HorizonUAM

A COLLABORATIVE SYSTEMS OF SYSTEMS SIMULATION OF URBAN AIR MOBILITY: ARCHITECTURE PROCESS AND DEMONSTRATION OF CAPABILITIES

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DLR

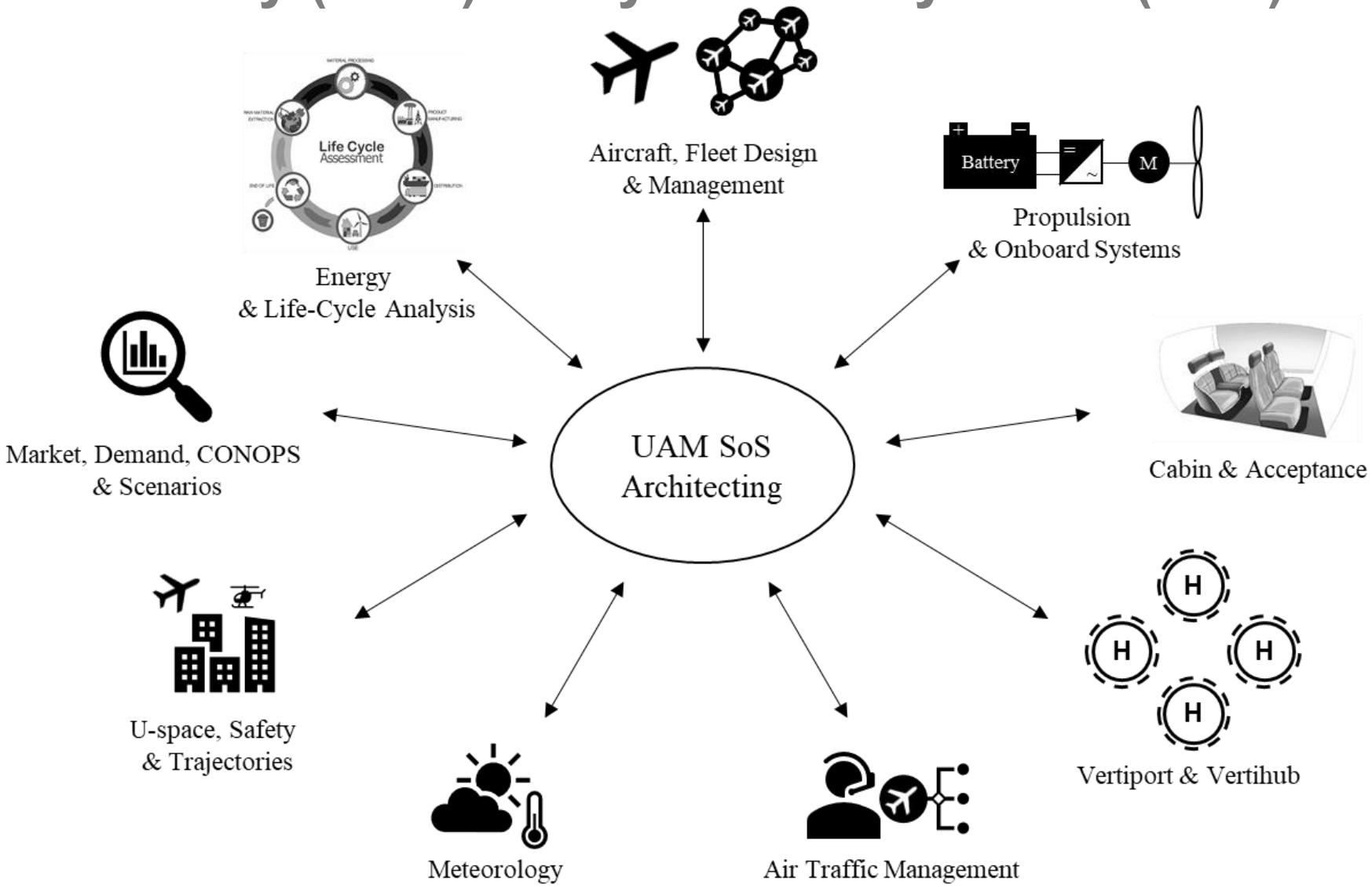
Outline

- Introduction
- System Architecting Process
- Enablers: CPACS and RCE
- Challenges and Resolution
- Workflow and Demo

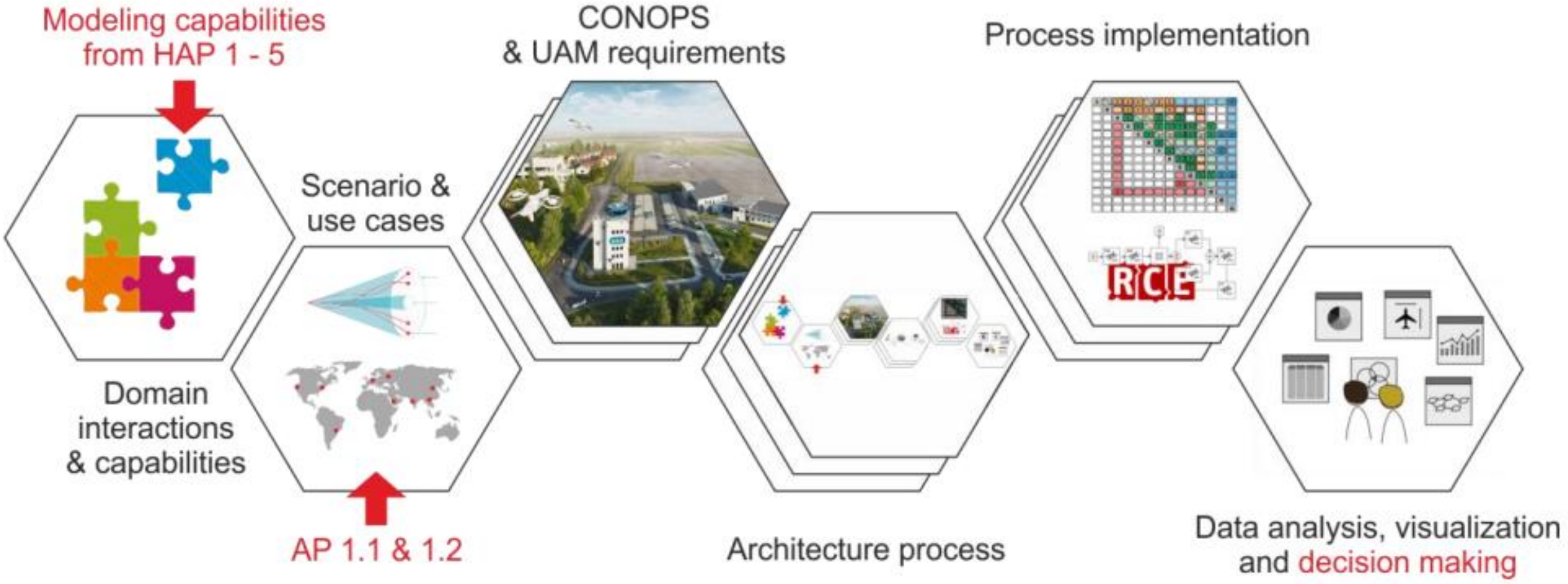
Introduction
System of Systems

ISO/IEC/IEEE 21839:2019 defines a System of Systems (SoS) as a
"set of systems or system elements that interact to provide a unique capability that none of the constituent systems can accomplish on its own."

