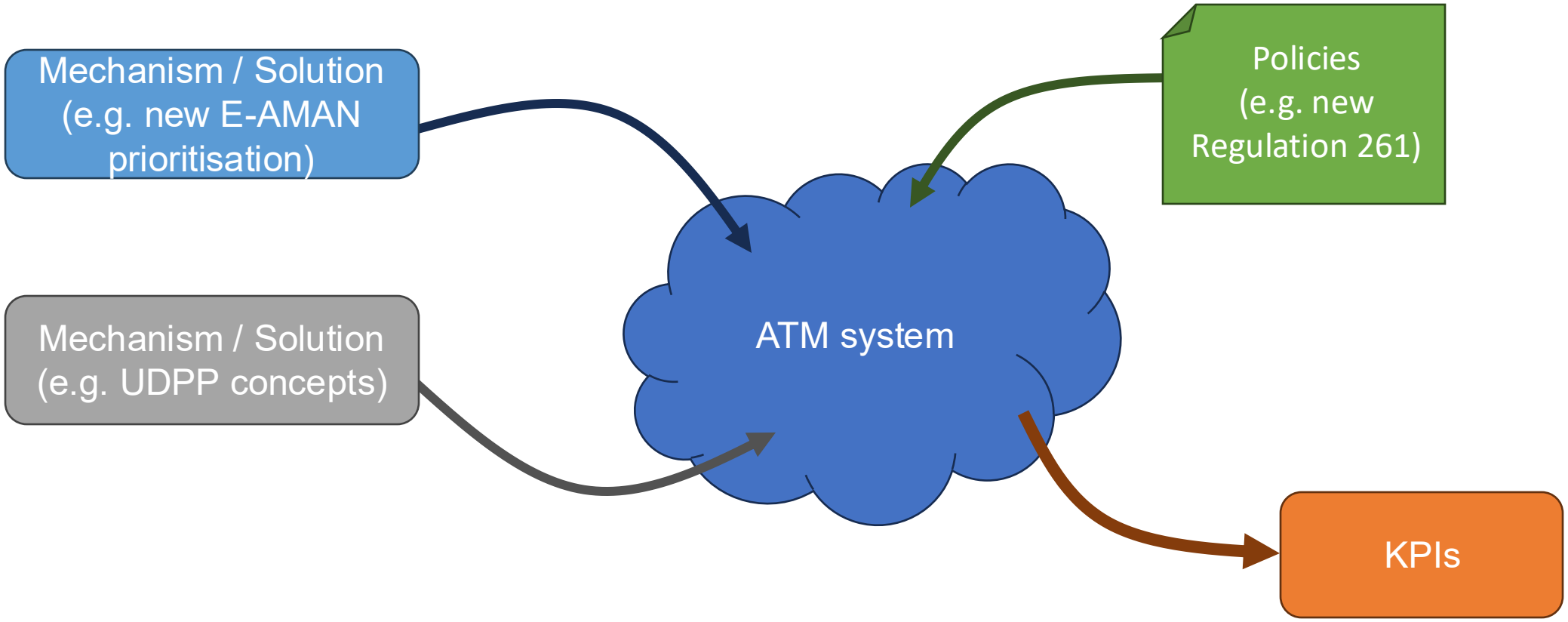
Changes in behaviour due to changes in mechanisms (Solutions) and policies



Modelling not only flights

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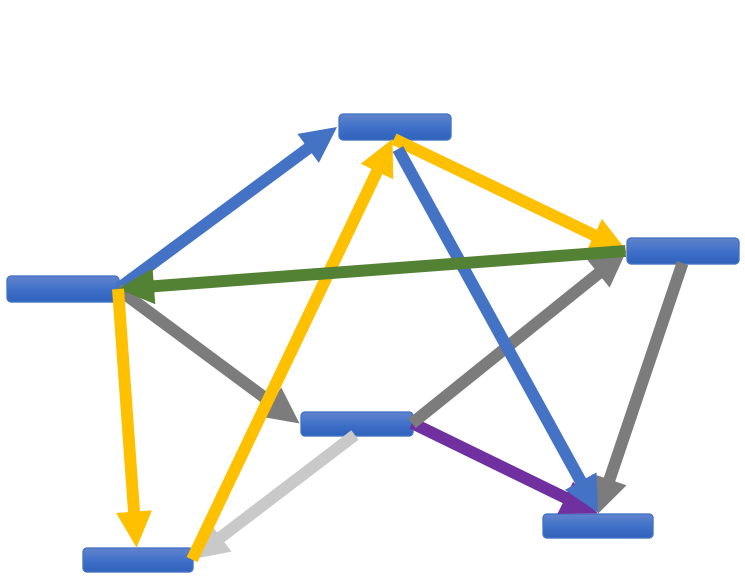
Different stakeholders = > different system perception



Reactionary delay

Knock-on effects

Modelling not only flights

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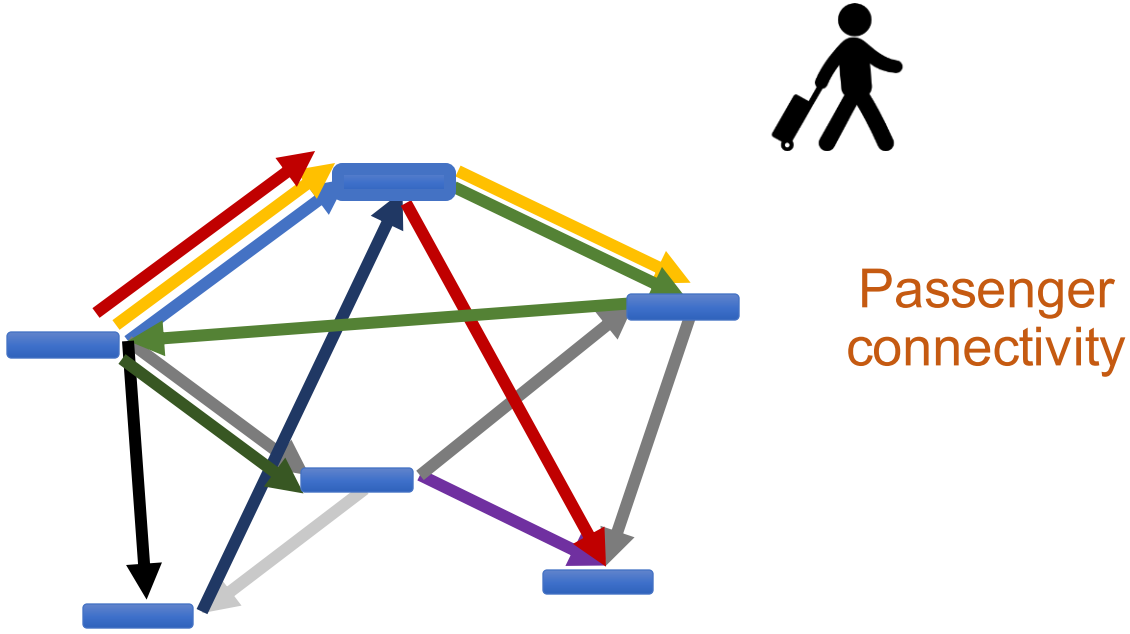
Different stakeholders = > different system perception



Passenger connectivity

Modelling not only flights

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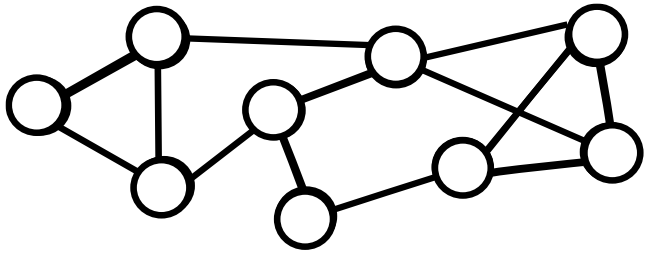
Different stakeholders = > different system perception

Reactionary delay

Flight

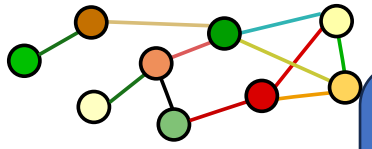
Passenger

Passenger connectivity

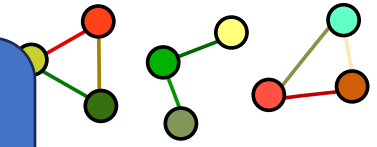


DOMINO

Flight network perspective



Passenger network perspective



- Network metrics
- Capturing distribution KPIs for stakeholders

Stakeholders' decision shape the system

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Actors have different objectives

- E-AMAN
  - Maintain runway capacity
  - Maximise throughput
  - Reduce holdings
  - …
- DMAN
  - Maintain runway capacity
  - …
- Network Manager
  - Maintain network capacity
  - Prioritise flights
  - …
- Airlines
  - Keep operations running smoothly
  - Keep delays to a minimum
  - Avoid extra costs
  - …
- …

Distributed information which is not shared!

Stakeholders' decision shape the system

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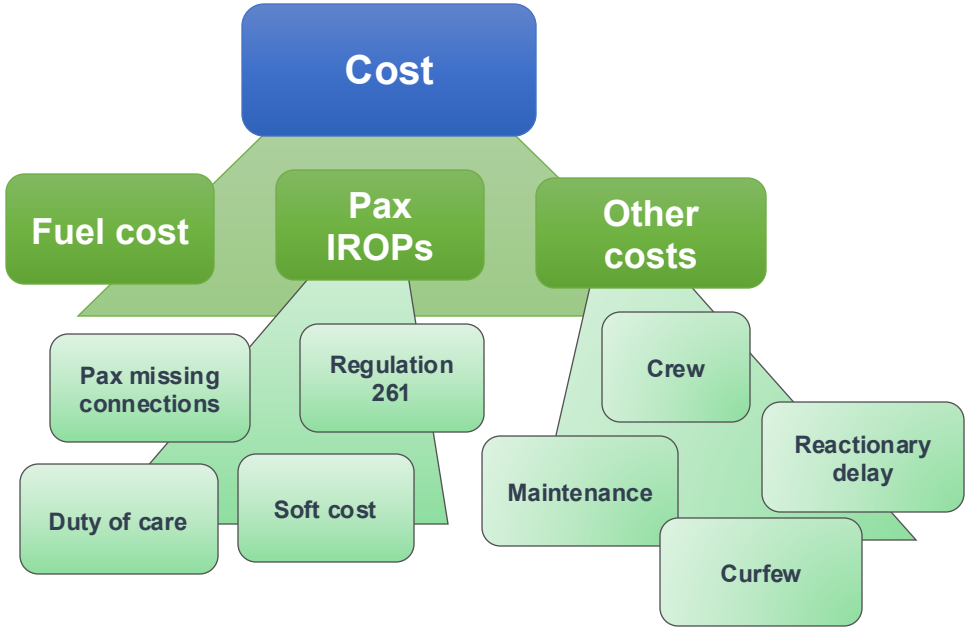
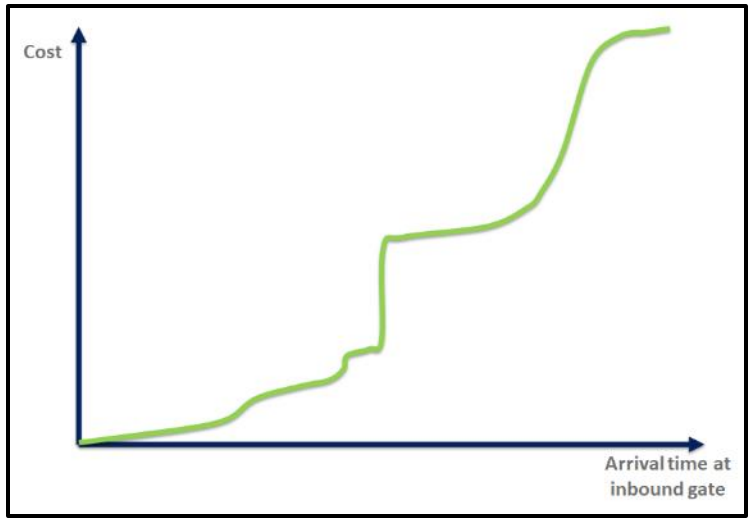
- Airlines are (mostly) cost minimization driven
  - Day(s) prior to operations airlines plan their flights
  - During the day of operations perform actions to maintain flight flows (and passengers)
  - Decisions are cost-driven (mostly)





- Non-linear
- Difficult to estimate
- Subject to uncertainties

Stakeholders' decision shape the system

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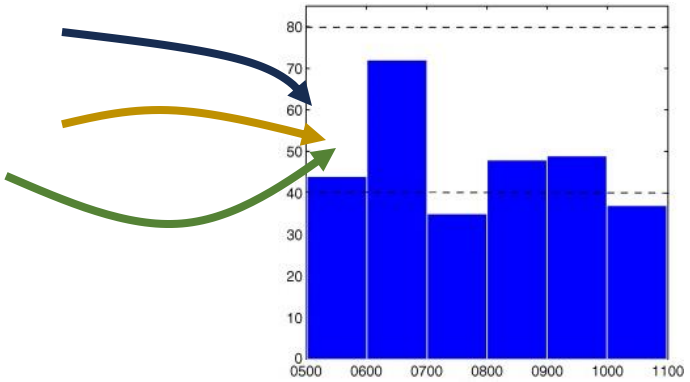
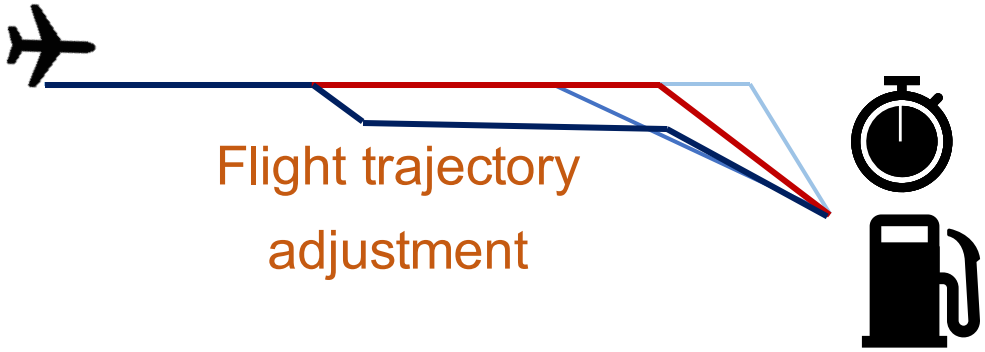
- Airlines are (mostly) cost minimization driven
  - Day(s) prior to operations airlines plan their flights
  - During the day of operations perform actions to maintain flight flows (and passengers)
  - Decisions are cost-driven (mostly)

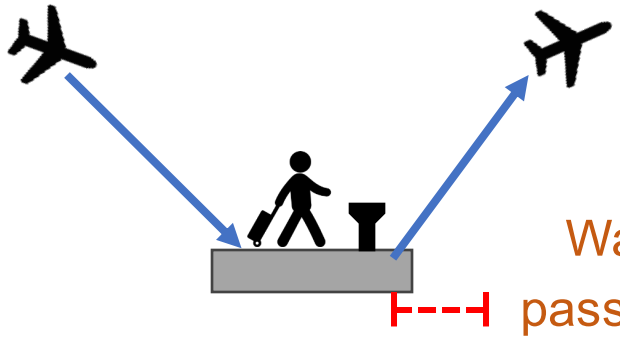
Flight plan selection



Flight prioritisation in ATFM regulations



Flight trajectory adjustment



Wait for passengers

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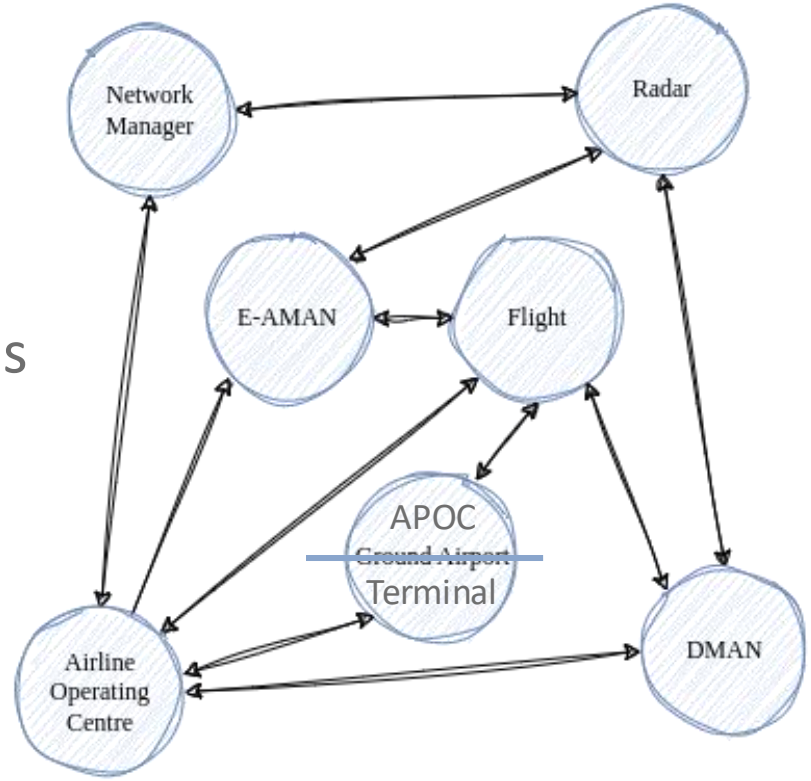
Requirements and Capabilities

