

Agent-Based Pilot Model for Alternative Primary Airport Slot Allocation with Price-setting Auctions

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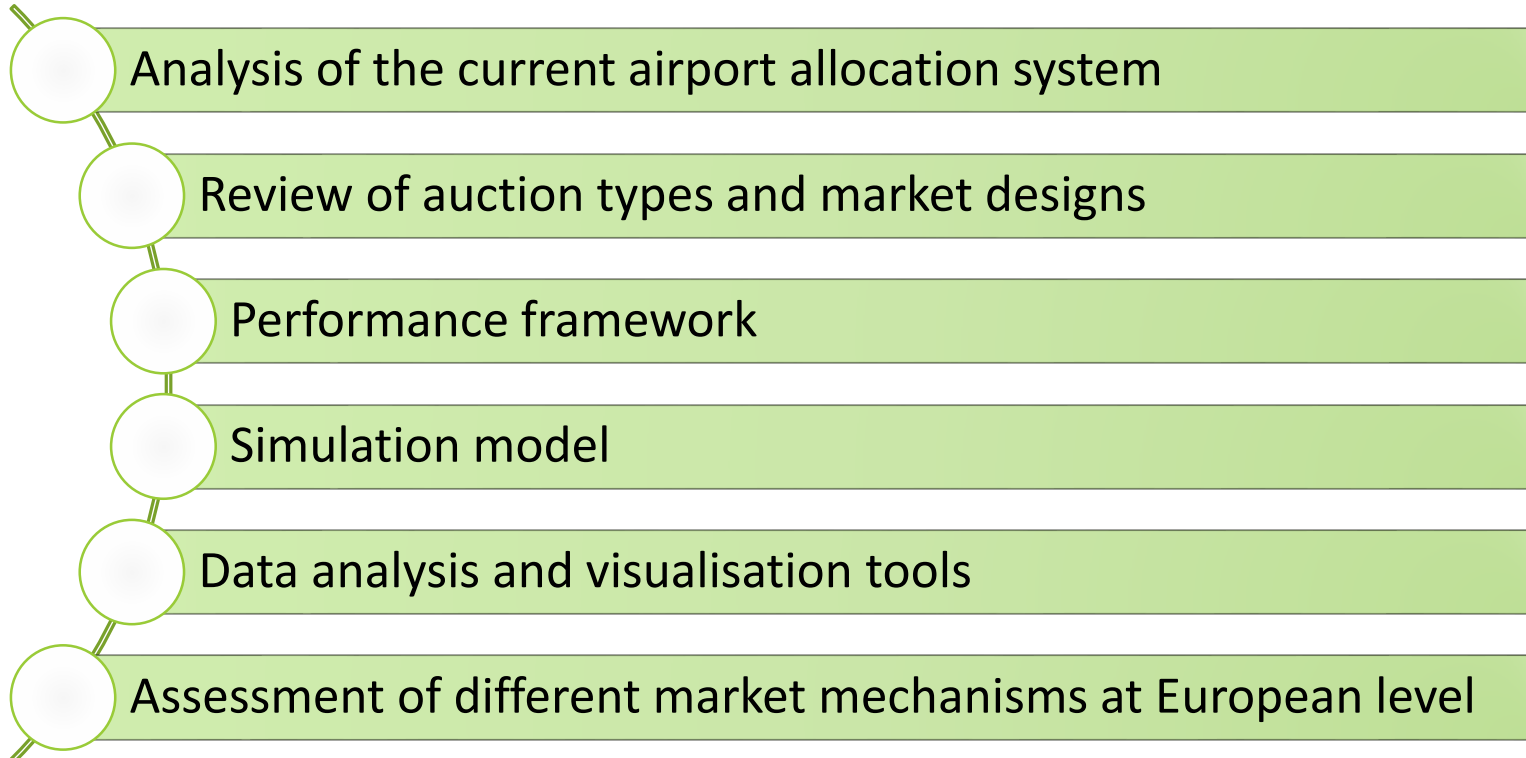
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This work is co-financed by EUROCONTROL acting on behalf of the SESAR Joint Undertaking (the SJU) and the EUROPEAN UNION as part of Work Package E in the SESAR Programme. Opinions expressed in this work reflect the authors' views only and EUROCONTROL and/or the SJU shall not be considered liable for them or for any use that may be made of the information contained herein.