Introduction
Urban Air Mobility (UAM) as System of Systems (SoS)



HorizonUAM Collaborative System of Systems Architecture Process



System Architecting Process
Domain Models within HorizonUAM SoS

Demand Forecasting

Mode Choice

Vertiport Airside Management

Urban Airspace Management

Cost and Revenues

Vehicle Allocation

Maintenance Considerations

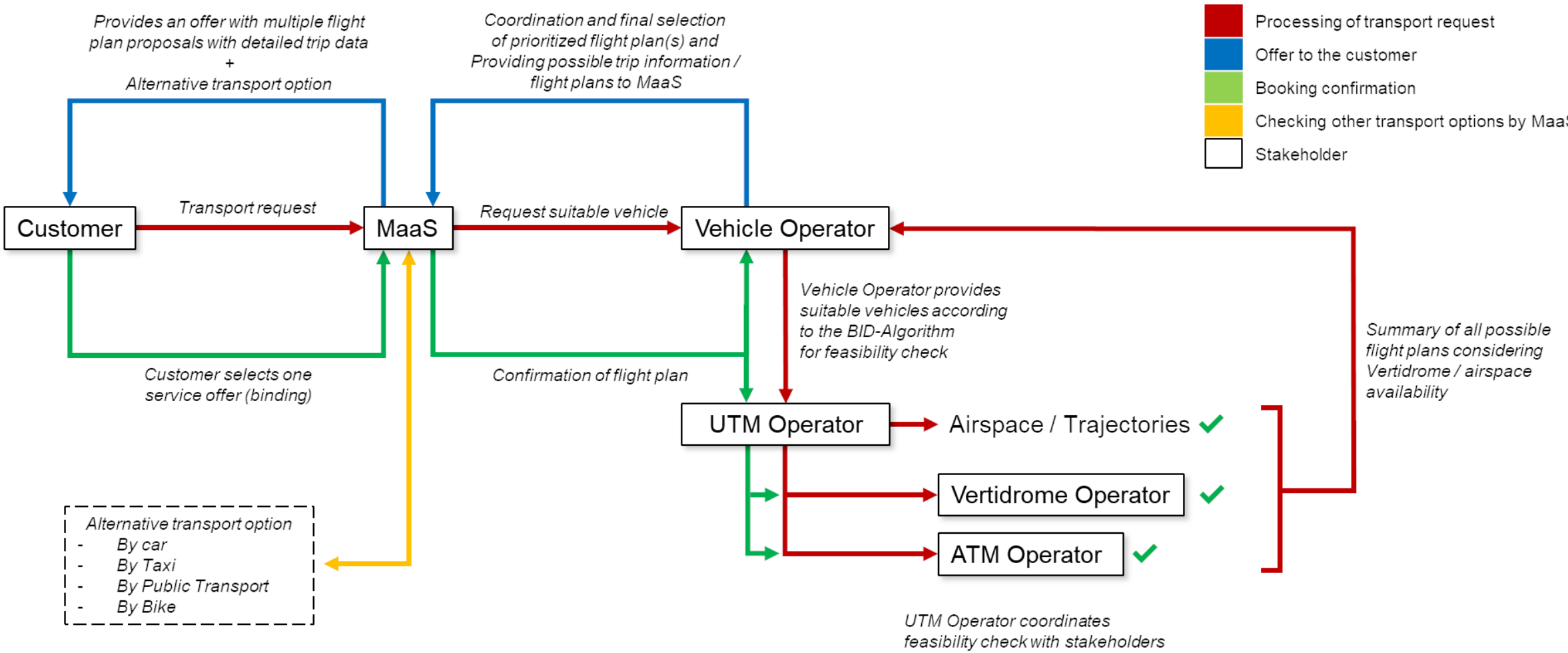
Vehicle and Fleet Design

System Architecting Process
Scenarios and Use Cases

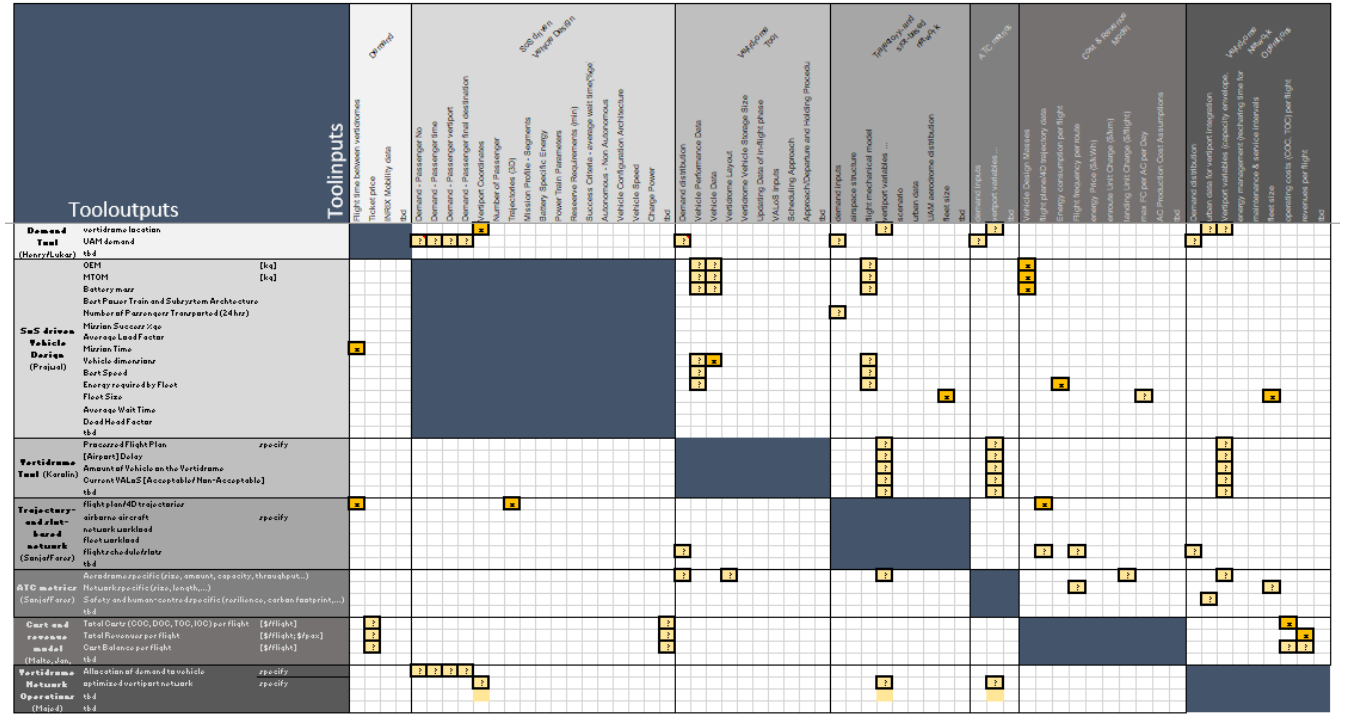
Various Scenarios:

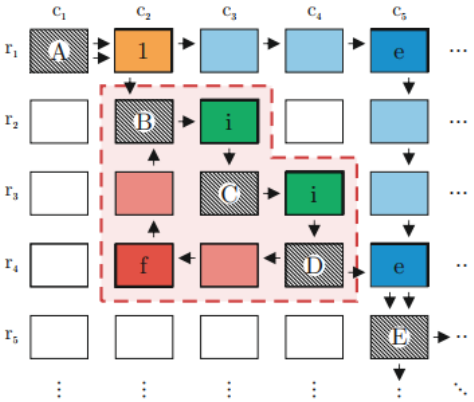
- On Demand
- Scheduled
- Battery Charging vs Swapping
- Demand Scenarios
- Heterogeneous Fleet Scenarios
- Vertiport capacity Scenario
- UAM U-Space and UTM Scenarios
- Weather Scenarios
- Single Hop vs Multi Hop