Mercury

https://github.com/UoW-ATM/Mercury

- Flight and passenger mobility model
  - Agent-based model
  - Describing main components of ATM system
  - Tracking individual flights and passengers
  - Multimodality and door-to-door estimation capabilities
  - 1 day of operations at ECAC level (27k flights, 3M pax)
  - Developed in various European projects over 10 years
  - Open source

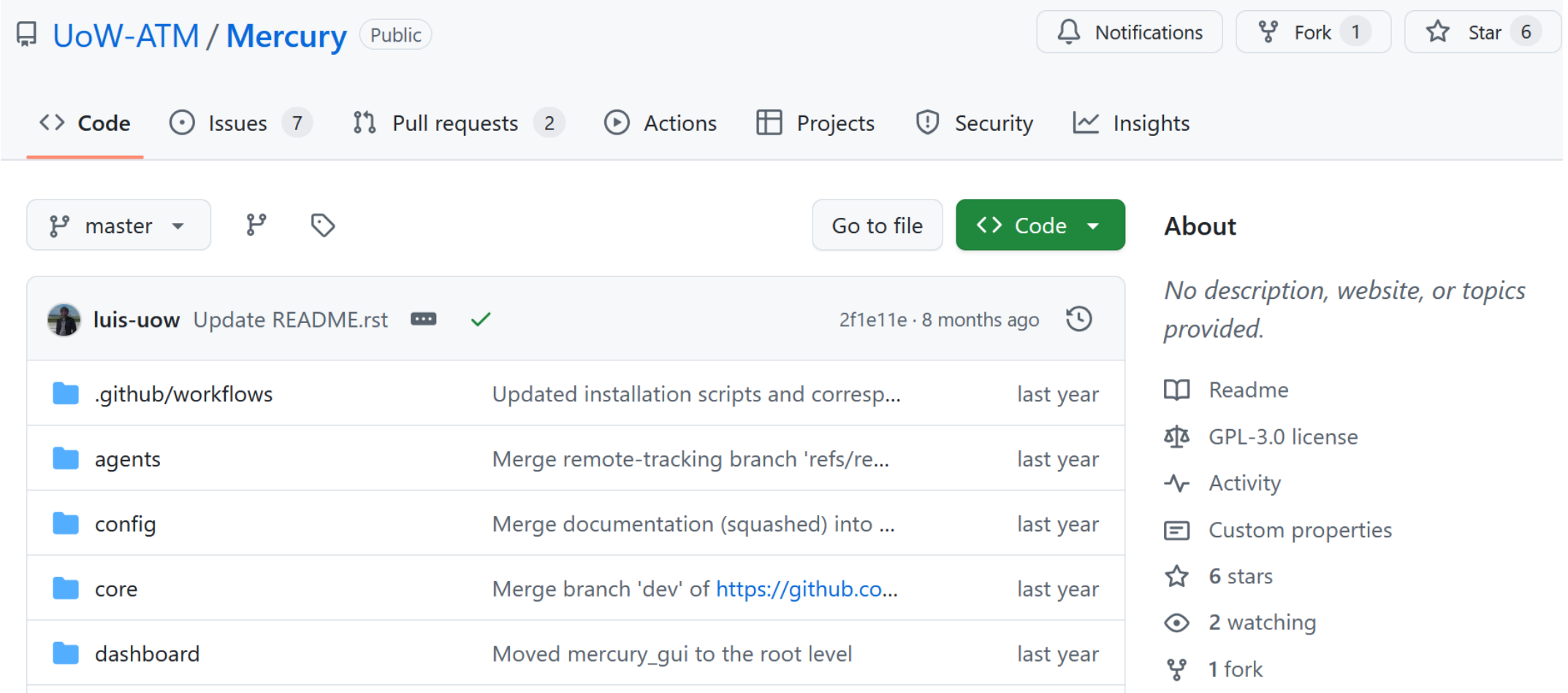


Computation requirements

- 1 day of operations simulation (ECAC region ~27K flights, ~3.4M pax):
  - ~ 8GB RAM
  - ~25 minutes baseline scenario (Intel i7-4790 @3.60GHz)
- **Individual low-level metrics** for different stakeholders

Mercury

https://github.com/UoW-ATM/Mercury



Requirements

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- Model main actors in ATM
- Model channels of propagation of delay (flight and passengers) and cost
- Evaluate Mechanisms / Solutions on
  - E-AMAN
  - Dynamic cost indexing + waiting for passenger strategies
  - Flight prioritization for ATFM regulations

- Need trade-off fuel and time in trajectory
- Need estimation of cost of delay at different points

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Design Approach

GAIA methodology

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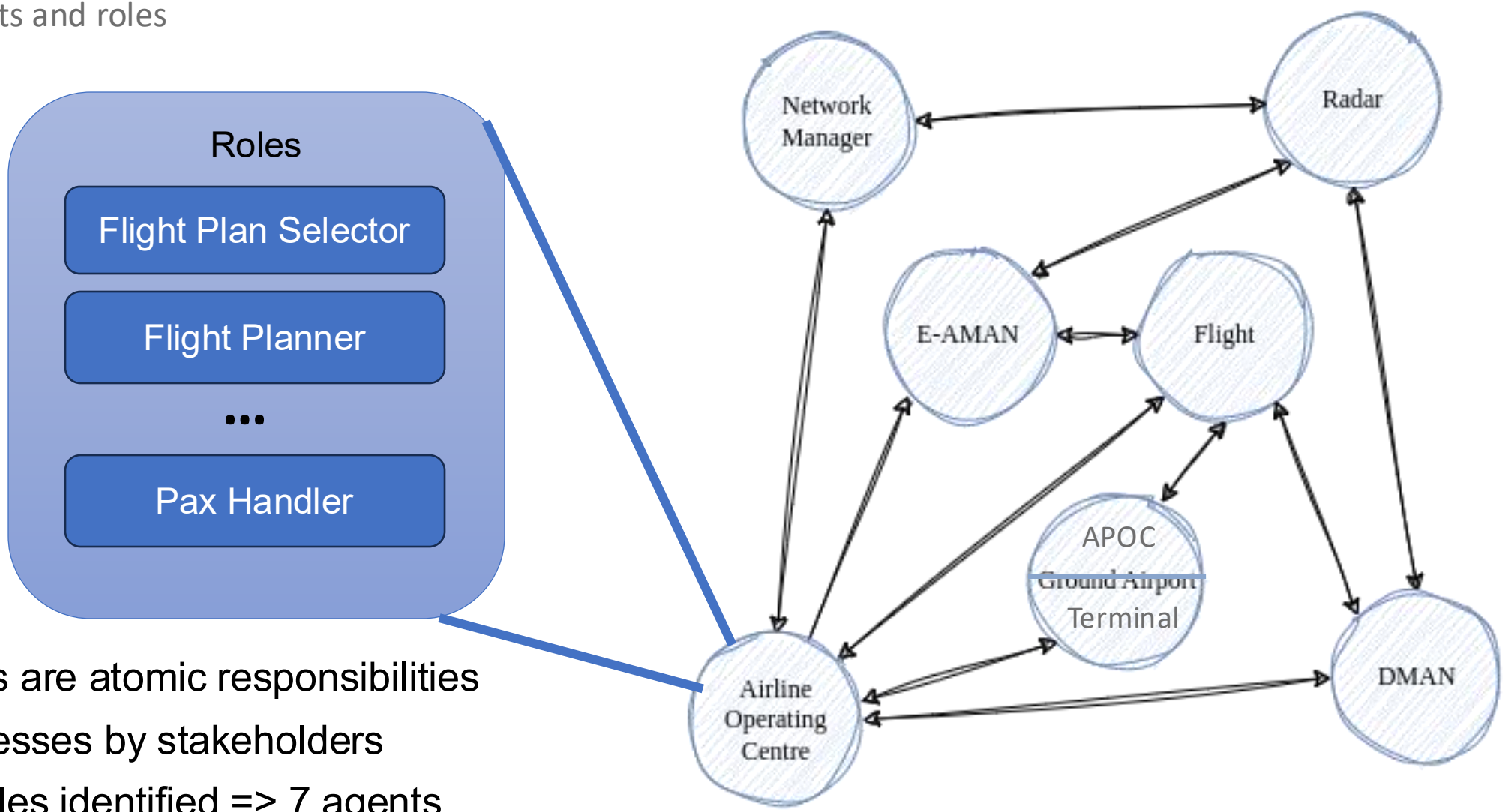
Agents and roles



- Roles are atomic responsibilities
- Processes by stakeholders
- 40 roles identified => 7 agents

Messaging, events and interactions

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Agent type	Roles
Airline Operating Centre	Airline Flight Planner, Dynamic Cost Index Computer, Passenger Reallocation, Turnaround Operations, Airline Passenger Handler, Flight Plan Selector
Flight	Aircraft Departing Handler, Departure Slot Requester, Flight Plan Constraint Updater, Flight Plan Updater, Flight Arrival Information Provider, Ground Arrival Handler, Operate Trajectory, Potential Delay Recovery Provider
Airport Operating Centre	Ground Handler, Taxi-out Estimator, Taxi-Out Provider, Taxi-In Provider
E-AMAN	Strategic Arrival Queue Builder, Arrival Queue Planned Updater, Arrival Cancellation Handler, Flight In AMAN Handler, Arrival Planner Provider, Arrival Tactical Provider, Slot Assigner, Arrival Planner Provider Queue, Arrival Tactical Provider Queue

- Agents react to
  - Changes in the environment (events)
  - Messages from other agents

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Communication and Simulation

Communication and simulation

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- Messaging, events and interactions
  - Discrete-event simulator
  - Roles are triggered by events with might trigger interaction (messages) with other agents
  - Concurrence is possible
  - Events can be generated, modified, cancelled (as needed)
  - Events track main operational milestones:
    - Flight plan submission
    - Push-back
    - Take-off
    - …
  - Use of resources (e.g. aircraft)

SimPy

Events

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Events: main operational milestones (9 key events)

Event	Short description
FP submission	First submission of flight plan for a flight. This is normally triggered 3 h before the flight SOBT.
Delay estimation	AOC checks the status of the flight and a random non-ATFM delay is drawn. This is normally triggered 1 h before the flight EOBT.
Passenger check	AOC checks which passengers are not ready to board their flights, 5 min before EOBT.
Pushback ready	Aircraft is ready to push-back. The flight requests a departure slot.
Pushback	The flight is off-block and begins taxi-out. Connecting passengers which are not boarded are rebooked.
Take-off	The flight begins an “operate trajectory” activity which integrates the trajectory between pre-defined waypoints in the flight plan (with stochastic noise).
Flight Crossing Point	A waypoint is crossed by the flight during its trajectory execution. This type of event triggered by the flight and captured by the Radar for the broadcast the position of the flight to interested parties in the model.
Landing	The flight reaches its final trajectory point. It begins taxi-in.
Flight Arrival	The flight arrives at the gate. Turnaround and connecting passenger processes begin.