Application of Agent-Based Computational Economics to Strategic Slot Allocation

WP-E Long-term R & I



Alternative allocation mechanisms

- Mathematical optimisation
- Market mechanisms

ACCESS methodology

- Agent-Based Modelling (ABM)
- Experiment design

Multi-Airport Slot Allocation

- Combinatorial Price-setting Auctions
- I×E×A

Pilot Model

- Simulation example

Current Primary Slot Allocation



ADVANTAGES

- Reduced costs
- Plan long-term operations
- It works!

DRAWBACKS

- High relevance of historical rights
- Does not guarantee maximum slot 'exploitation'
- Slot value is unknown
- Not multi-airport

Can we solve some drawbacks with alternative methods?

Main alternative mechanisms

Mathematical Optimisation

Best possible solution
Multi-airport extendable

Need for a complete specification

- Airlines may be sensitive to disclose private information (costs, preferences, etc.)
- Some information may not be easily expressed in mathematical terms

Market Mechanisms

(Sub)Optimum solutions

- Participants do not disclose private information
- Explicit economic outcomes (value of slots)
- Maximisation of global surplus
- Multi-airport extendable

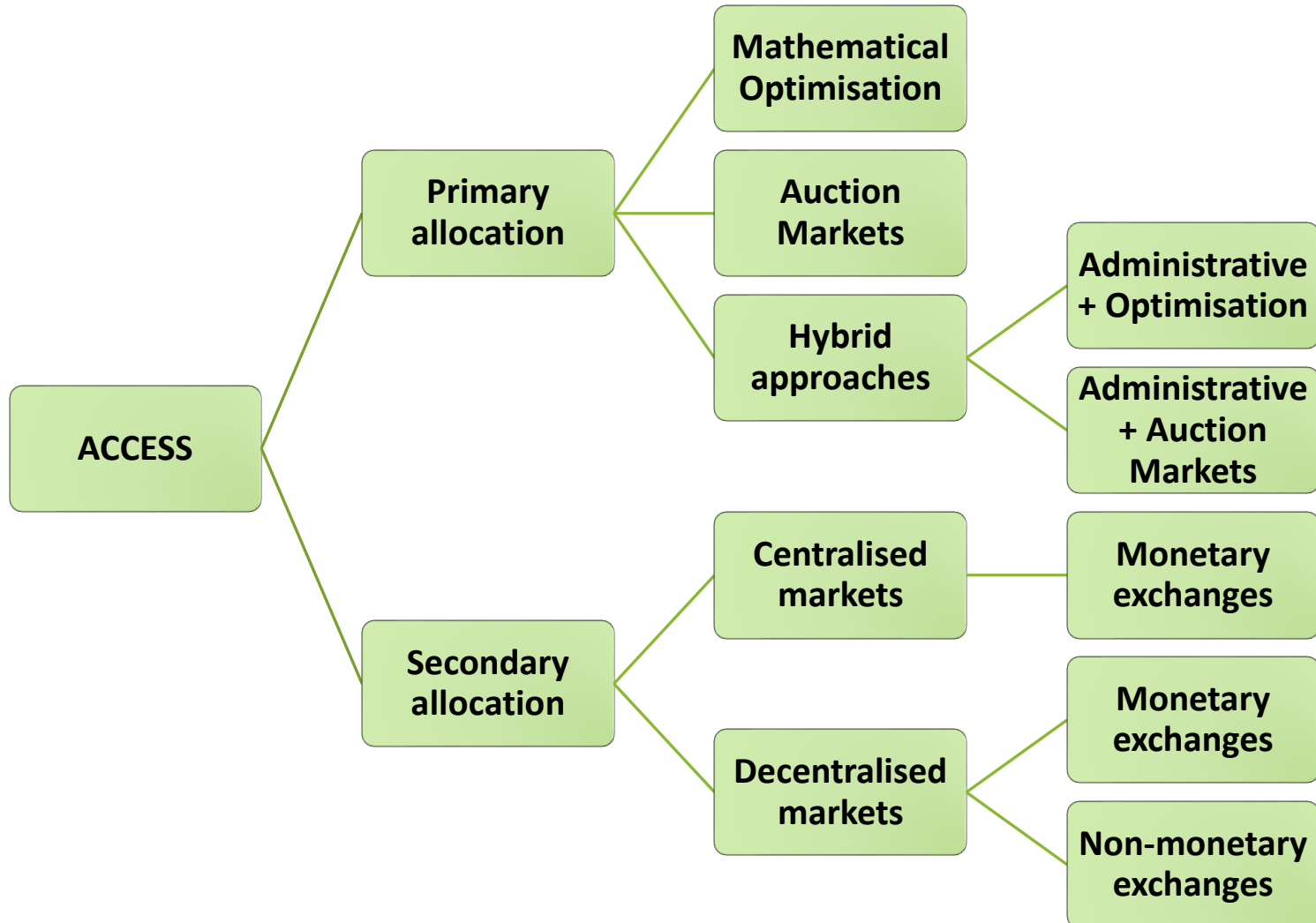
Uncertainty about their impact

- Economic impact on Airlines, passengers, etc.