System Architecting Process
Concept of Operations



System Architecting Process
Architecting Process

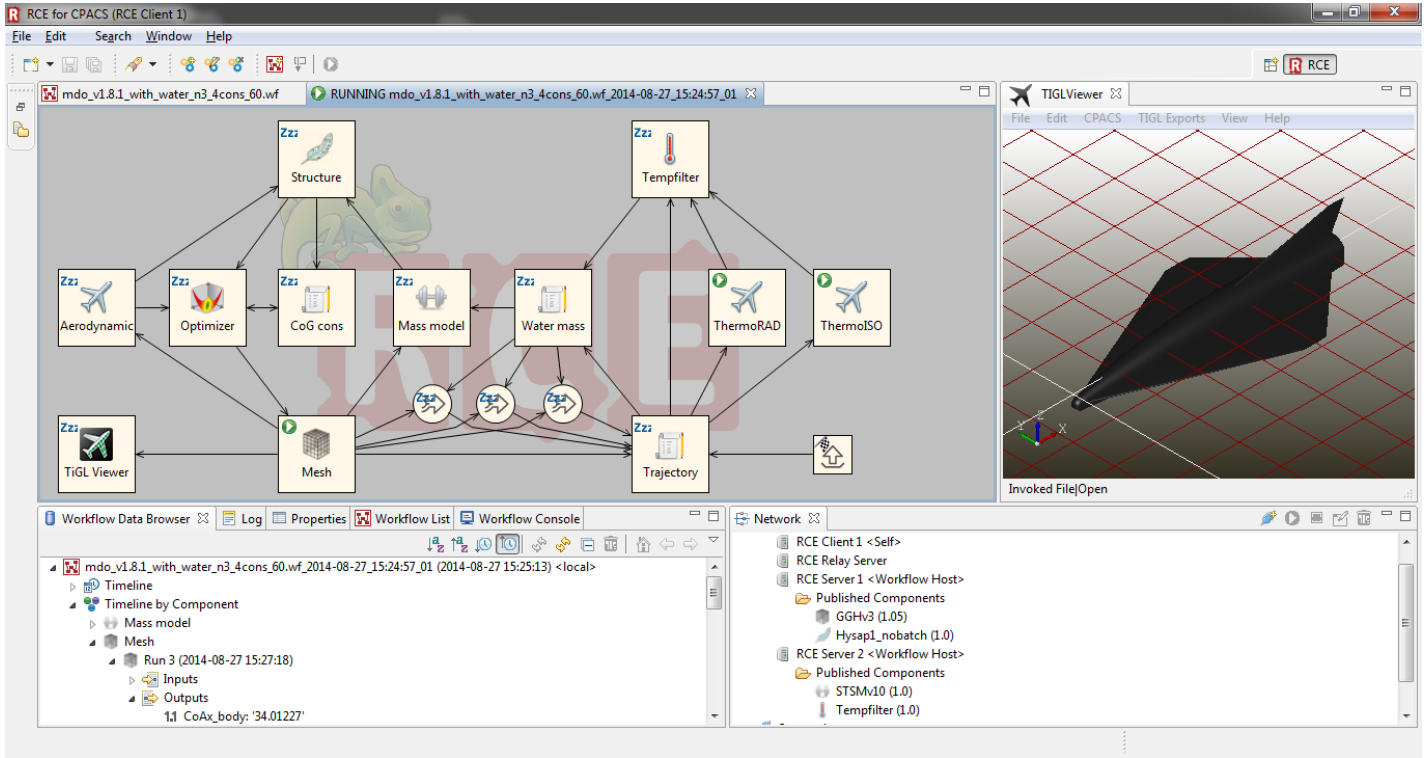




Several workshop with domain stake partners or model owners to align coupling Input & Output parameters

Enablers
RCE: Remote Component Environment

- RCE is an Open Source distributed, workflow-driven integration environment
- It enables the design and simulation of complex systems through collaboration
  - by integrating our own design and simulation tools
  - without sharing code itself, but rather an executable “blackbox”



Enablers
CPACS: Common Parametric Aircraft Configuration Schema

- CPACS is a data definition for the air transportation system
- CPACS enables engineers to exchange information between their tools
- Communication can only be possible by speaking the same language

cpacs
A Common Language for Aircraft Design

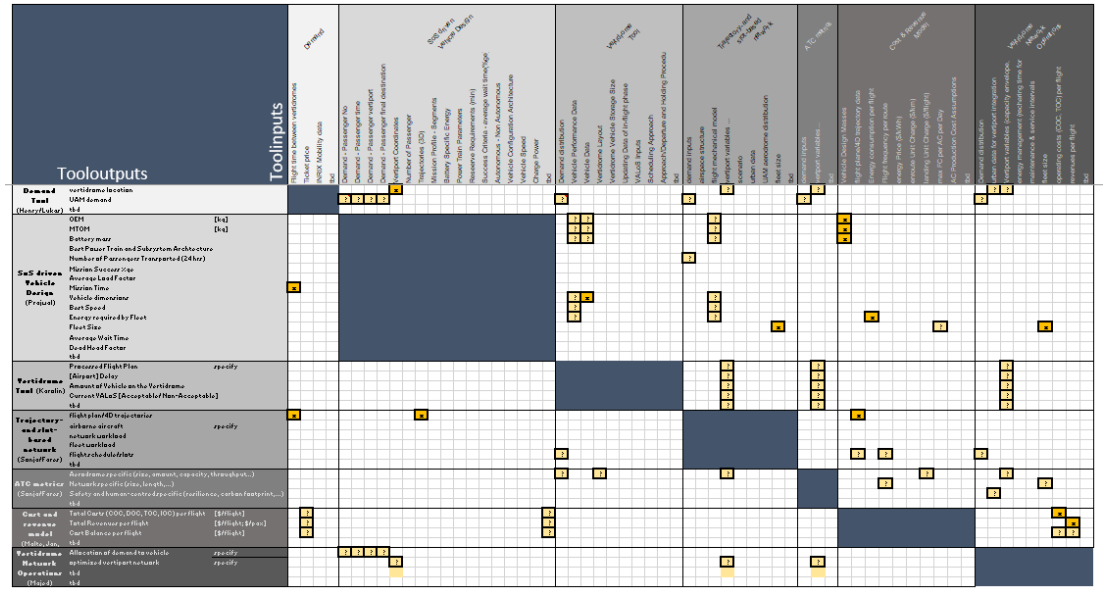
System Architecture Process
Challenges and Resolution

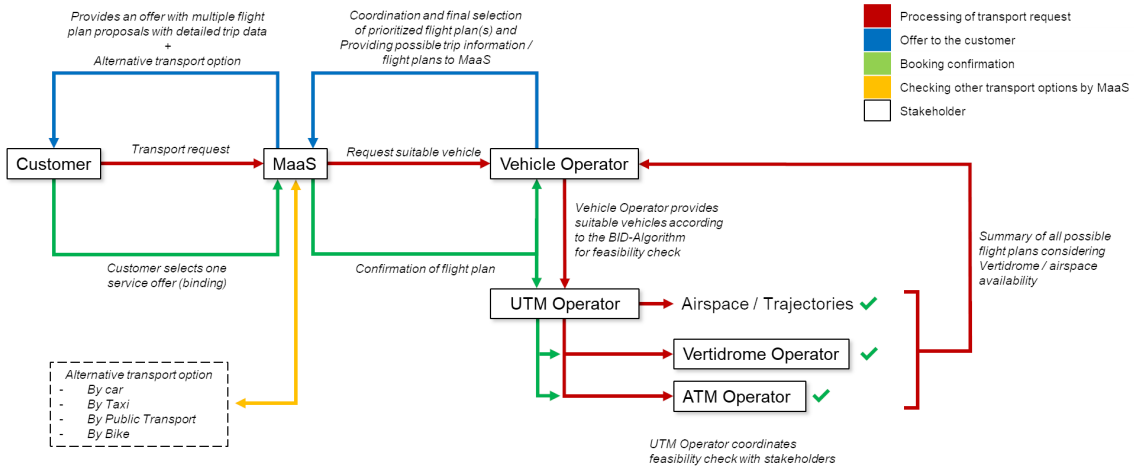
Requirements

- Model Workflow as in Concept of Operations
- Connect tools and *simulations* spanning different domains

Challenges

- Tool execution happens sequentially
- Input -> Execute -> Output
- Tools need to be stateless