Discrete event simulation – Reactionary modelling

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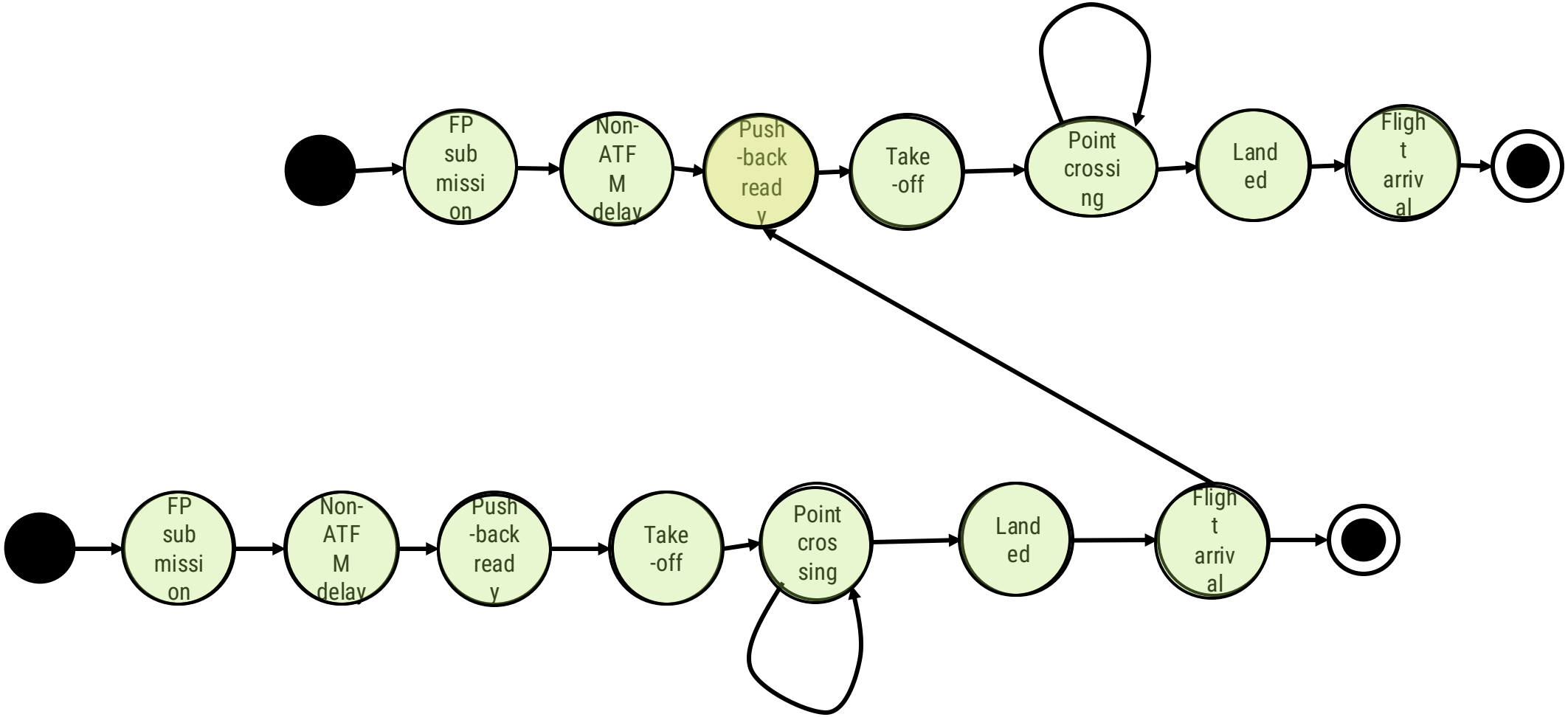
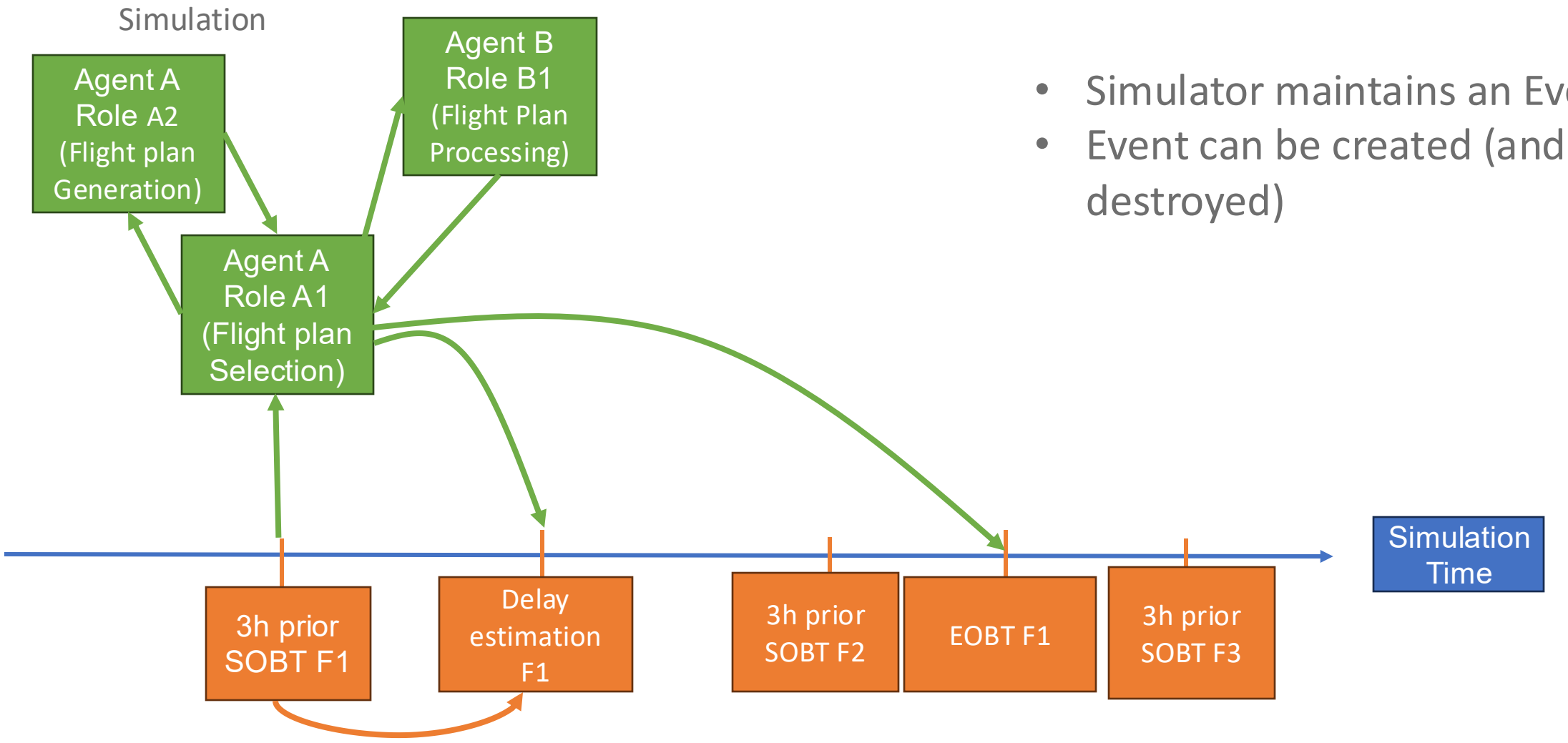
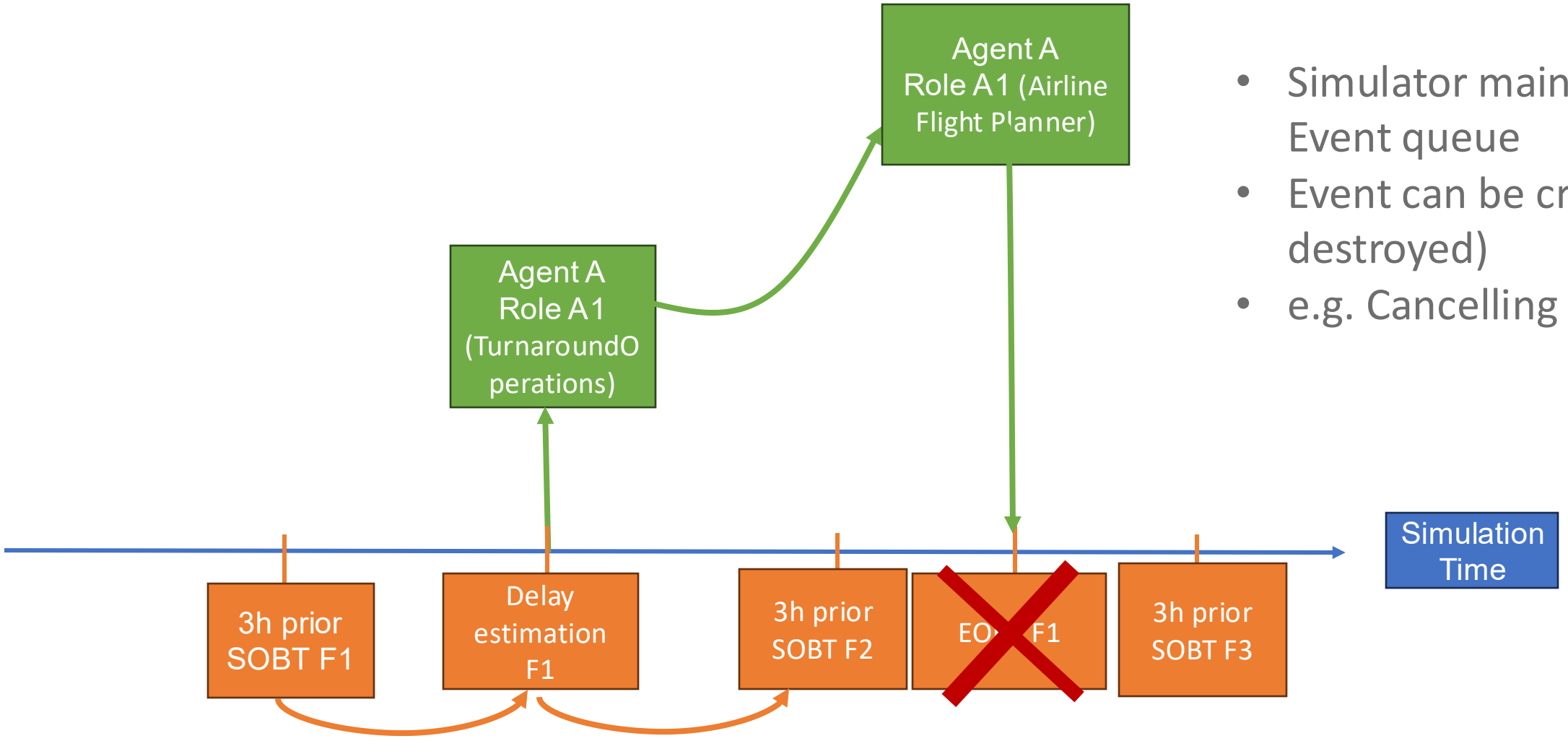


Simulation – Events principle



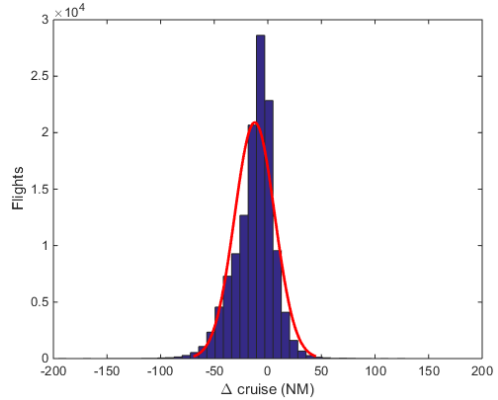
- Simulator maintains an Event queue
- Event can be created (and destroyed)

Simulation – Events principle

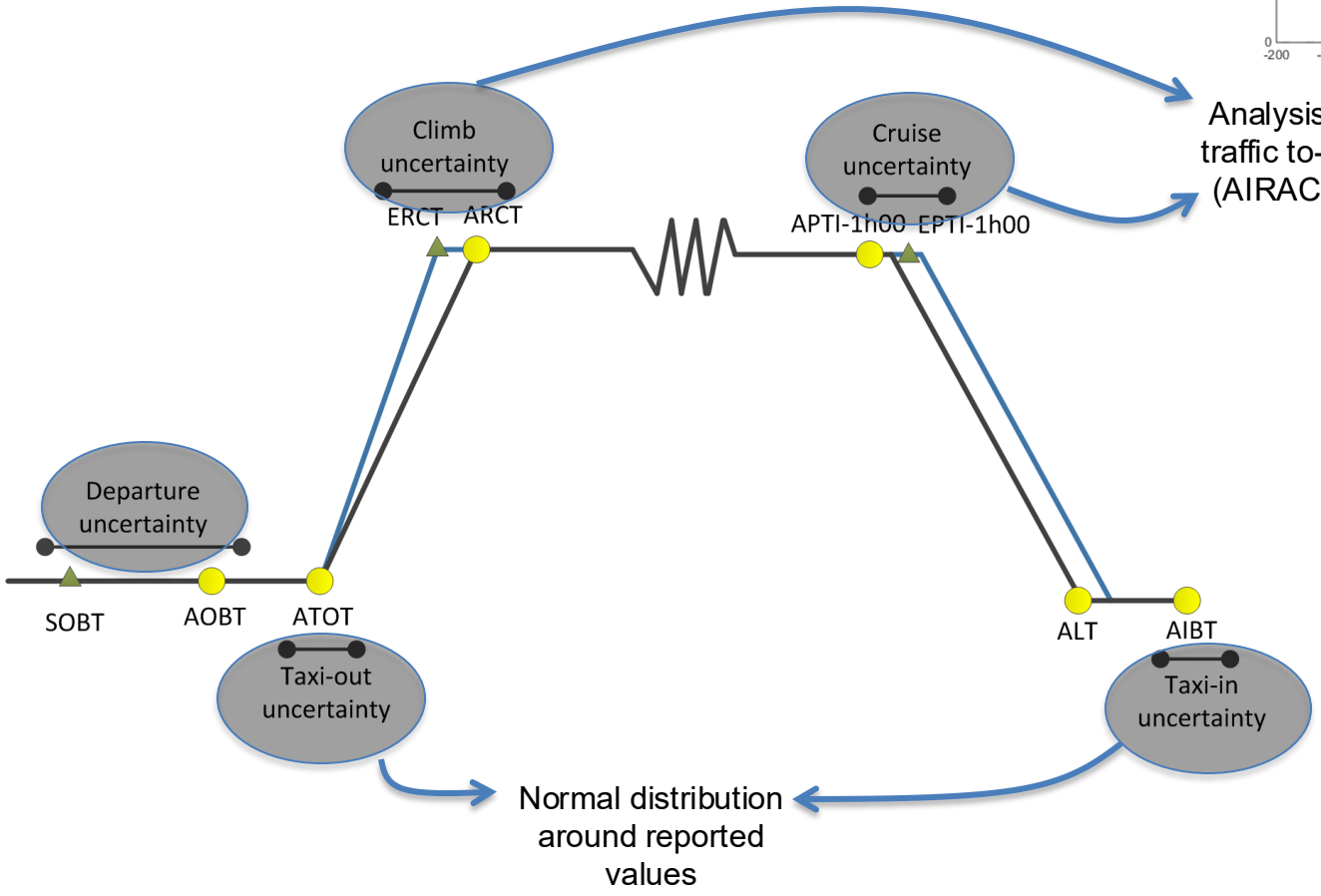


- Simulator maintains an Event queue
- Event can be created (and destroyed)
- e.g. Cancelling flight

Uncertainty modelling



Analysis of a year of traffic to-from the hub (AIRAC 1313-1413)



Inter and intra agents communication

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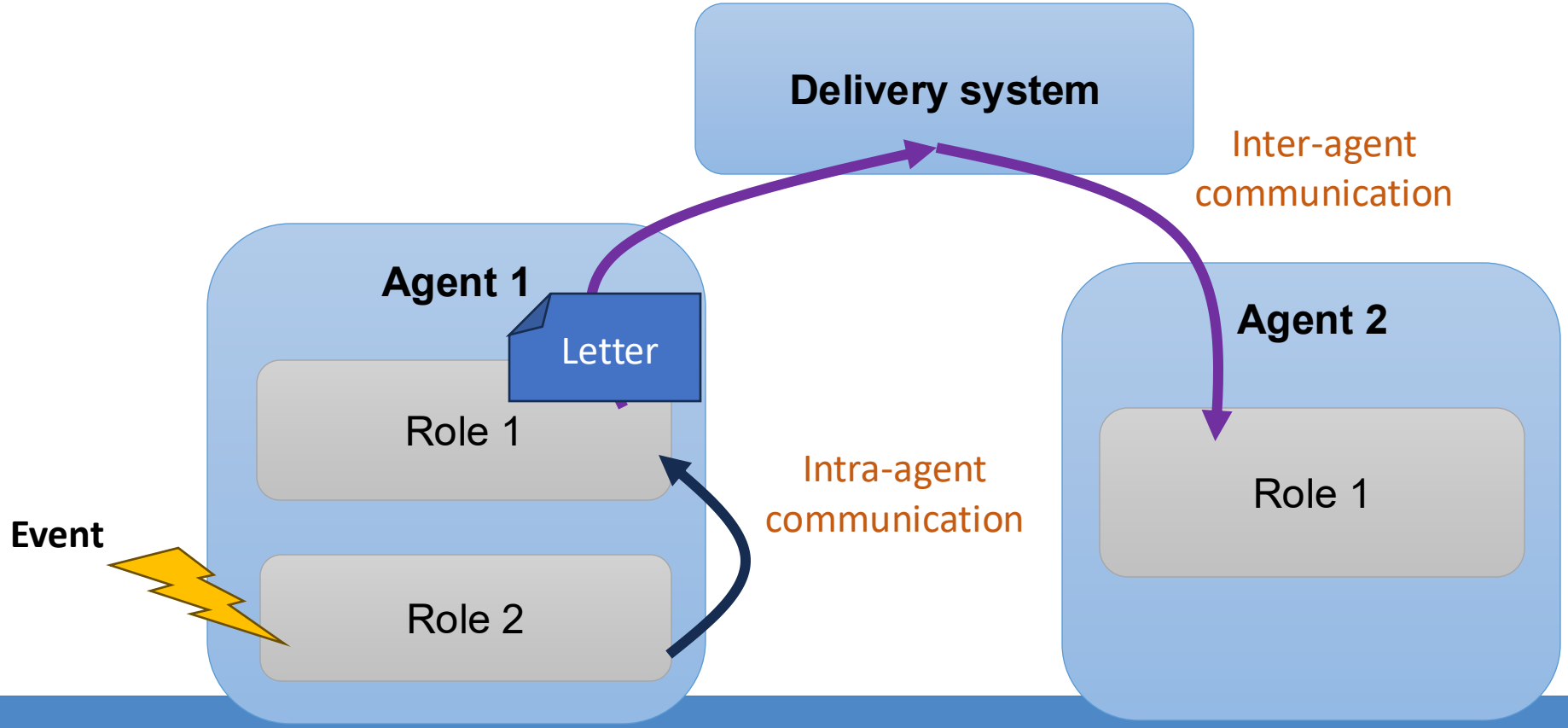
- Communications
  - Inter-agents: two agents interacting (messaging system)
  - Intra-agents: two roles within the same agent (direct memory access)