- Revenues distribution



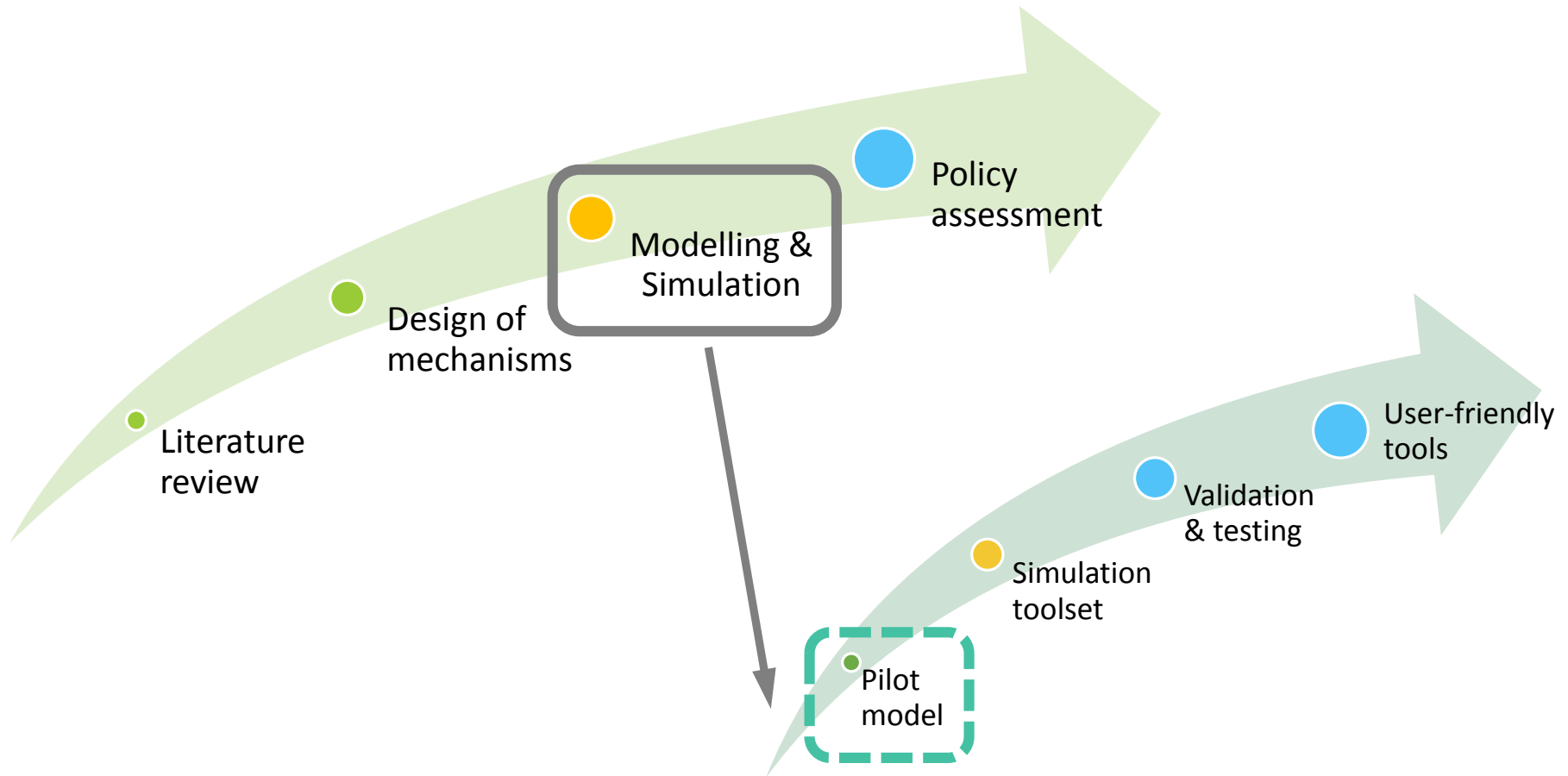
ACCESS scope and methodology

ACCESS scope



Roadmap status

Alternative Multi-Airport Slot Allocation



BOTTOM-UP approach

Agent-Based Models (ABM)

- Airports
- Airlines
- Coordinator
- Passengers



Specification of slot allocation mechanisms

- Primary, Secondary
- Optimisation
- Markets
- Auction types



Specification of KPIs

- Economic efficiency
- Equity (market)
- Resilience
- Interoperability
- Capacity & Delay



Analysis of results

- Statistical analysis of data
- Comparison of mechanisms and scenarios
- Recommendations & assessment