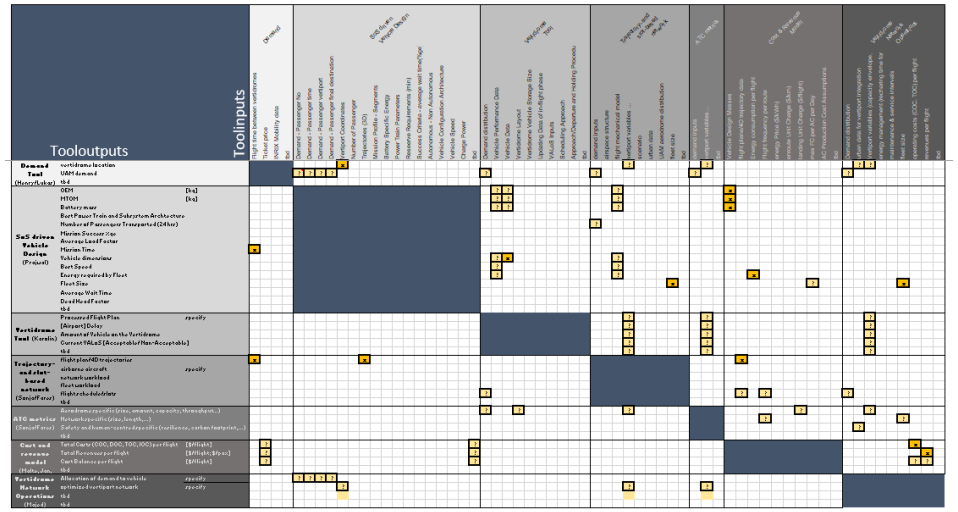


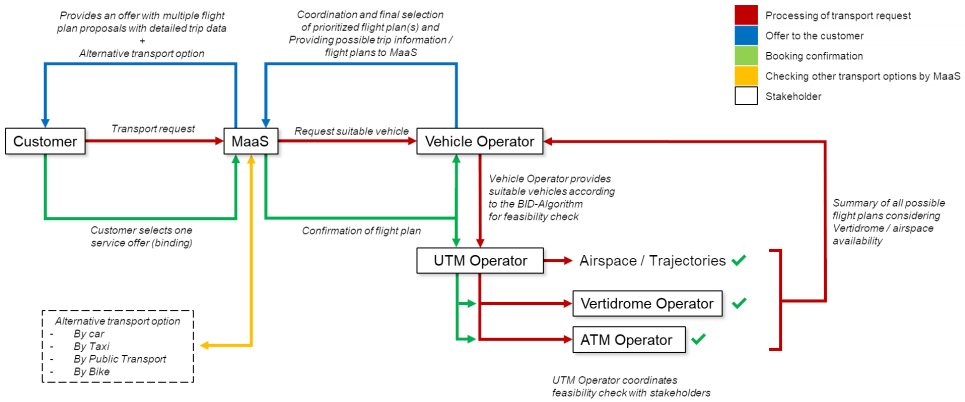


System Architecture Process
Challenges and Resolution

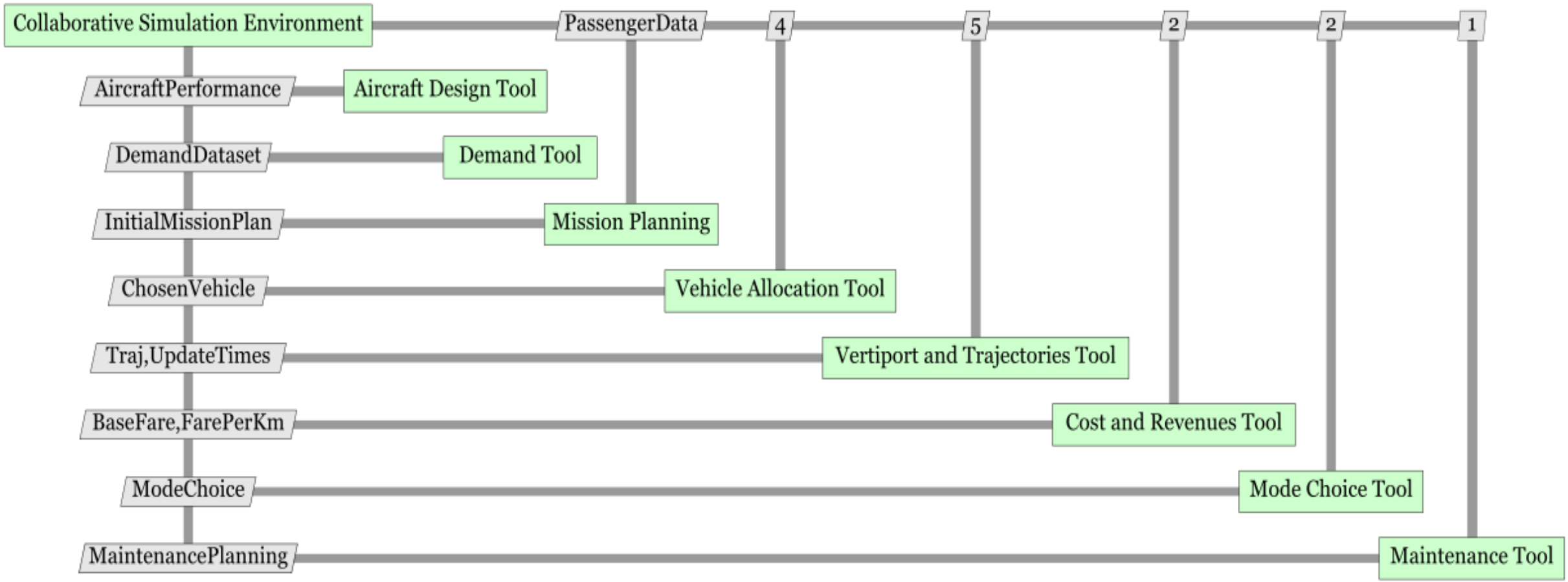
Resolution

- Leverage a bridge between Agent-Based Simulation and RCE
- Collaborative Simulation Environment acts as backbone for integration
  - Triggers modules as defined in ConOps
  - Act as orchestrator of the workflow
  - Act as single source of truth
  - Simulate UAM trips and manage fleet





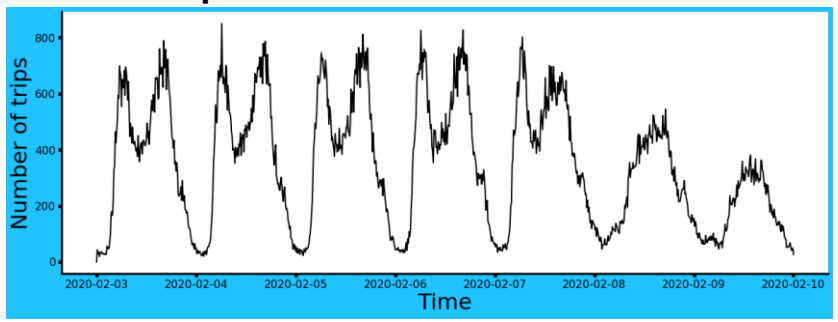
Workflow


Collaborative Simulation Environment
PassengerData
4
5
2
2
1
AircraftPerformance
Aircraft Design Tool
DemandDataset
Demand Tool
InitialMissionPlan
Mission Planning
ChosenVehicle
Vehicle Allocation Tool
Traj,UpdateTimes
Vertiport and Trajectories Tool
BaseFare,FarePerKm
Cost and Revenues Tool
ModeChoice
Mode Choice Tool
MaintenancePlanning
Maintenance Tool

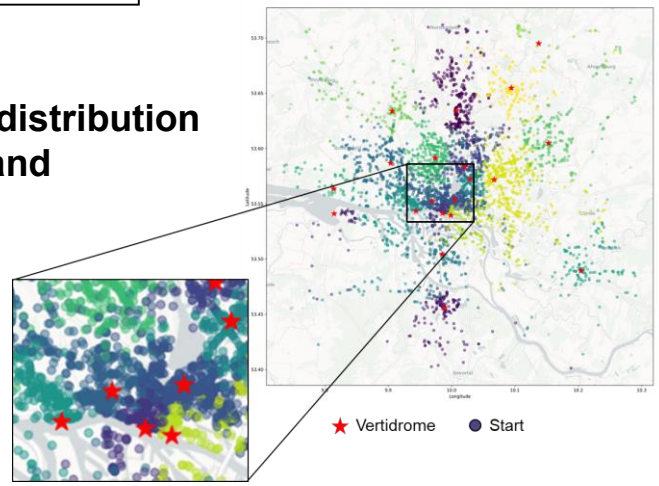
UAM Demand Tool
Provides demand data in high spatial and temporal resolution

Mobility data for Hamburg
- GPS-based recording
- Start and end point of trips
- Survey period: 2020, February 2. – 9.
- Sample size: about 3 – 5% of motorized individual transport