Internal communication

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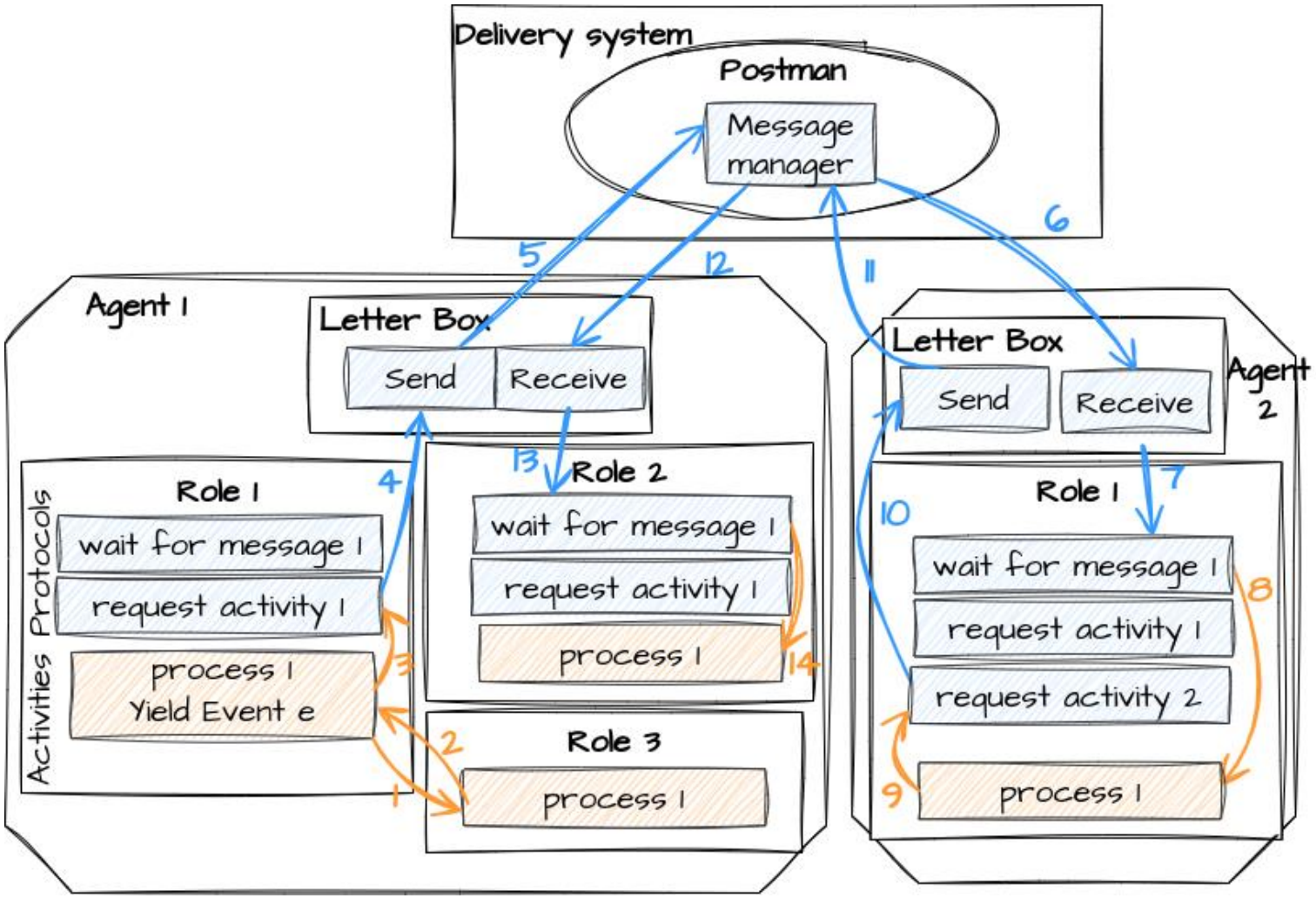

Events with communications

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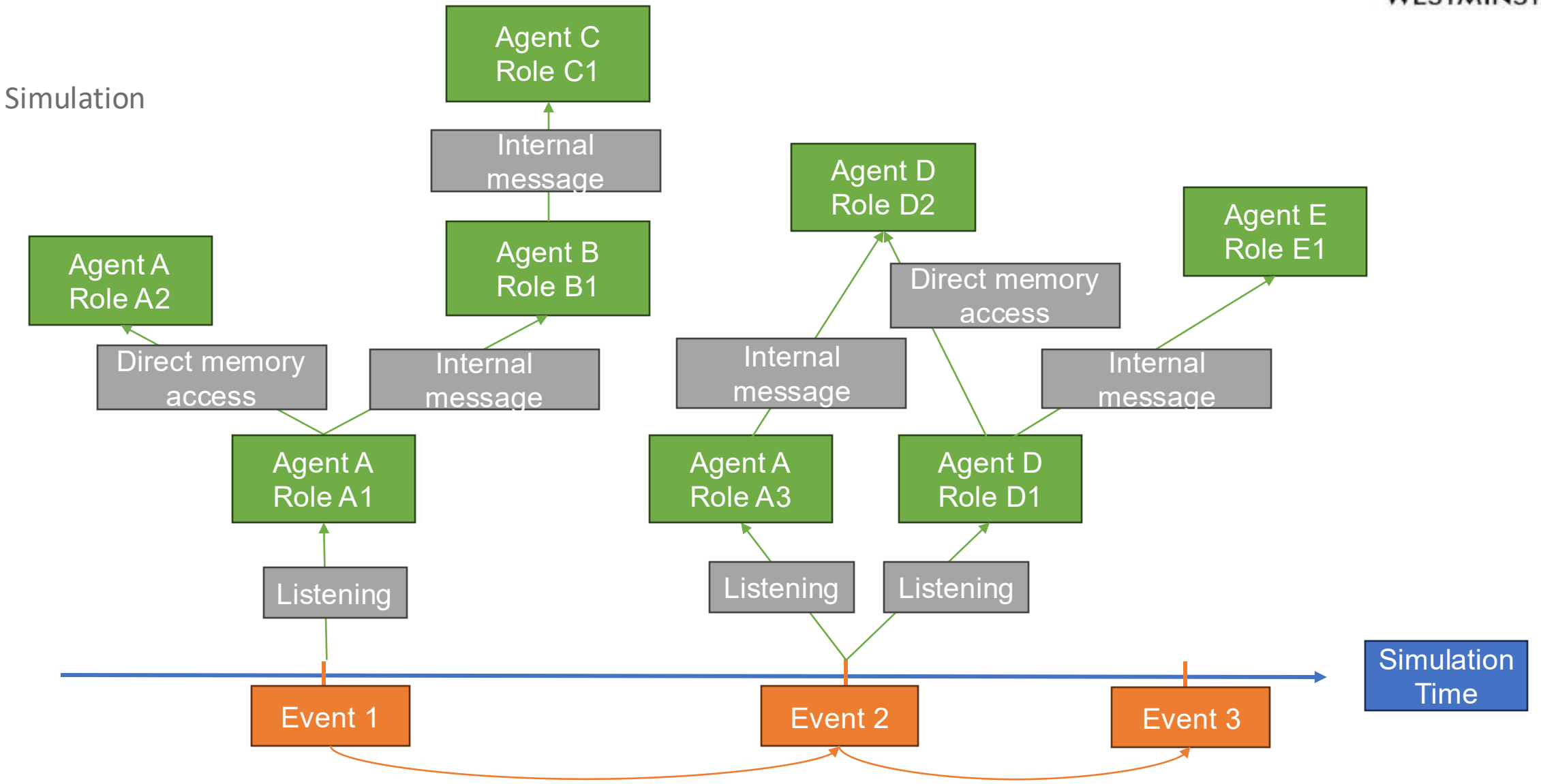
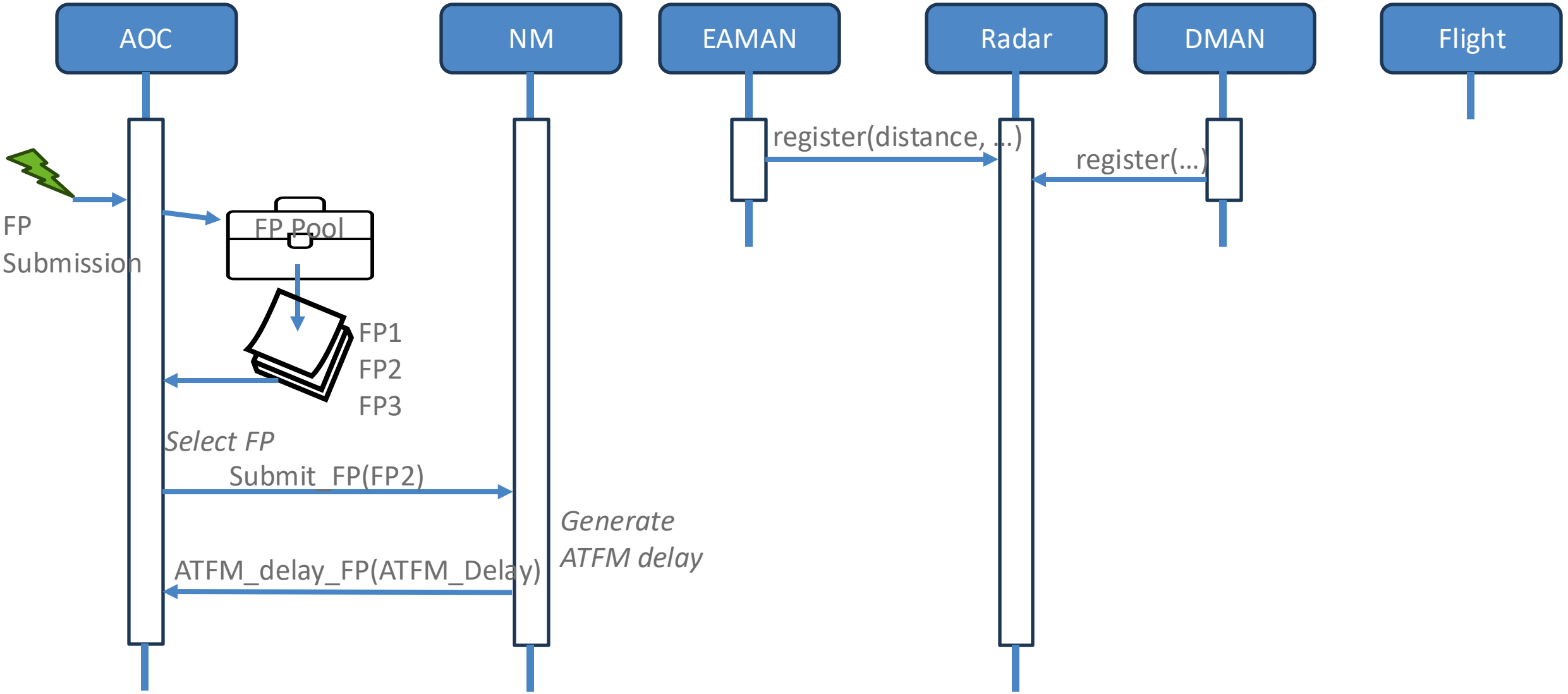
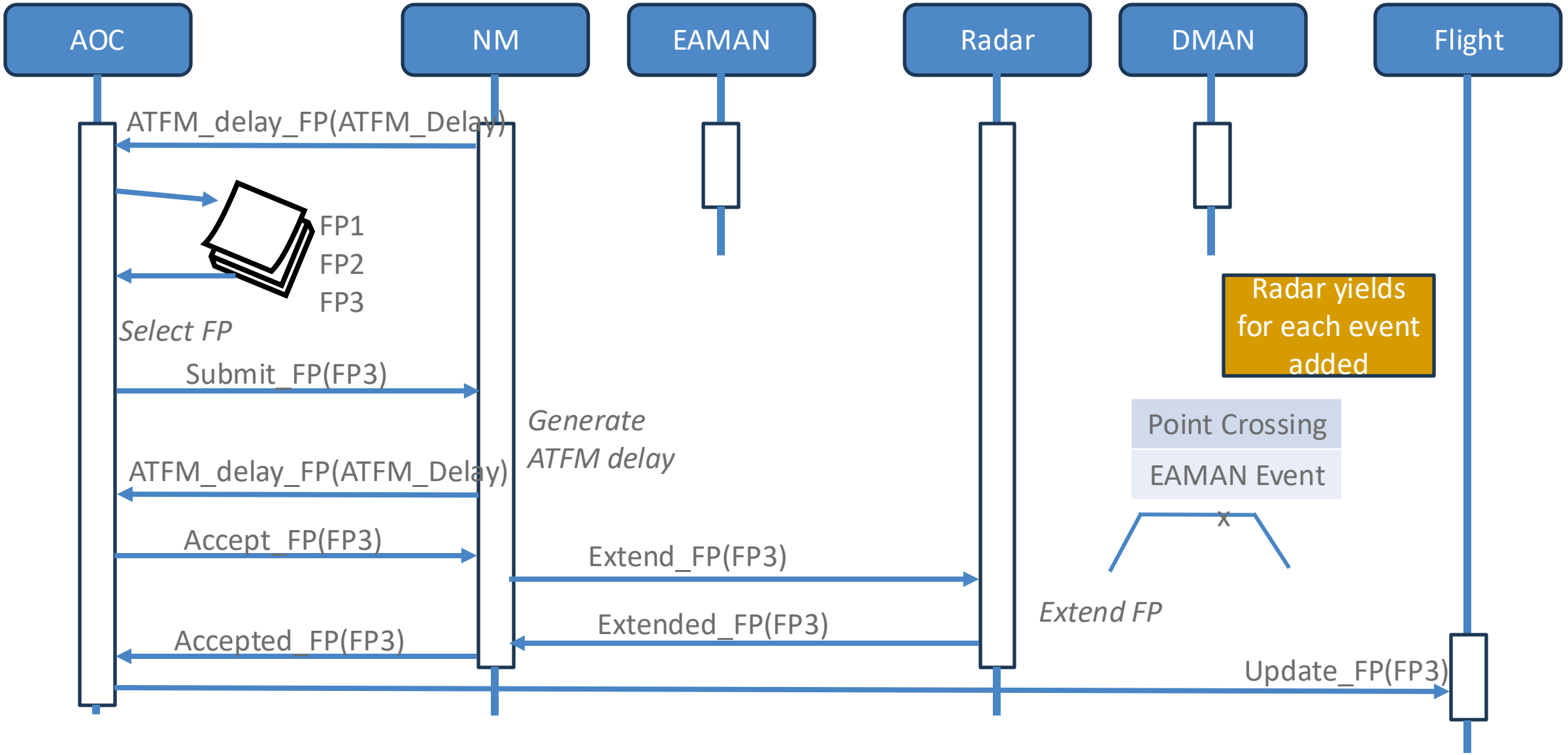