Simulation

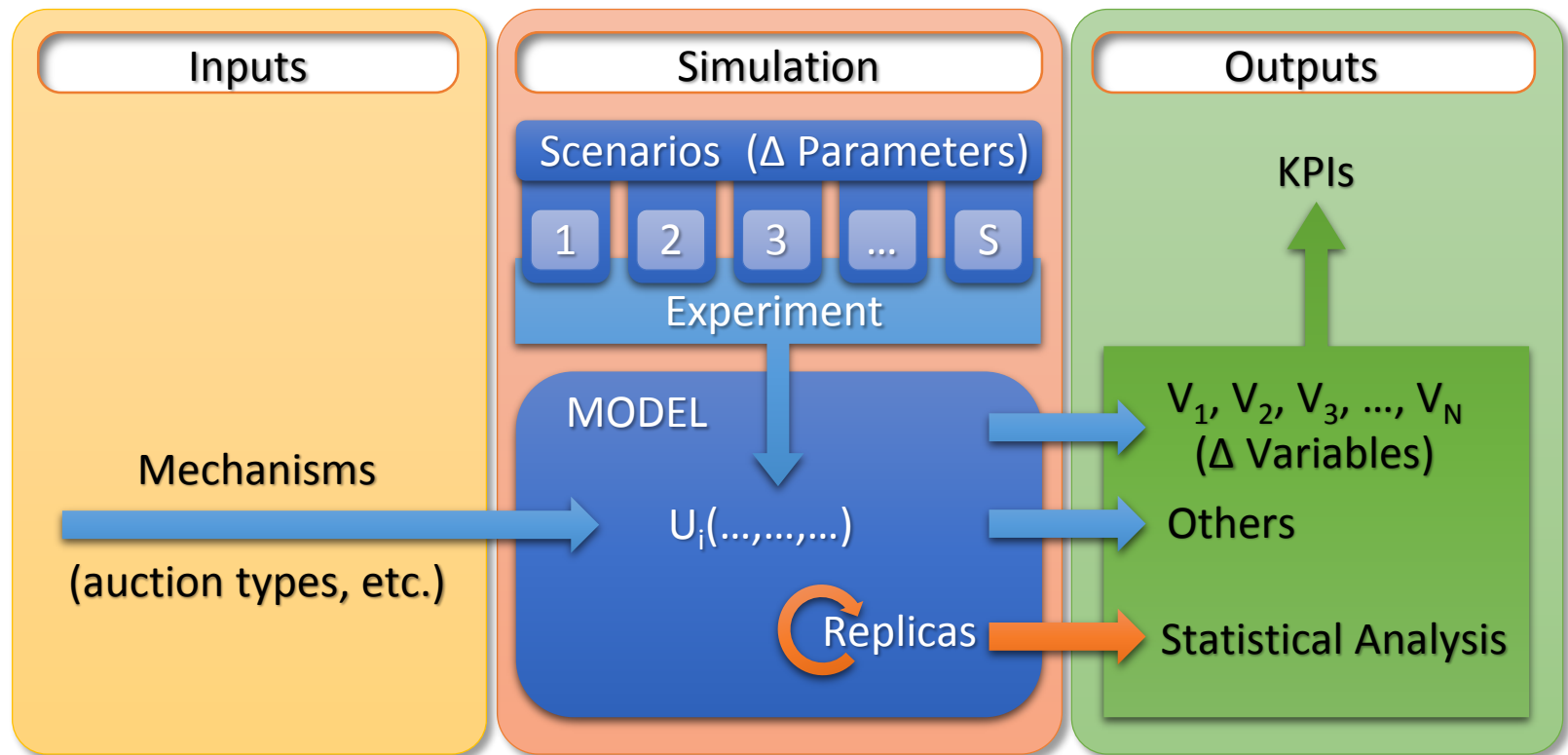
- Executions of the toolset
- Generation of output data