Temporal distribution of demand



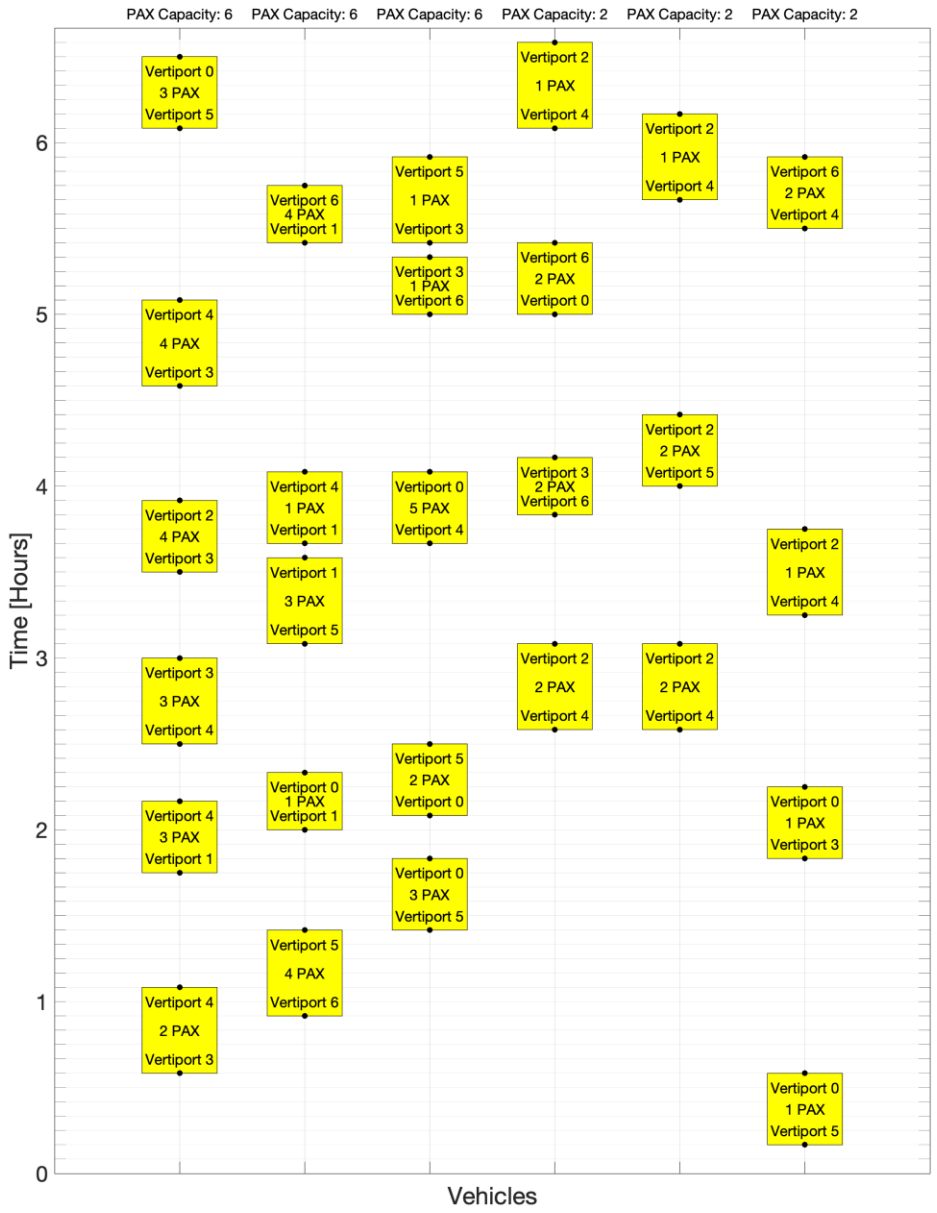
Spatial distribution of demand



Input data for simulation

	A	B	C	D	E
1	Trip_ID	TripStartTime	OriginVertiportArrivalTime	OriginVertiportID	DestinationVertiportID
2	127	19:57:34	20:01:17	7	10
3	139	10:34:42	10:35:29	5	0
4	184	21:52:19	21:57:54	13	4
5	307	10:41:55	10:50:47	18	13
6	343	11:25:00	11:31:10	17	3
7	403	06:25:29	06:27:29	13	7

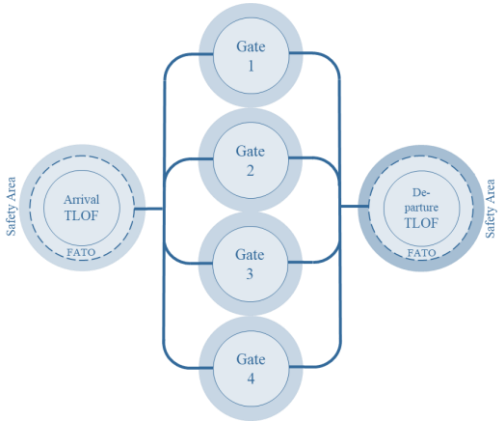
Vehicle Allocation Tool

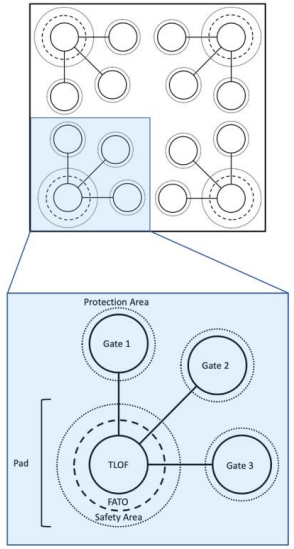


- Allocation of demand to available vehicles
  - Consideration of a heterogeneous fleet with individual cruise speeds and PAX-capacities
- Optimization based on Mixed-Integer Linear Programming approach
  - Today: Maximization the number of revenue seat kilometers
  - Minimization the number of empty seat kilometers
  - The number of feasible missions is limited due to the available fleet pool

Vertidrome Tool

Vertidrome Capacity Mangement





Aircraft Characterics:

- Aircraft Size
- Aircraft Performance

Mission Request:

- Take-off vertidrome
- Destination vertidrome
- Requested take-off time

Current UAM Operation:

- Actual missions at take-off vertidrome
- Actual missions at destination vertidrome

Vertiport layout and operational concept (LIEDT, PAW)

↓

Calculate arrival and departure mission profile

↓

Conduct strategic scheduling and sequencing

↓

Fast-time simulation of vertiport‘s airside traffic

↓

Tactical conflict resolution of airside traffic

→ Allocated take-off & landing slot

→ Dispatched/Processed UAM flight Plan

→ Occupancy of each vertiport element (FATO, taxiways, gates, parking positions)

→ # of aircrafts on vertiport

→ Vertidrome airside level of service performance

Airspace Tool

Aircraft characteristics

Origin Vertidrome

Available time slots

Destination vertidrome

Route network

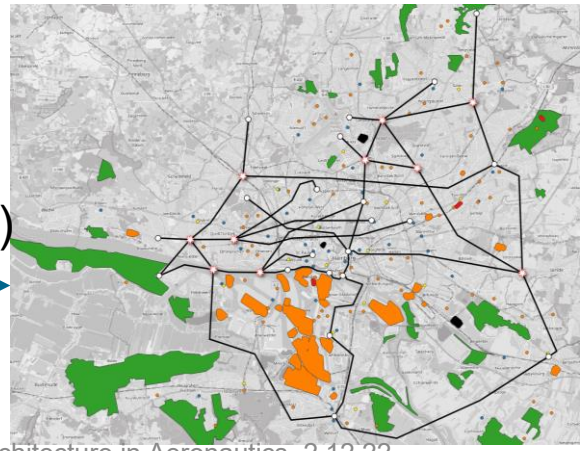
Calculate x different trajectories

Check for conflicts with active missions

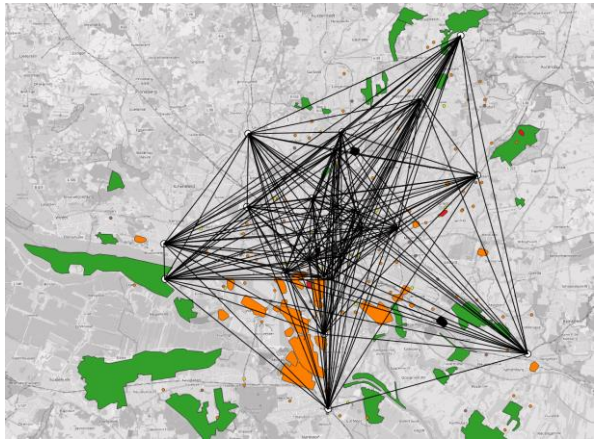
Solve conflicts by changing the departure time for each calculated trajectory