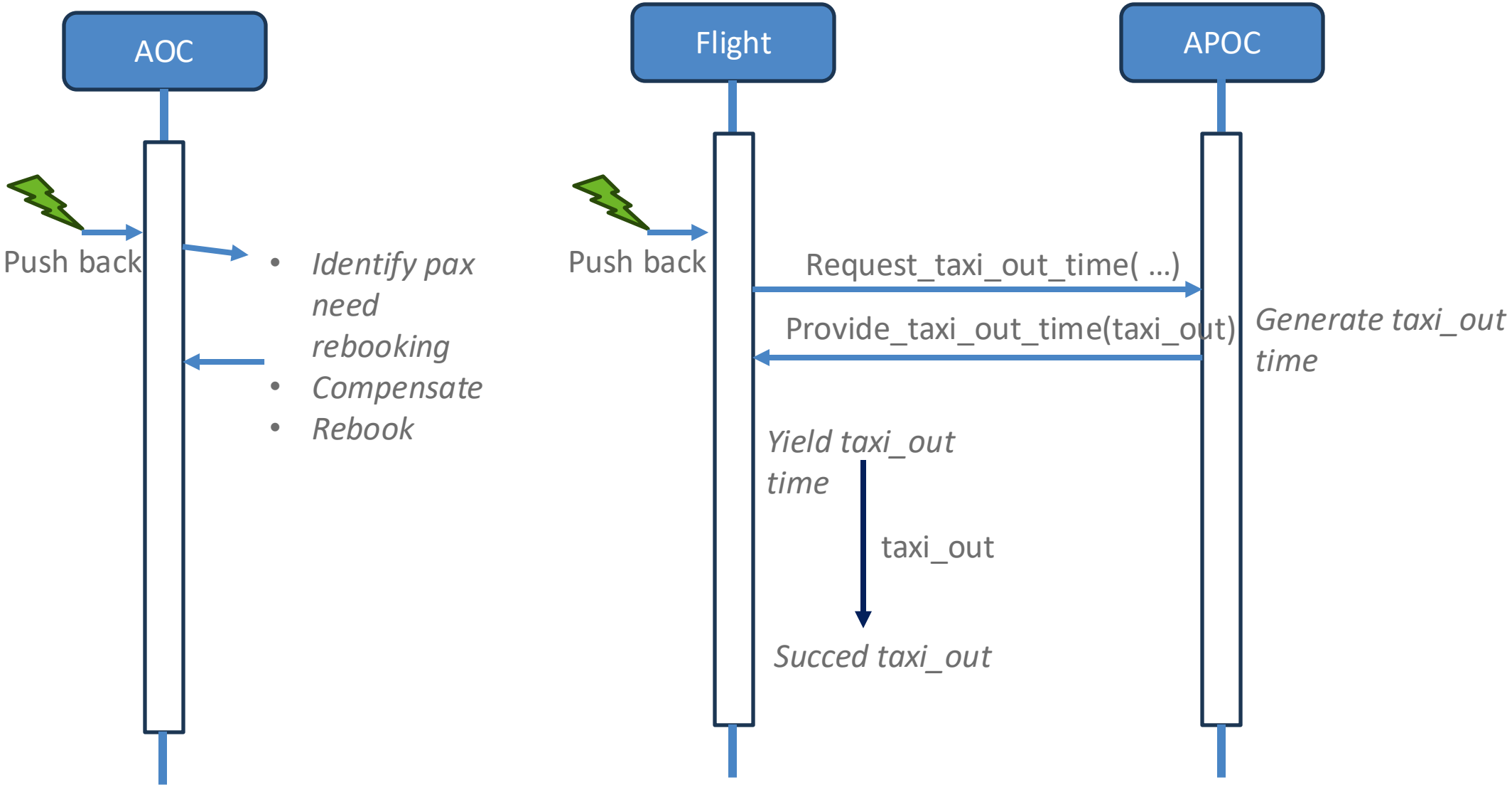
Reaction to events



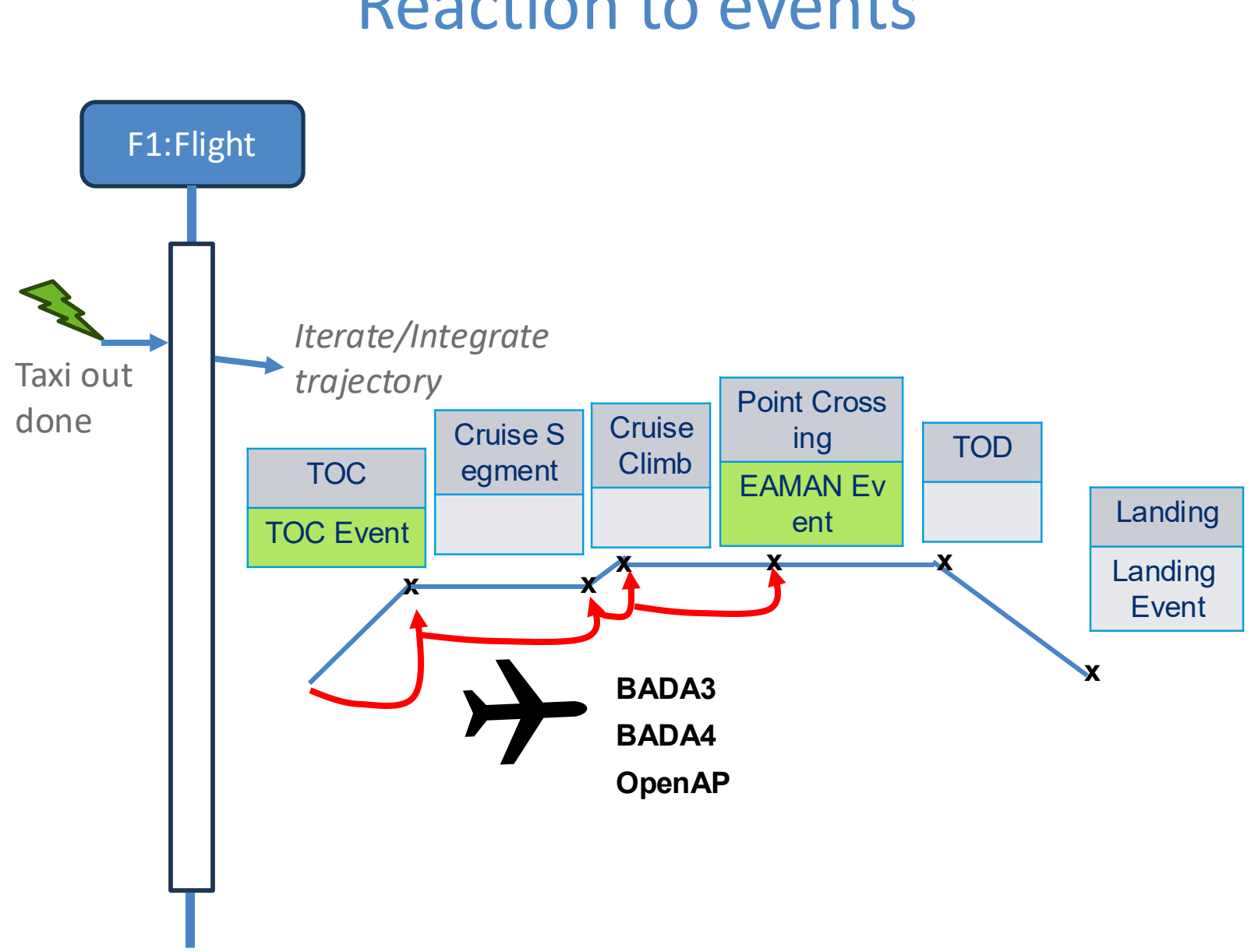
Reaction to events

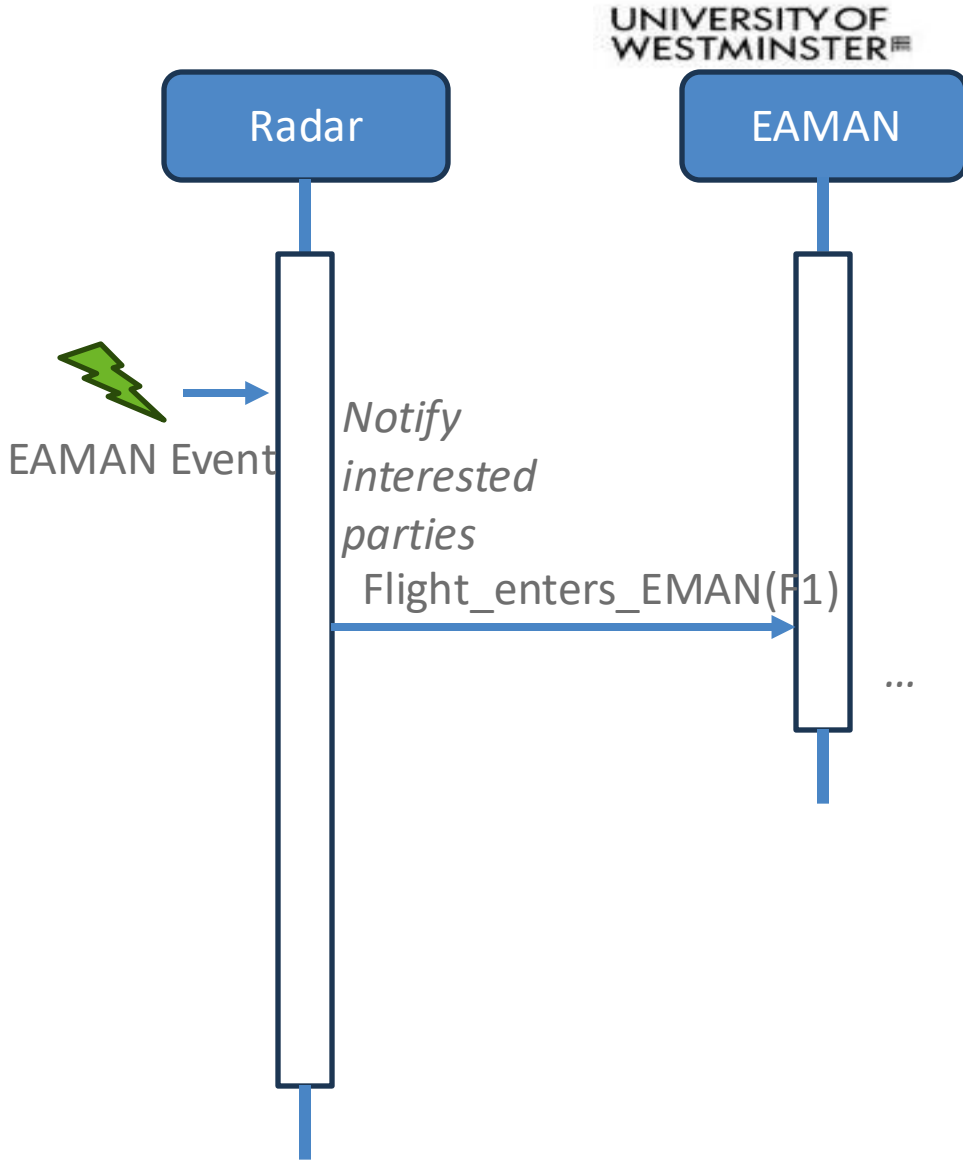


Reaction to events



Reaction to events





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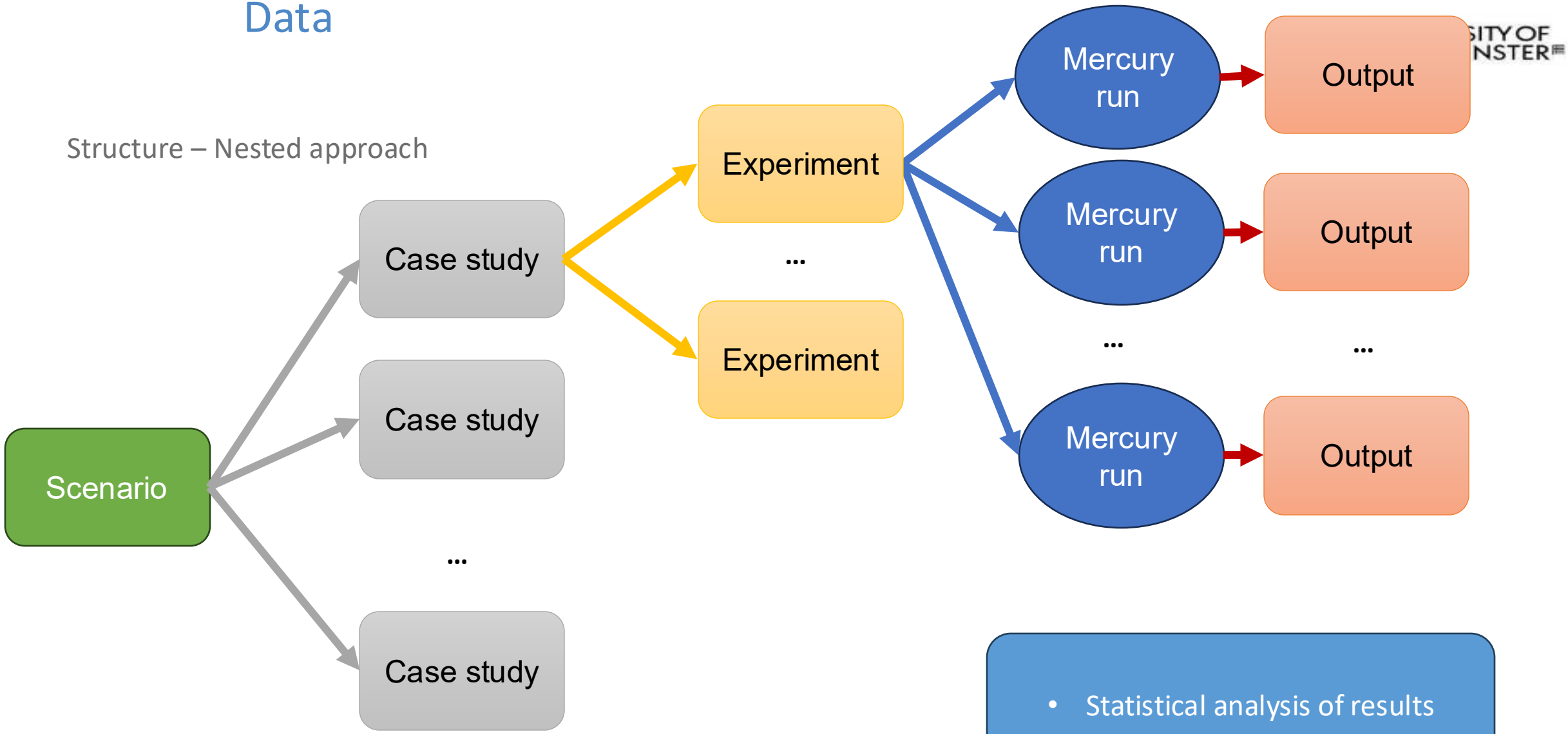
Scenarios / Case Study / Experiments

Data

Structure – Nested approach



- Statistical analysis of results

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- Scenario
- All possible flights (and pax) for a given period and region
- Information required to simulate ATM operations

E.g.

- All flights and pax for a day of operation in Europe (27k flights, 3.8M pax)

- Distributions for probability delay (High, Medium, Low) from historical data analysis

- …

- Case study
- All possible flights (and pax) for a given period and region
- Information required to simulate ATM operations

E.g.

- All flights and pax for a day of operation in Europe (27k flights, 3.8M pax)

- Distributions for probability delay (High, Medium, Low) from historical data analysis

- …

- Experiment
- Iteration on parameters to evaluate case study

E.g.

- Cost of fuel from 0.1 to 0.7 EUR/Kg

…

Key data exploration

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Give some input data.

Choose a scenario.

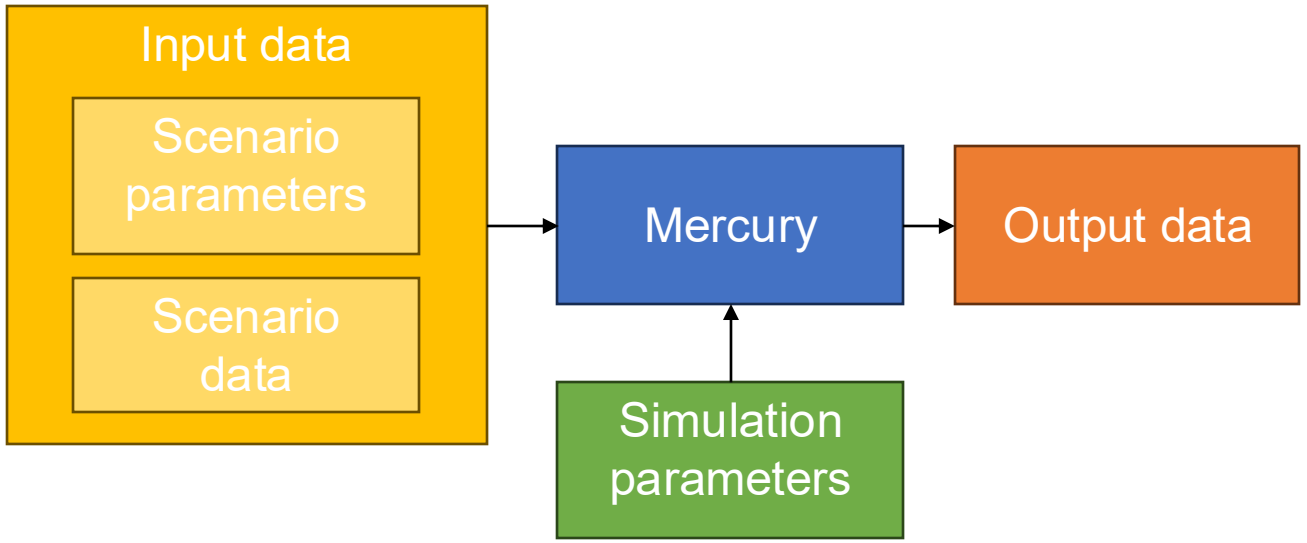
Choose case study (opt.).

Choose some parameters to set or sweep (opt.)

Choose number of iteration (by default only 1).

Run.

Get results: summarised and detailed.