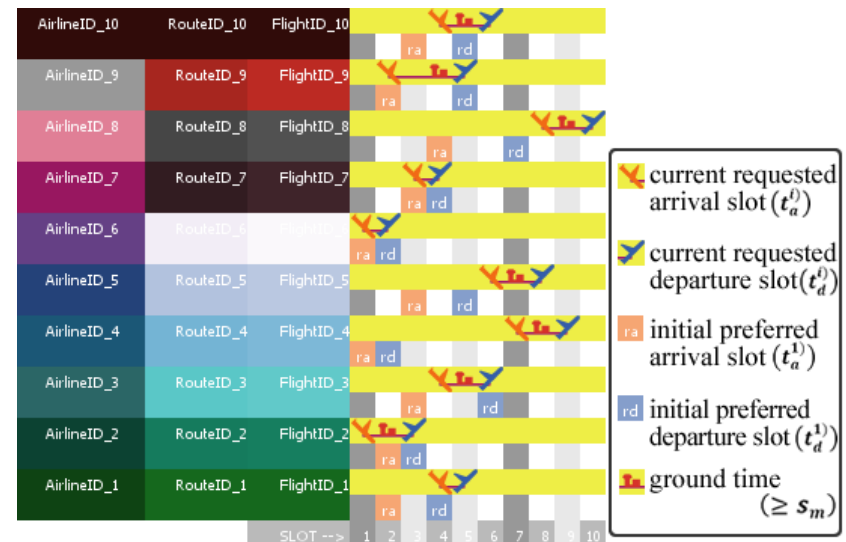
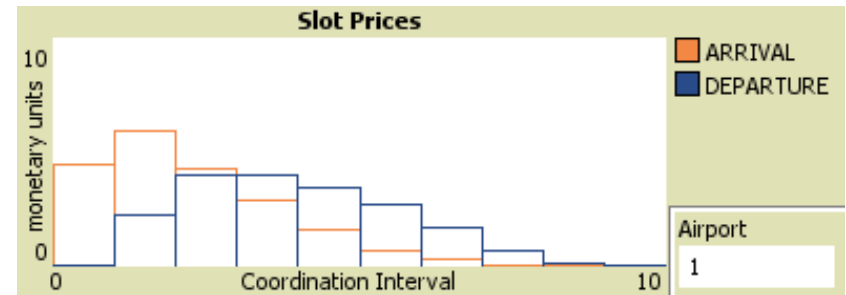
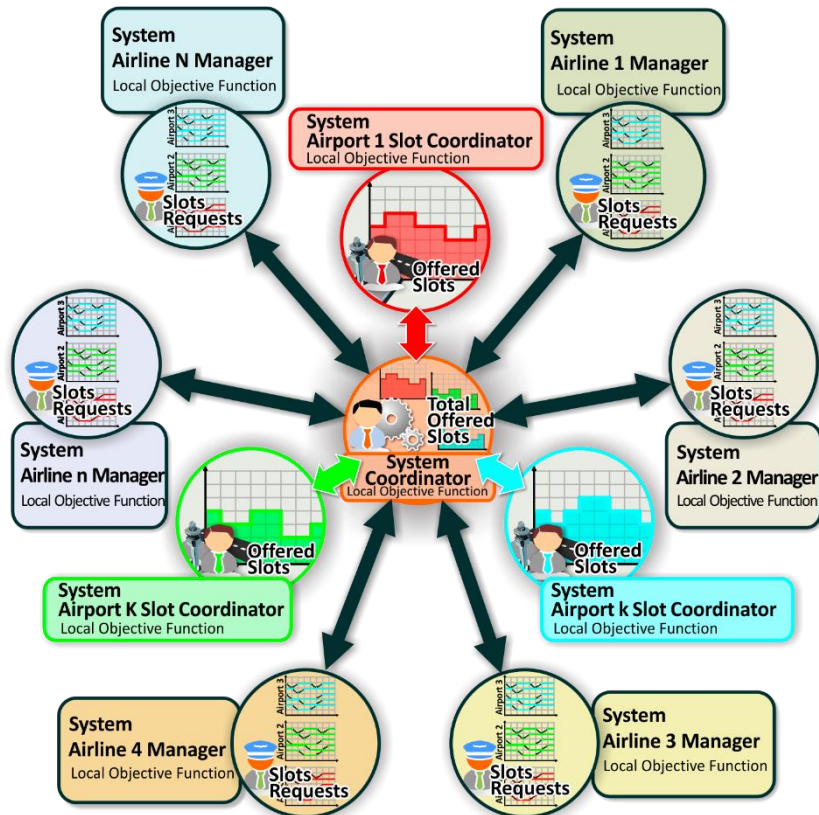


Experiment Design

- Parameters
- Variables
- Scenarios
- Replicas

Experiment Design





Combinatorial Price-Setting Auctions for Multi-Airport Slot Allocation – Pilot Model

Iterative Combinatorial Price-setting Auctions

- **Price-setting:** provide prices for slots
 - Different prices for arrival and departure slots
 - Same prices for slots in the same coordination interval
- **Combinatorial:** allow airlines to bid for combinations of slots
- **Iterative:** consecutive rounds improve the results

Decentralisation

- Split logic: buyer and sellers solve different problems
- Split complexity: each particular problem is simpler
- The auctioneer only modifies prices to balance supply/demand
- Information privacy (only slot prices and final allocation are public)