Deconflicted 4D Trajectories with arrival time at destination

Rigid route structure („Slot-based Approach“)

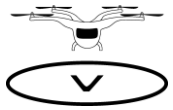


Free route structure („Trajectory-based Approach“)



Flight Guidance Sub-Workflow
Vertidrome and Airspace Tools

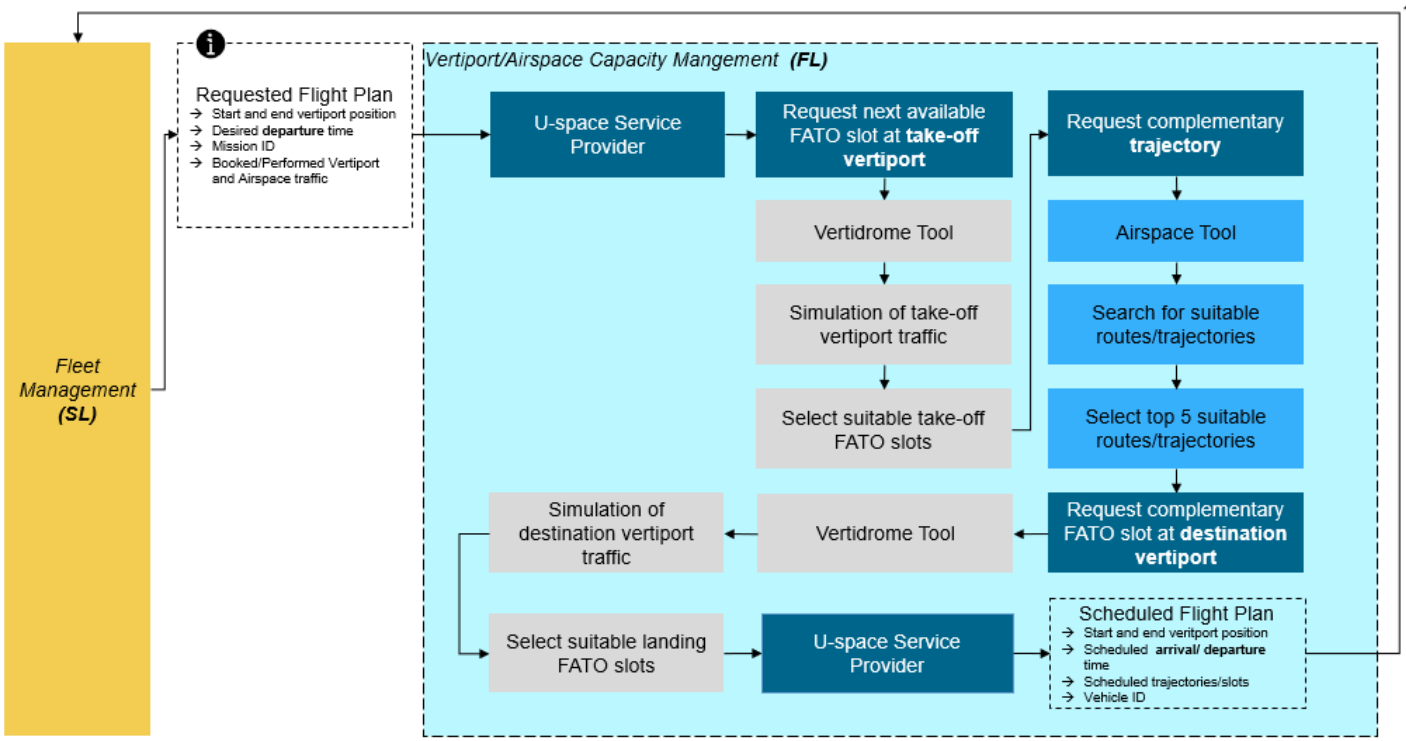
Vertidrome Capacity Mangement



- Two vertiport layouts and operational concepts: PAW & LIEDT
- Strategic and tactical conflict resolution of airtaxi traffic on vertiports
- Allocation of next available take-off and landing FATO slot

Airspace Capacity Mangement

- Two network mangement concepts: Trajectory and Slot-based approach
- Strategic conflict detection and resolution
- Allocation of availbe flight trajectories



Cost and Revenue Model

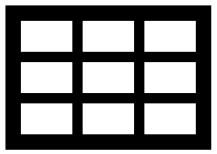
Flight missions

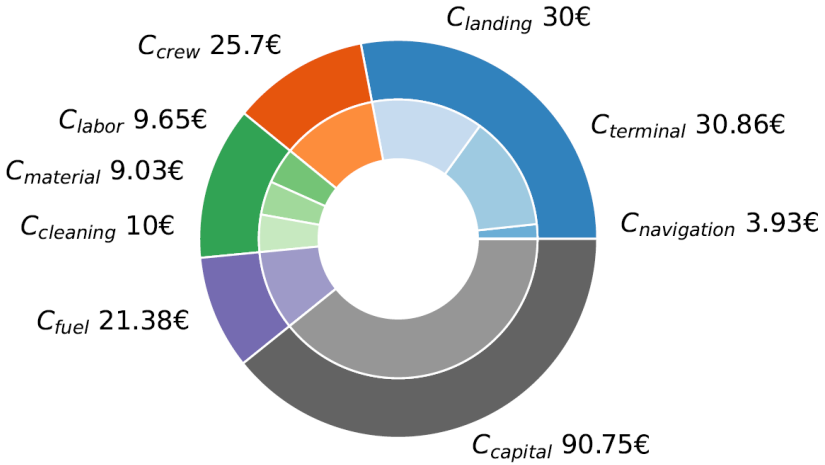
Vehicle data

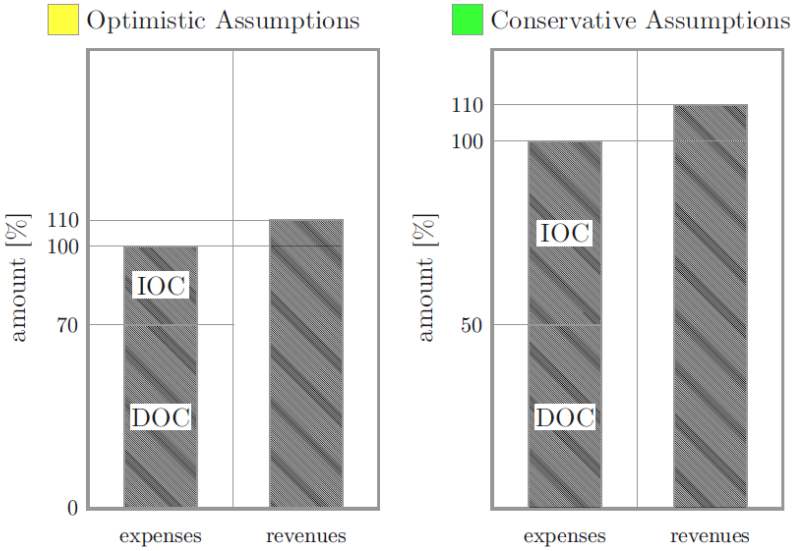
DOC Model
- Fee costs
- Crew costs
- Maintenance and Overhaul
- Fuel costs
- Capital costs