Data sample zenodo

https://zenodo.org/records/11384379

Key data exploration

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In config/mercury_config.py: how the simulation should run

```
[computation]
parallel = false
pc = 1 # Parallel computing when possible
num_iter = 1
first_iter = 0 # iteration number to start
deep_clean_each_iteration = true
verbose = false
batch_size = 0 # Put a positive number N t
    [computation.ac_performance]
        # Table with relationship between
```

- Scenario parameters in input folder: what the simulation should run

```
[paras.modules]
modules_to_load = ['CM']
path = 'modules'

[paras.airlines]
non_ATFM_delay_loc =  0.0
compensation_uptake = 0.11
delay_estimation_lag = 60
threshold_swap = 100.0
heuristic_knock_on_factor = 1.8
smoothness_fp = 200.0
fp_anchor = 0.3
#extra_climb_tweak = 2.
cancel_cascade_curfew = false
```

Input Data

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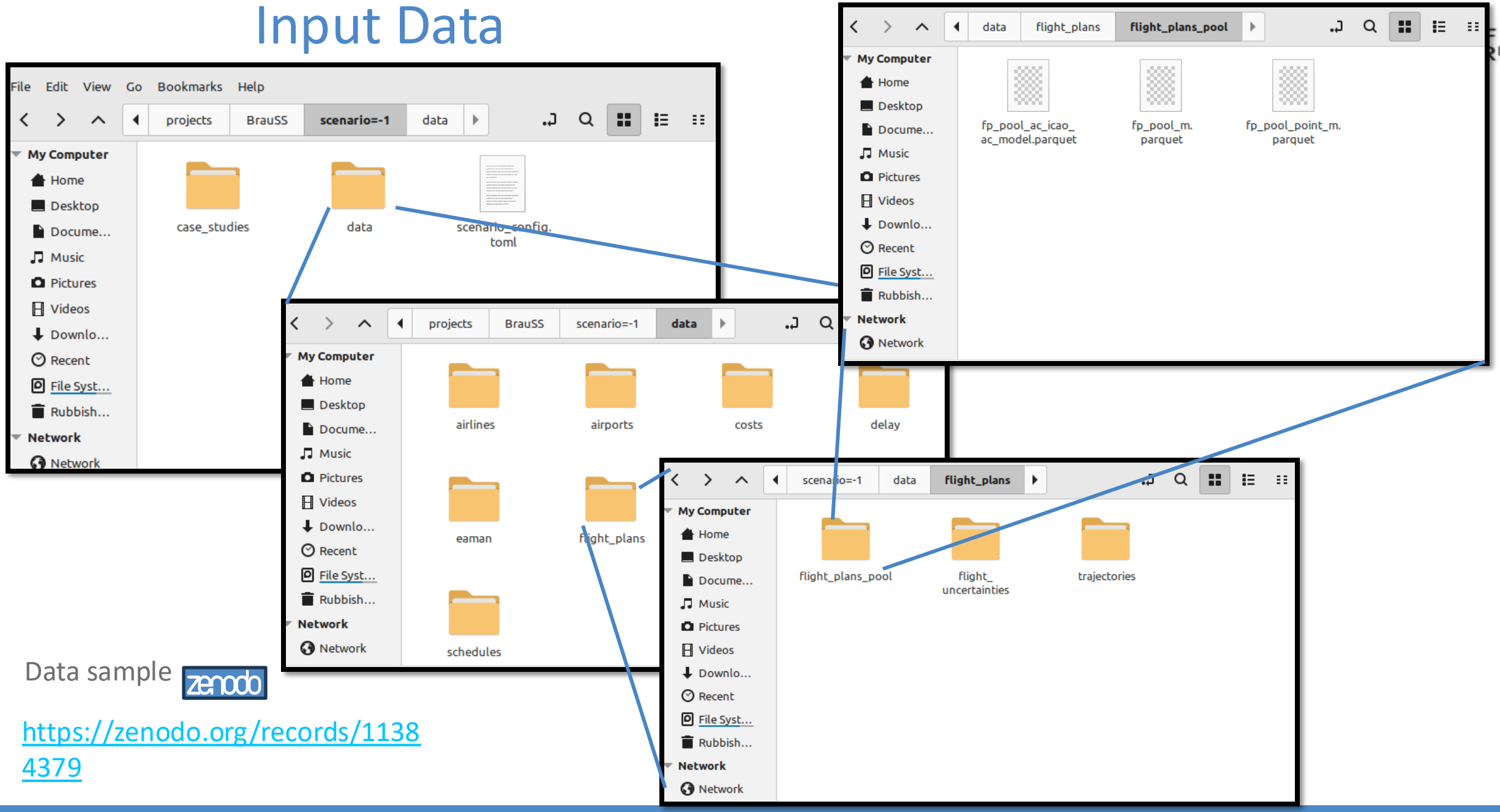
scenario_config.toml

```
[info]
scenario_id = -1
description = "Anonymised test scenario - 1k flights"

[data]
    [data.scenario]
    input_scenario = 'scenario'

    [data.delay]
    input_delay_paras = 'delay_parameters'

    [data.network_manager]
    input_atfm_delay = 'iedf_atfm_static'
    input_atfm_prob = 'prob_atfm_static'

    input_regulation_at_airport_days = 'regulation_at_airport_days_static'
    input_atfm_regulation_at_airport = 'regulation_at_airport_static'
    input_atfm_regulation_at_airport_manual = 'regulation_at_airport_manual'

    [data.costs]
    input_soft_cost = 'soft_cost_delay_static'
    input_compensation = 'passenger_compensation_static'
    input_doc = 'duty_of_care_static'
    input_non_pax_cost = 'non_pax_delay_static'
    input_non_pax_cost_fit = 'non_pax_delay_fit_static'
    input_cost_curfews = 'curfew_non_pax_costs'
    input_estimated_cost_curfews = 'curfew_costs_estimated'

    [data.pax]
    input_itinerary = 'pax_itineraries'

    [data.airports]
    input_airport = 'airport_info_static'
    input_mtt = 'mtt_static'
    input_airport_modif = 'airport_modif_cap'

        [data.airports.curfew]
        icao_airport_name = 'icao'
        curfew_airport_name = 'arrival_curfew_start'
        input_airport_curfew = 'airports_curfews_times'
        input_curfew_extra_time = 'airports_extra_time_curfews'
        input_airports_with_curfews = 'airports_with_curfews'
        input_airports_curfew2 = 'airport_curfew'

    [data.airports.taxi]
    input_taxi_in = 'taxi_in_static'
    input_taxi_out = 'taxi_out_static'


[data.eaman]
input_eaman = 'eaman_definition' # table name

[data.airlines]
input_airline = 'airline_static' # table name

[data.schedules]
input_schedules = 'flight_schedule' # table name

[data.flight_plans]
    [data.flight_plans.crco]
    #CRCO if computing FPs
    input_crco_charges = 'crco_charges_static_old1409'
    input_crco_vat = 'crco_vat_static_old1409'
    input_crco_fix = 'crco_fix_static_old1409'
    input_overfly = 'crco_overfly_static_old1409'
    input_crco_weight = 'crco_weight_static_old1409'

    [data.flight_plans.routes]  # Not used, directly flight plans
    input_route_pool = 'route_pool'
    input_route_pool_has_airspace = 'route_pool_has_airspace_static'
    input_airspace = 'airspace_static'

    [data.flight_plans.trajectories]  # Not used, directly flight plans
    input_trajectory_pool = 'trajectory_pool'
    input_trajectory_segments = 'trajectory_segment'  # missing

    [data.flight_plans.flight_plans_pool]
    input_fp_pool = 'fp_pool_m'
    input_fp_pool_point = 'fp_pool_point_m'
    input_fp_pool_ac_icao_ac_model = 'fp_pool_ac_icao_ac_model' # relationsl

    [data.flight_plans.flight_uncertainties]
    input_flight_uncertainties = 'flight_uncertainties_static'
    input_extra_cruise_if_dci = 'increment_cruise_dci_static'

    [data.flight_plans.en_route_wind]
    input_iedf_wind_static = 'iedf_wind_static_old1409'
    wind_type = 'LIKE \"%%segment%%\"'
```

Input Data



Data sample zenodo

https://zenodo.org/records/11384379

Output Data

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Pax

_id	initial_sobt	final_sibt	initial_aobt	final_aibt	modified_itinerary	tot_arriv
61	2019-09-06 15:35:00	2019-09-06 20:50:00	2019-09-06 19:47:24.380680	2019-09-07 07:27:00.000000	True	
157	2019-09-06 14:20:00	2019-09-06 19:35:00	2019-09-06 14:51:11.188765	2019-09-07 07:32:00.000000	True	
170	2019-09-06 04:40:00	2019-09-06 10:49:00	2019-09-06 04:55:49.318364	2019-09-06 10:49:00.000000	False	
186	2019-09-06 07:20:00	2019-09-06 11:45:00	2019-09-06 08:08:58.684235	2019-09-06 12:47:00.000000	True	
201	2019-09-06 05:05:00	2019-09-06 09:46:00	2019-09-06 05:10:18.836478	2019-09-06 09:46:00.000000	False	

tot_arrival_delay	connecting_pax	final_destination_reached	multimodal	missed_air2rail	missed_rail2air	ground_mobility_time
637	False	True	True	True	False	67.49
717	False	True	True	True	False	92.92
0	False	True	True	False	False	97.49
62	False	True	True	True	False	92.59
0	False	True	True	False	False	103.72

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Human Machine Interface

Human-Machine Interface

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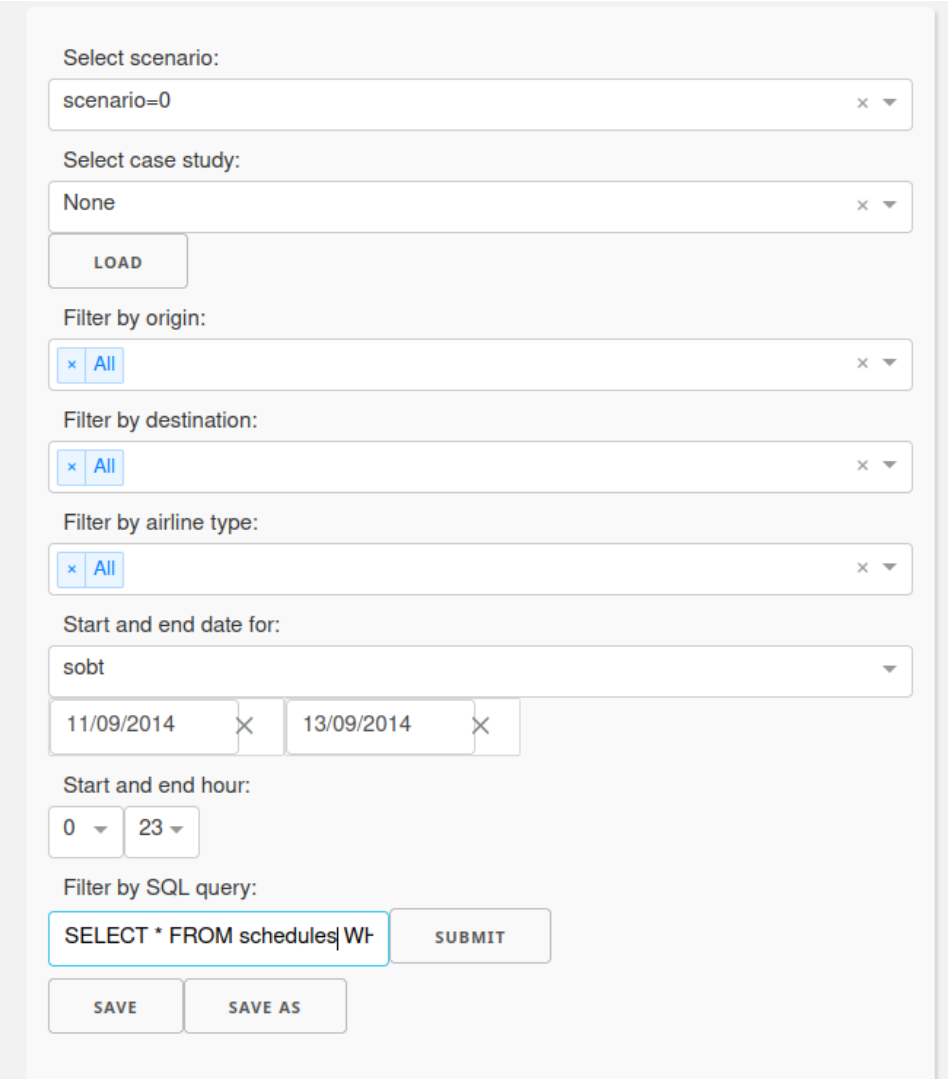
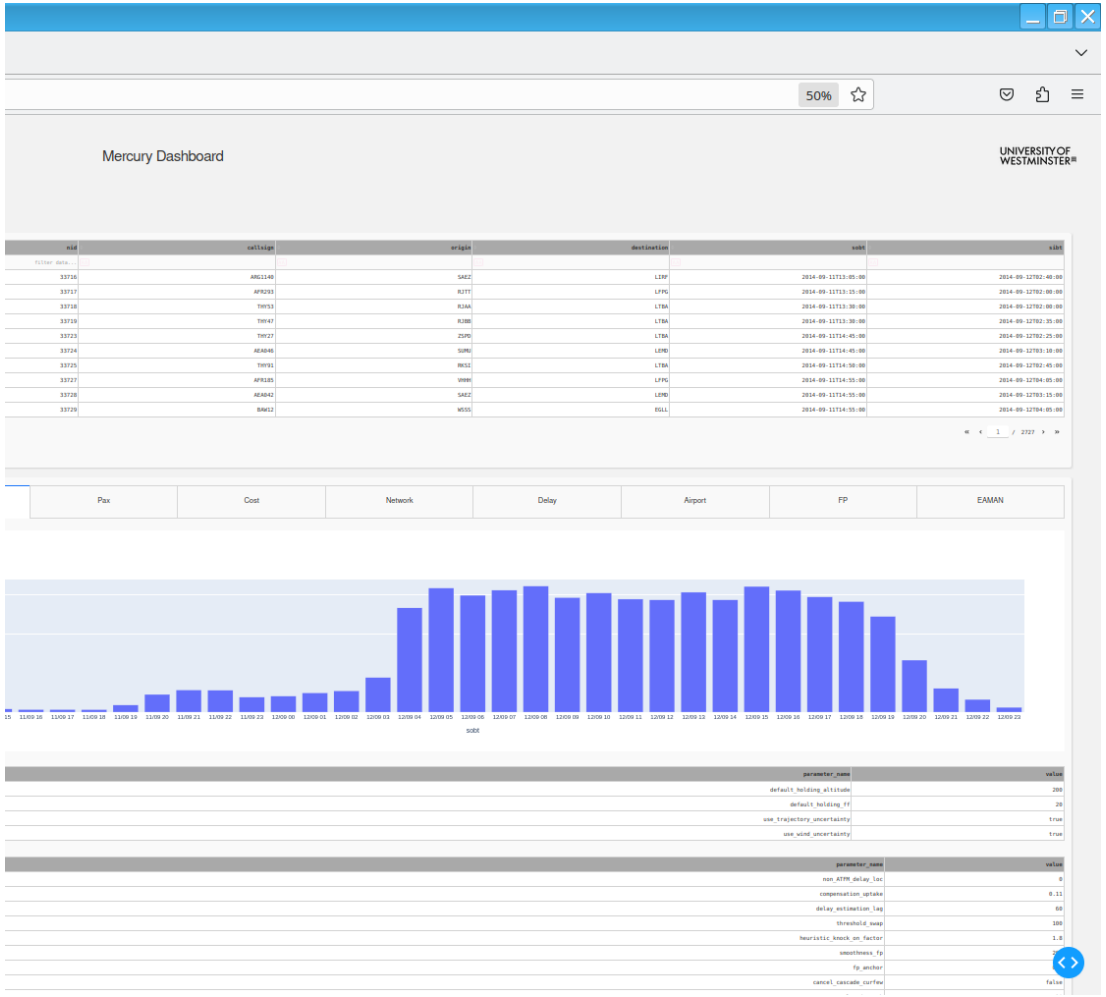
Facilitate manipulation input/output data and configuration