Revenue Model
- TOC estimation
- Profit margin

Economic ticket fare



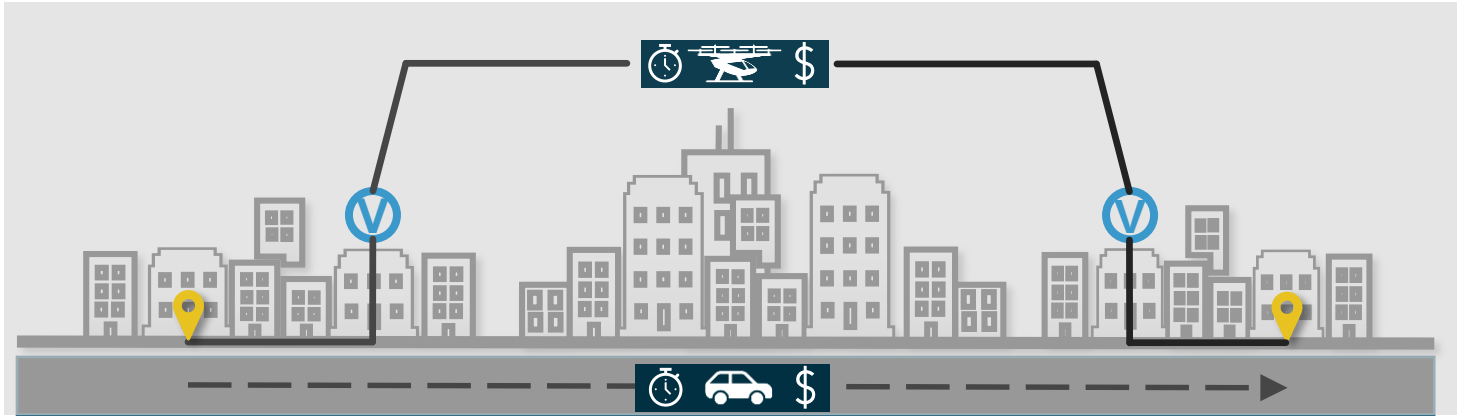




Mode Choice Tool
Simulates mode choice of each individual traveler

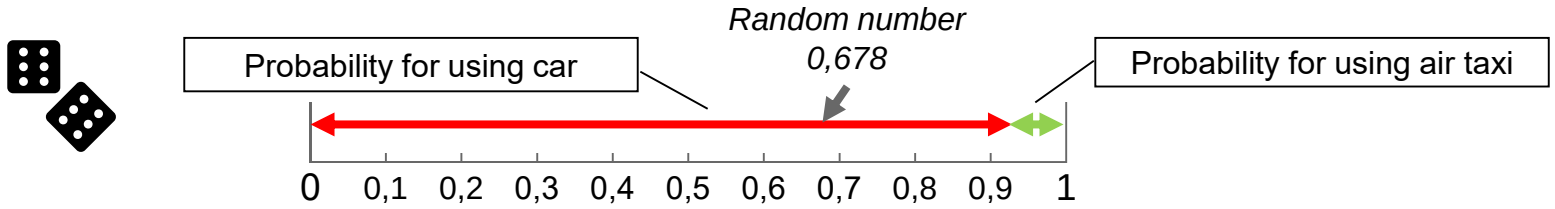
Generalized costs for transport

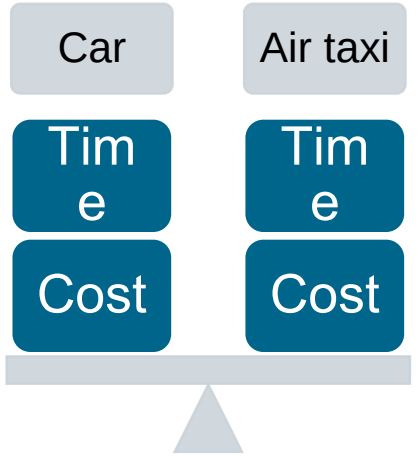
- Monetary costs
- Monetized travel-time costs
- First and last mile included



Simulating individual choices

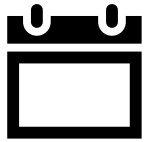
- Generalized costs determine probability of choosing car or air taxi
- The actual selection is determined by a random experiment (random number 0.678: car is selected)





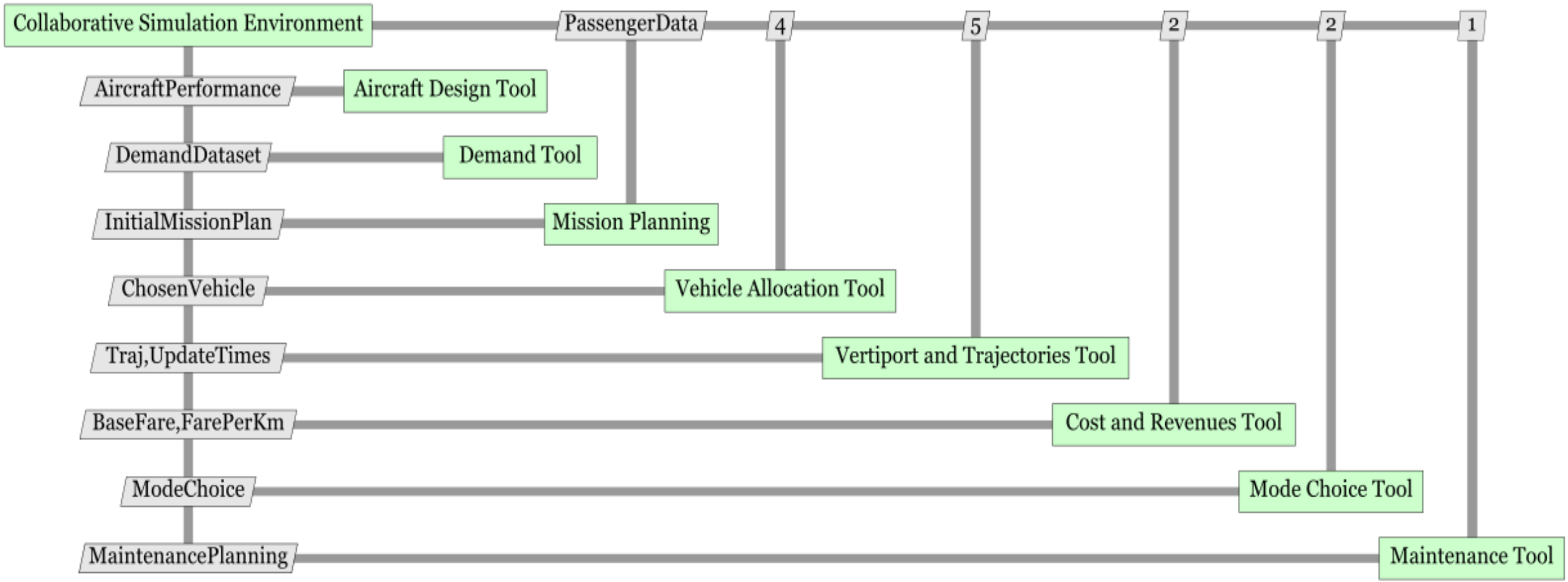
Maintenance Tool

- Goal:
  - Integration of **Battery Degradation** in SoS
- Status Quo:
  - Capacity Fade Simulation tailored for one flight mission
  - Simulation for thousands of cycles
- Next steps
  - Creating interface with SoS
  - Individual battery degradation for every UAMV



- Goal:
  - Implement **Maintenance Scheduling** in Aircraft Assignment
- Status Quo:
  - First Ideas and next working package
- Next steps
  - Establishment of an transfer interface with SoS
  - Implementing of ideas
  - Testing of heuristics for validations

Workflow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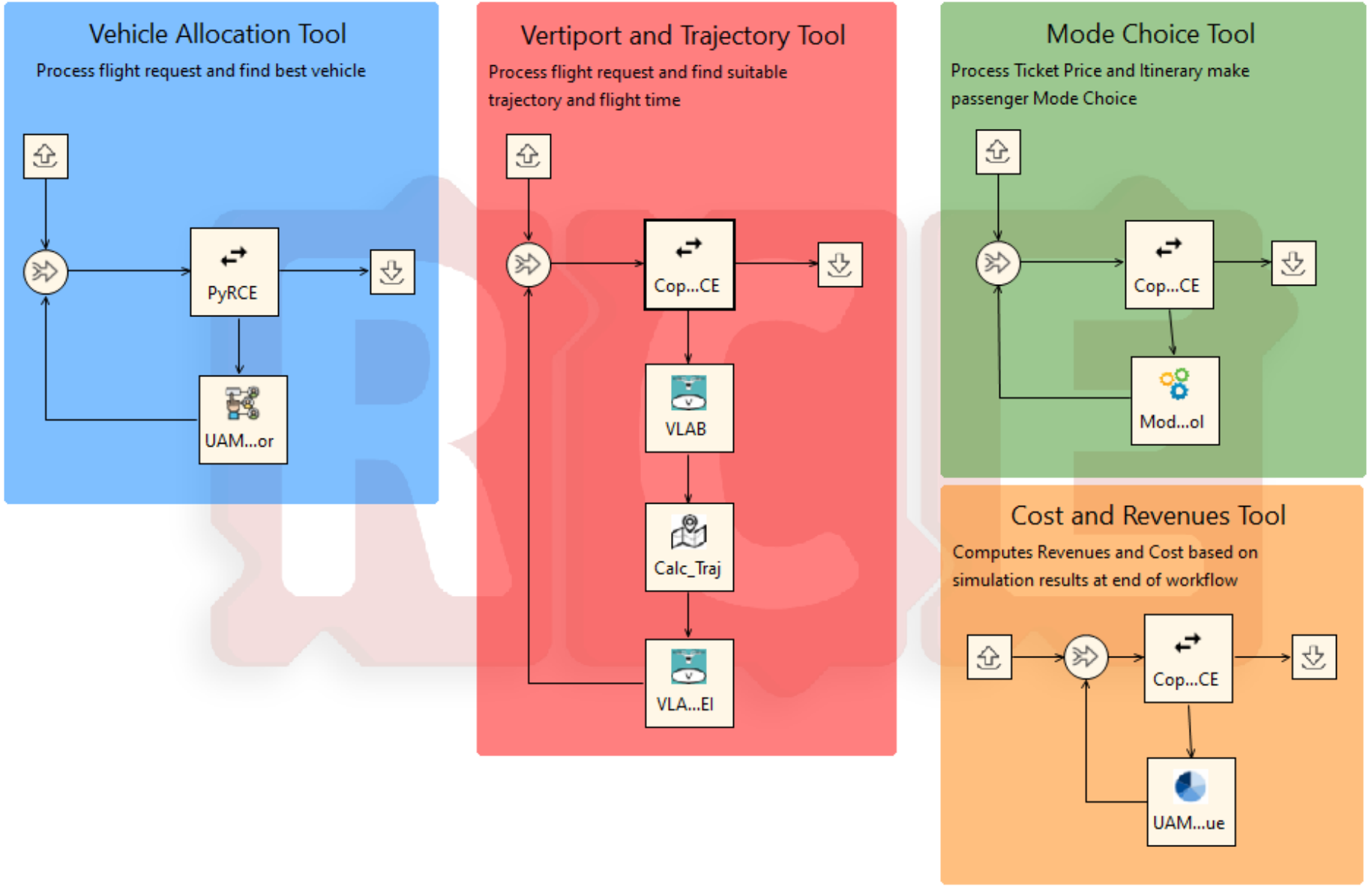
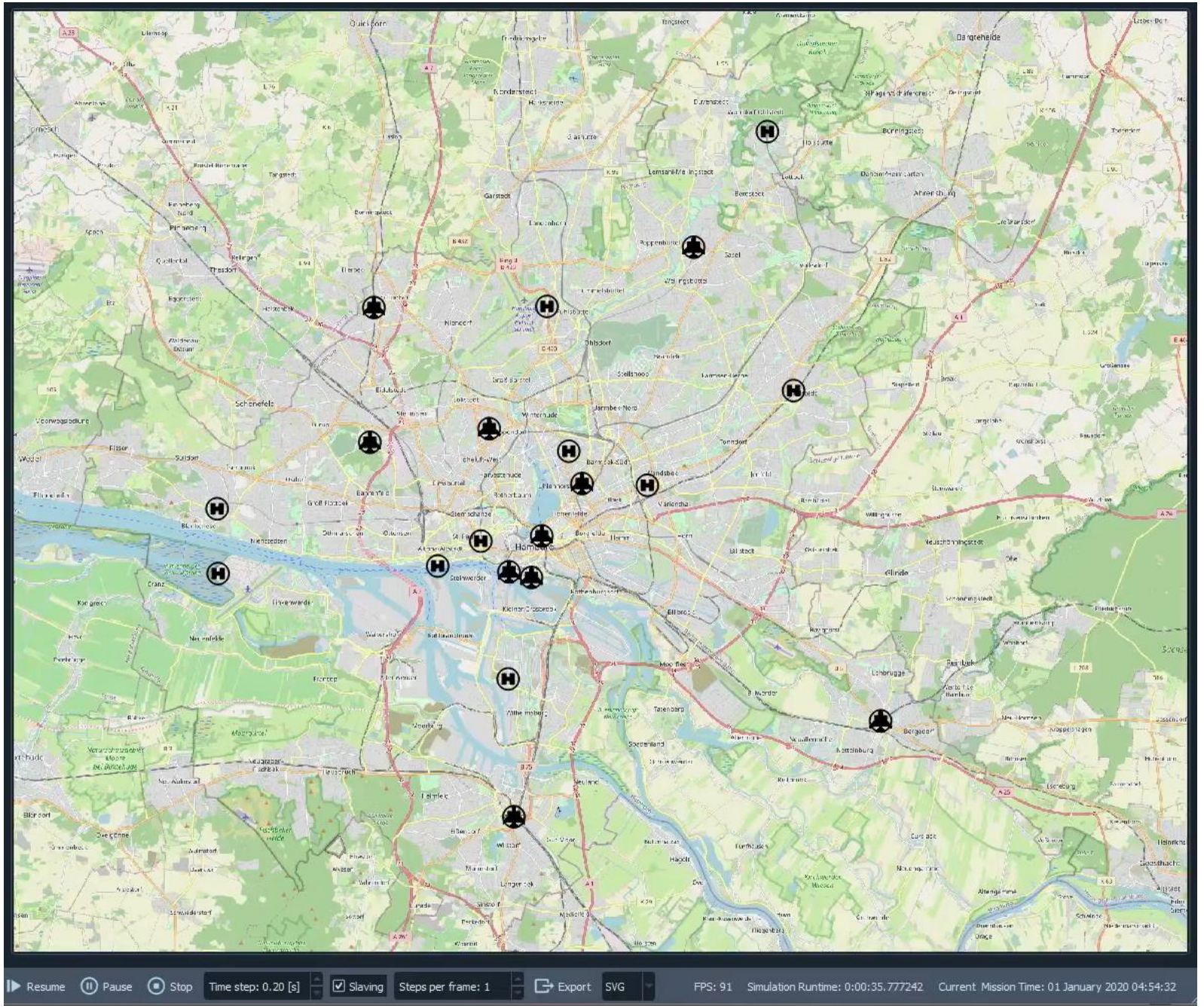
Vehicle Allocation Tool
Traj,UpdateTimes
Vertiport and Trajectories Tool
BaseFare,FarePerKm
Cost and Revenues Tool
ModeChoice
Mode Choice Tool
MaintenancePlanning
Maintenance Tool

RCE Workflow



Demo


Resume
Pause
Stop
Time step: 0.20 [s]
Slaving
Steps per frame: 1
Export
SVG
FPS: 91
Simulation Runtime: 0:00:35.777242
Current Mission Time: 01 January 2020 04:54:32

Future Work

- Harmonizing `CPACS` definitions across tools
- Fine-tuning and optimizing **runtime** of workflow
- Overall results of Collaborative Simulation
- Sensitivity studies of each domain tool
- Scenario analysis and further investigations
- Results from the Collaborative Simulation to be presented at AIAA Aviation 2023

Contact Details

Topic: **A Collaborative Systems of Systems Simulation of Urban Air Mobility: Architecture Process and Demonstration of Capabilities**

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Organization: German Aerospace Center (DLR)
Institute of System Architectures in Aeronautics

Conference: 2nd Urban Air Mobility Symposium

Date: 02.12.2022

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