Human-Machine Interface

Facilitate manipulation input/output data and configuration



Human-Machine Interface

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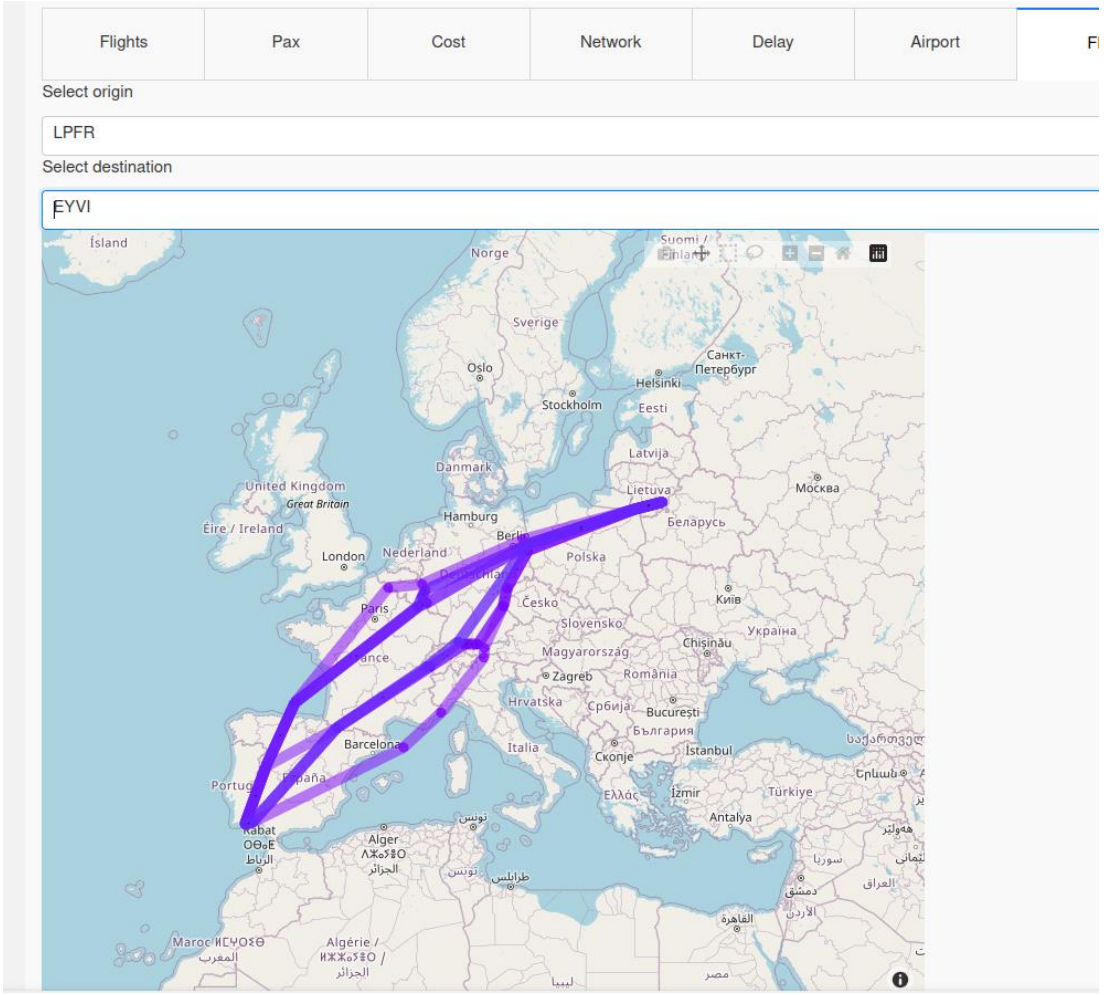
Facilitate manipulation input/output data and configuration



Human-Machine Interface

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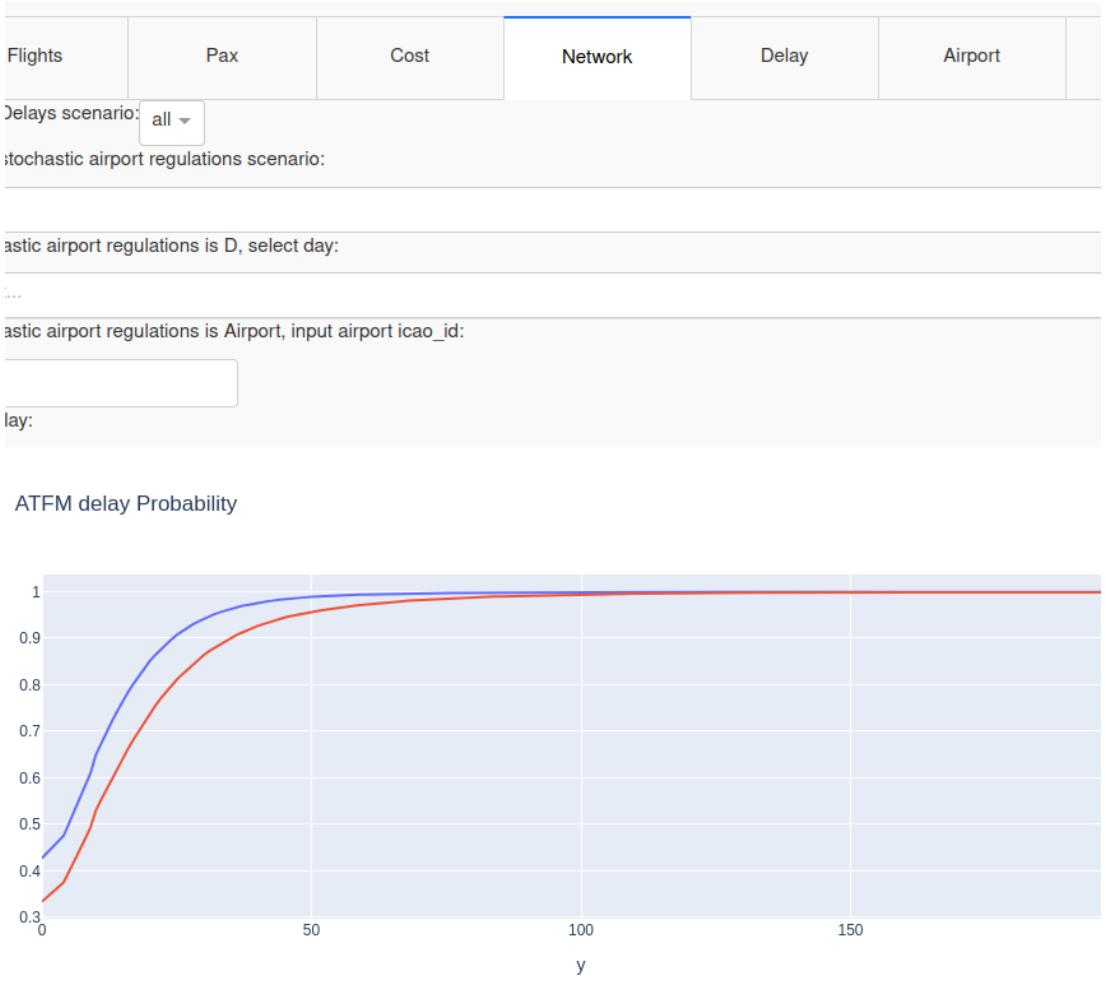
Facilitate manipulation input/output data and configuration



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Extension of Mercury to Multimodality

Extending Mercury to multimodality

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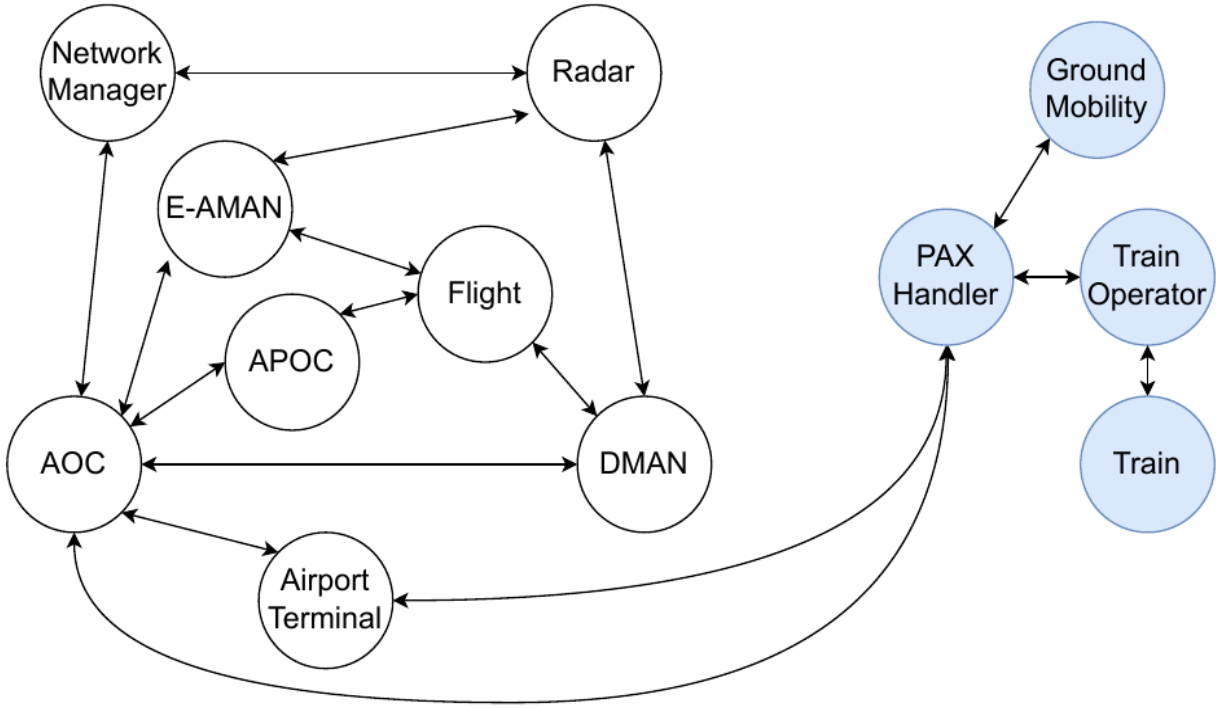

New agents:

Train, Train Operator, Ground Mobility, Passenger Handler.

Extending Mercury to multimodality

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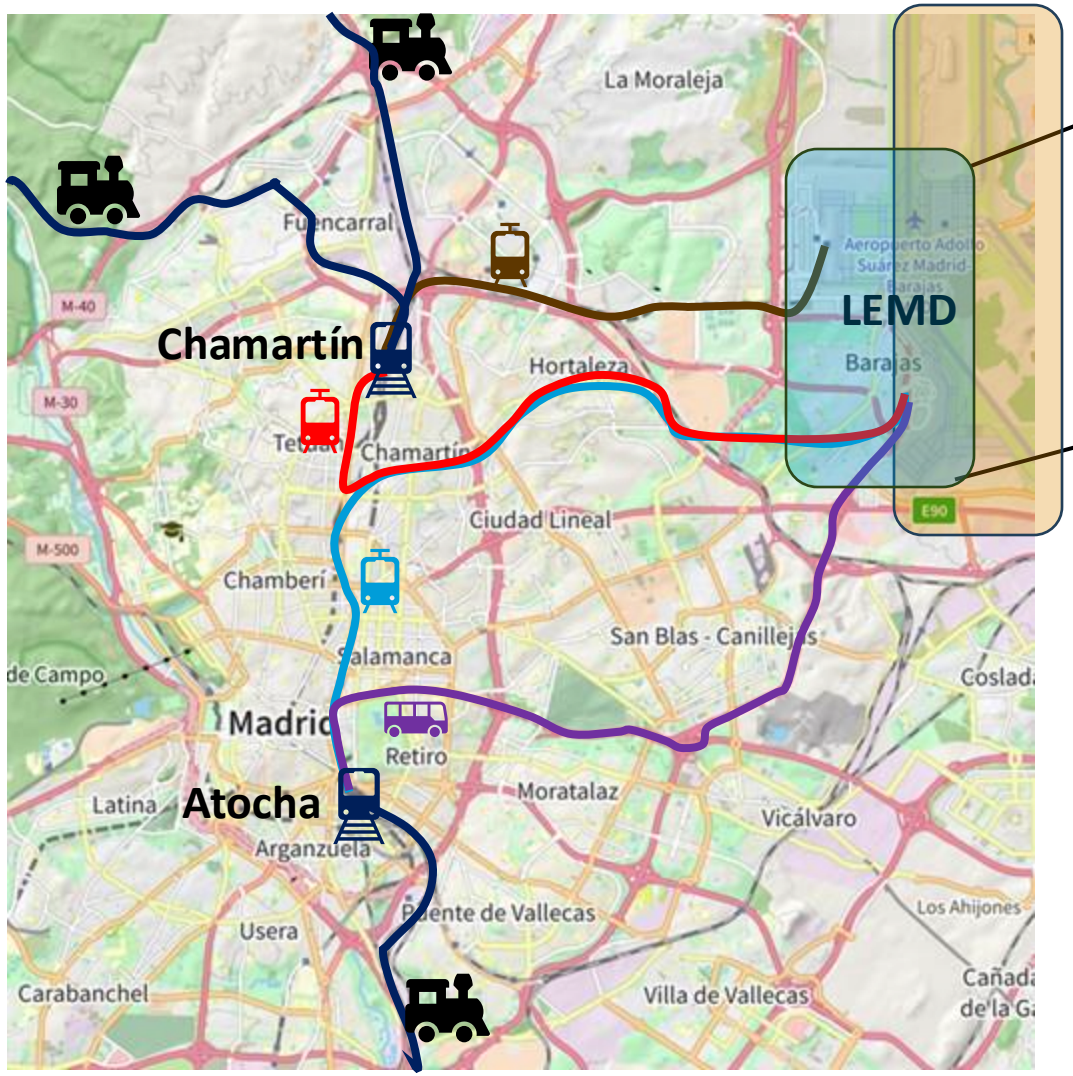

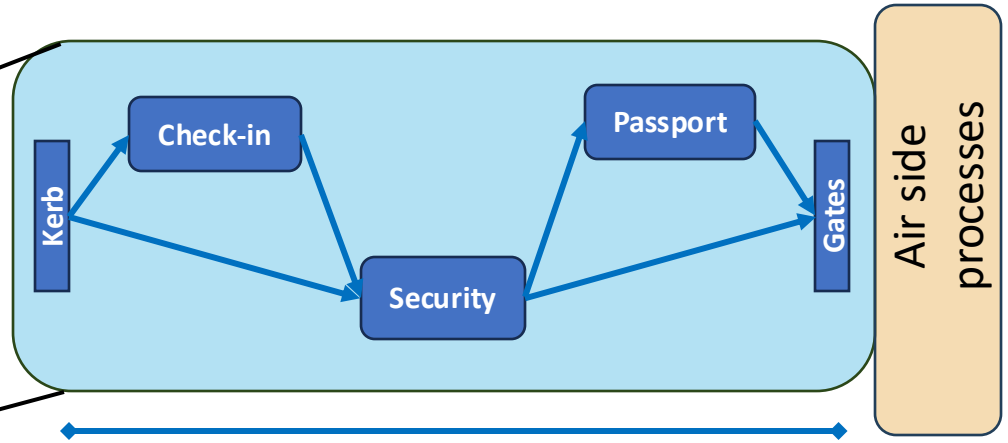

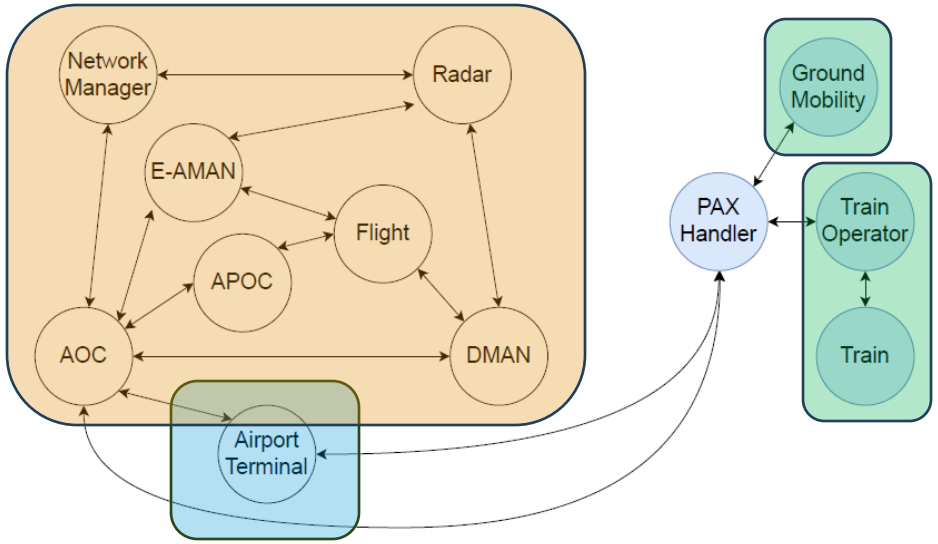

Extending Mercury to multimodality

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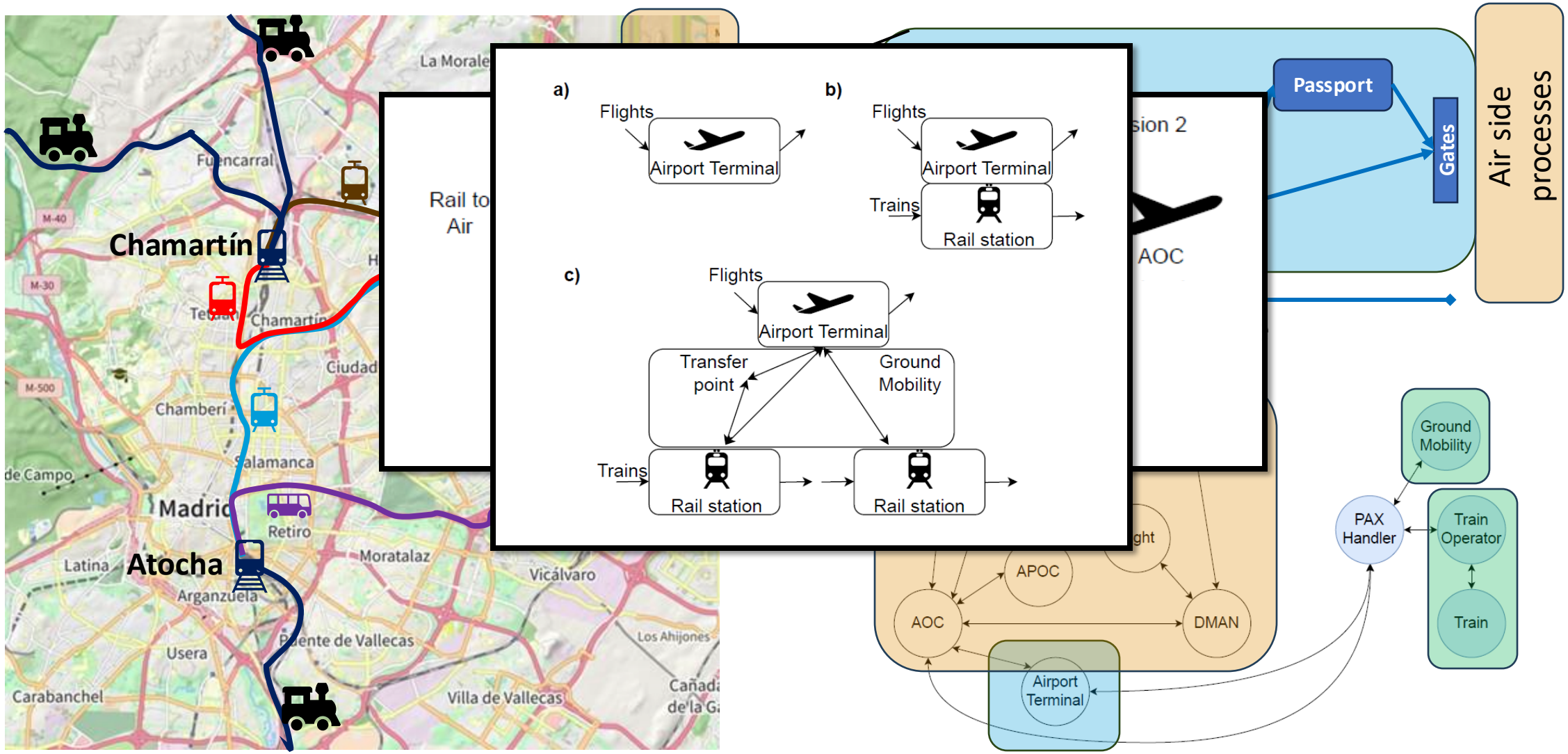

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Example of use of Mercury

Examples use of Mercury

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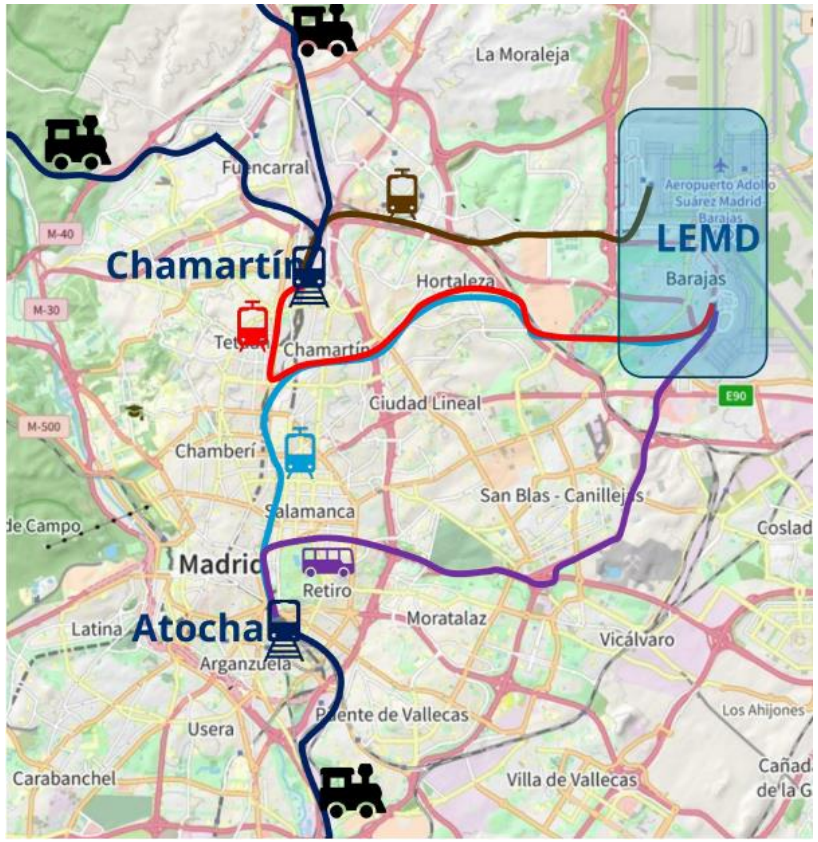
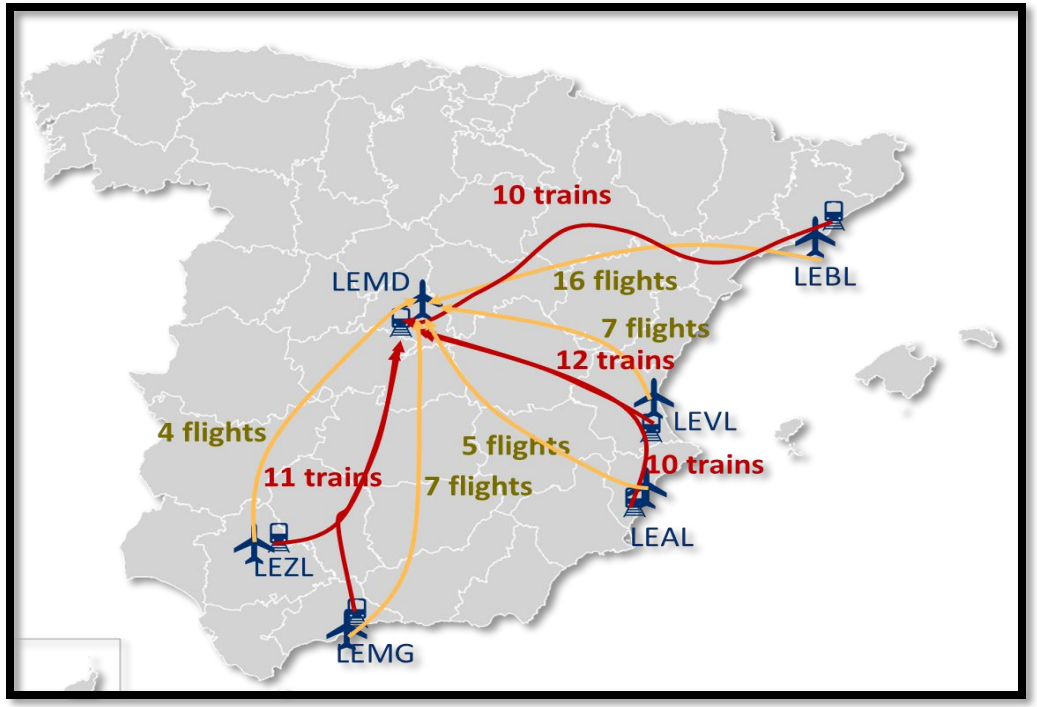
- Evaluate different versions of Dynamic Cost Indexing – Waiting for Passengers
- Evaluate different version of E-AMAN
- Evaluate different version of Flight Prioritisation
- Changes of policies (e.g. Regulation 261)
- Behavioural economics aspects with human in the loop simulations
- Multimodal connectivity at hubs
- …

Extending Mercury to multimodality



- 1 day of air traffic on 22nd September 2023 to/from Madrid Barajas (LEMD) (816 flights)
- GTFS dataset from Renfe (154 trains)
- Passenger OD matrix from Aviation Week
- All flights with a rail alternative < 2h30 removed (air ban policy)
- OD matrix is disaggregated into the flights and trains

Extending Mercury to multimodality



- Out of 90k pax,
- 66.8% are single-flight,
- 18.8% are connecting flight-flight,
- 14.4% are multimodal.

Extending Mercury to multimodality

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- Fast-track process for pax
  - Speed up Kerb-to-Gate for delayed passengers by a given factor,
  - Affects only rail-air connections
- Disrupted delayed ground mobility (10 – 30 minutes)

Extending Mercury to multimodality

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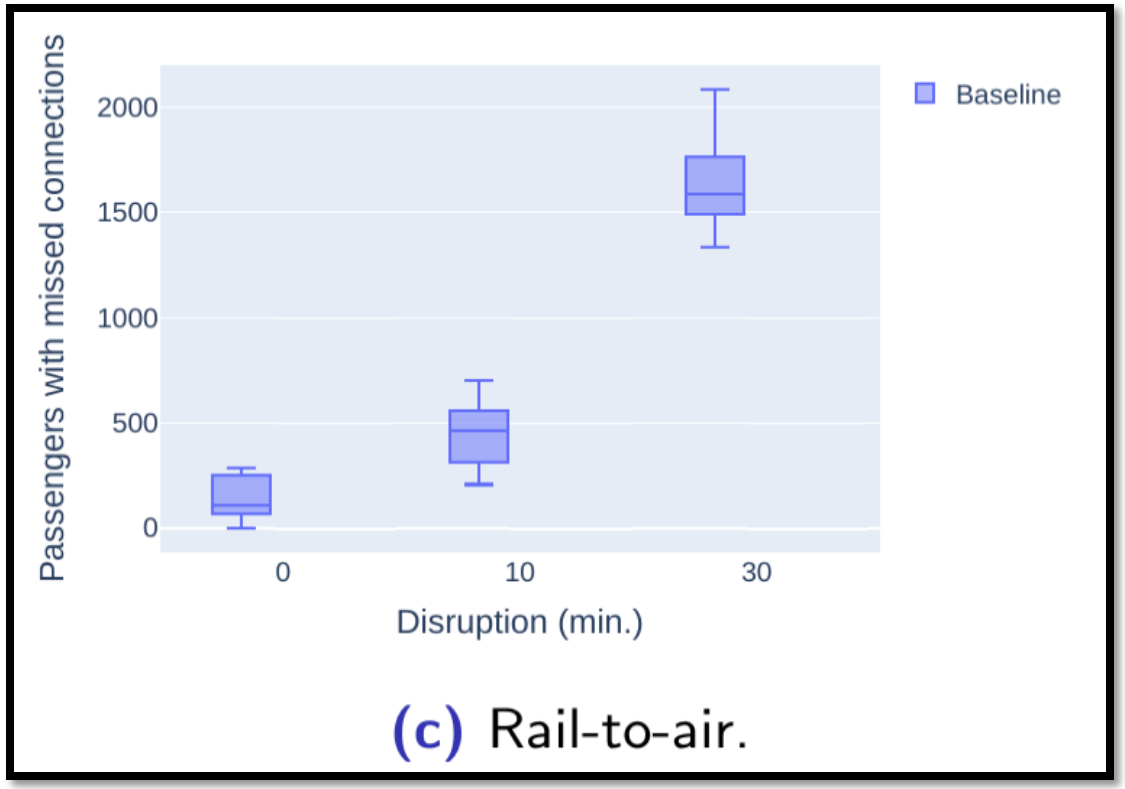
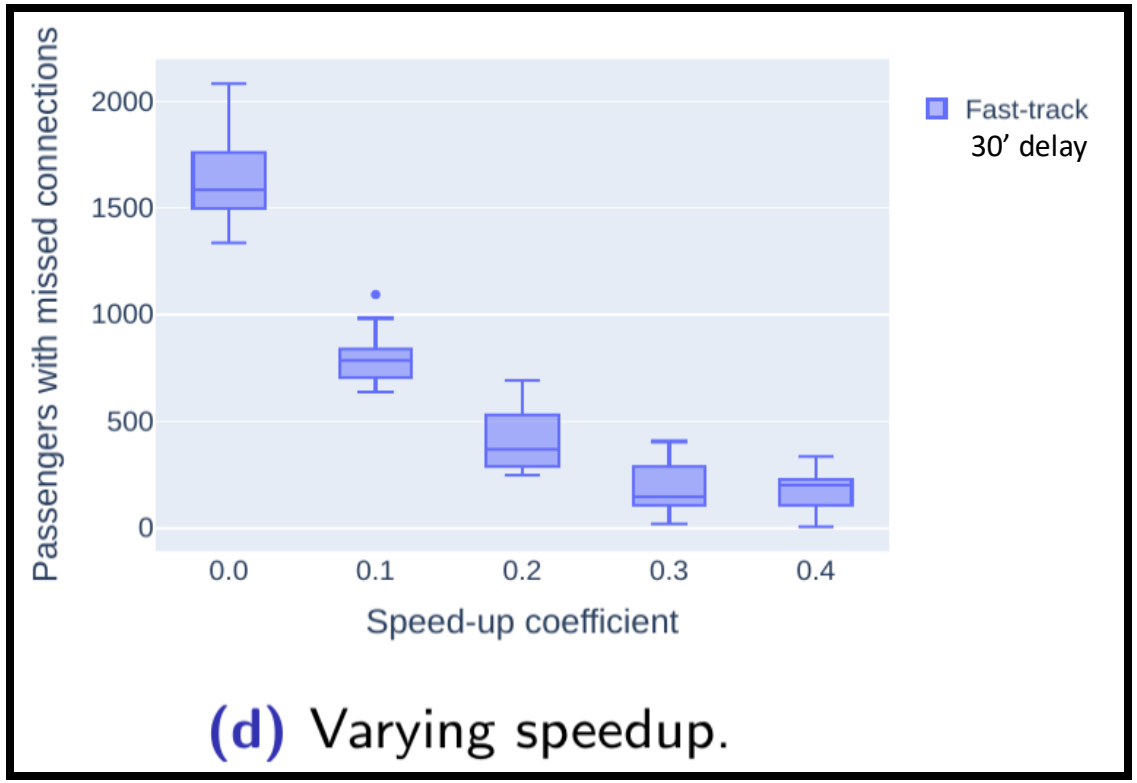
- Fast-track for processing passengers



(c) Rail-to-air.



(d) Varying speedup.

Conclusions

Conclusions

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MERCURY

https://github.com/UoW-ATM/Mercury

- Multi-agent-based system
- Decisions based on cost estimation
- Event-driven tracking main processes
- Modelling flight and passenger mobility
- Capturing low level indicators (and distributions) for relevant stakeholders
  - Delay, costs, emissions, etc.
- Modular: possible to modify behaviour of element in system
- Open source (and libraries): Python

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- THANK YOU