Auction Institution

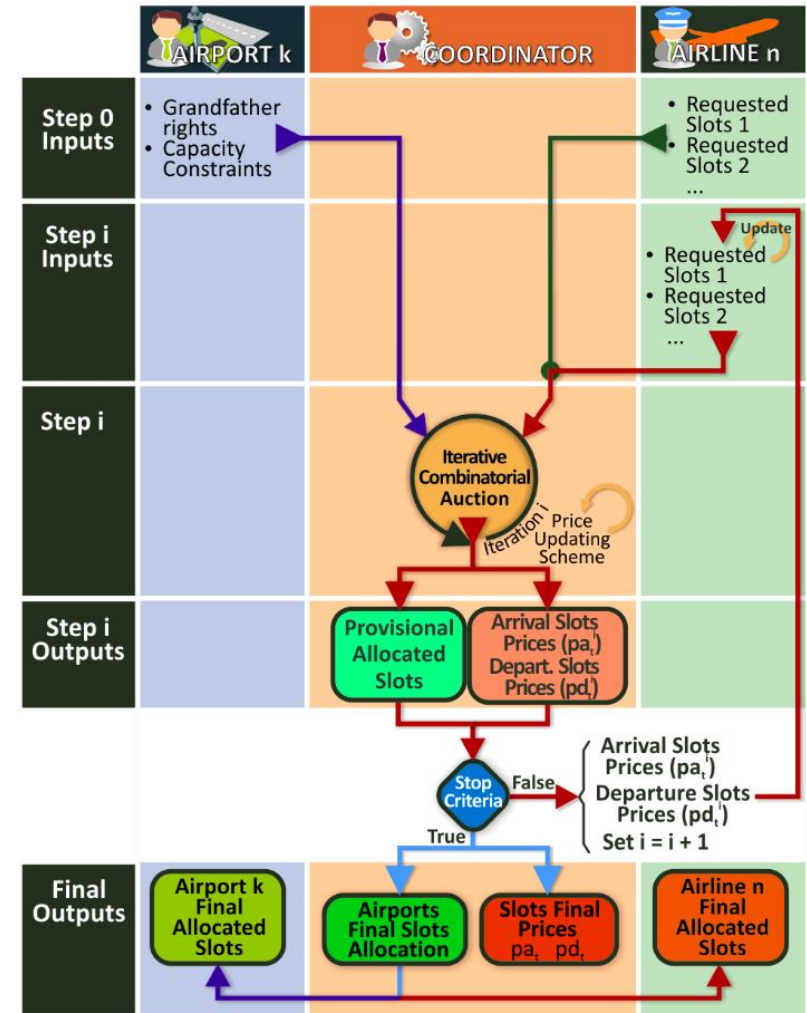
Process steps (iterative)

1. Slot prices communicated (a/d)
2. Airlines request their preferred slots according to current prices
3. The coordinator:
 1. Aggregates the requests
 2. Compares with available slots
 3. Modifies slot prices
 4. Checks stop criteria

Tie-breaking and final allocation

Information exchange

- Slot prices (arrivals/departures)
- Slot requests for current prices
- Final slot allocation



Pilot model (primary allocation)

Airport

- 10 coordination intervals
- Rolling slot constraints

		Rolling constraint order (h)			
		1	2	3	4
Number of available slots	Arrivals (a)	2	3	5	7
	Departures (d)	2	3	4	5
	Total (t)	3	5	8	10

Coordinator

Slot prices (arrivals/departures): $(\overline{P_{at}^i}, \overline{P_{dt}^i})$, initially set to 0

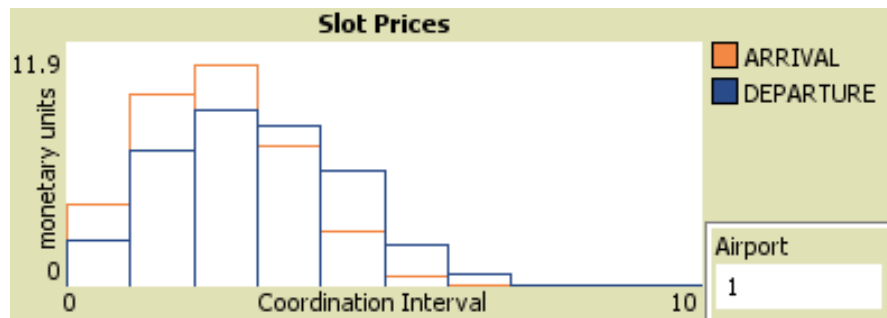
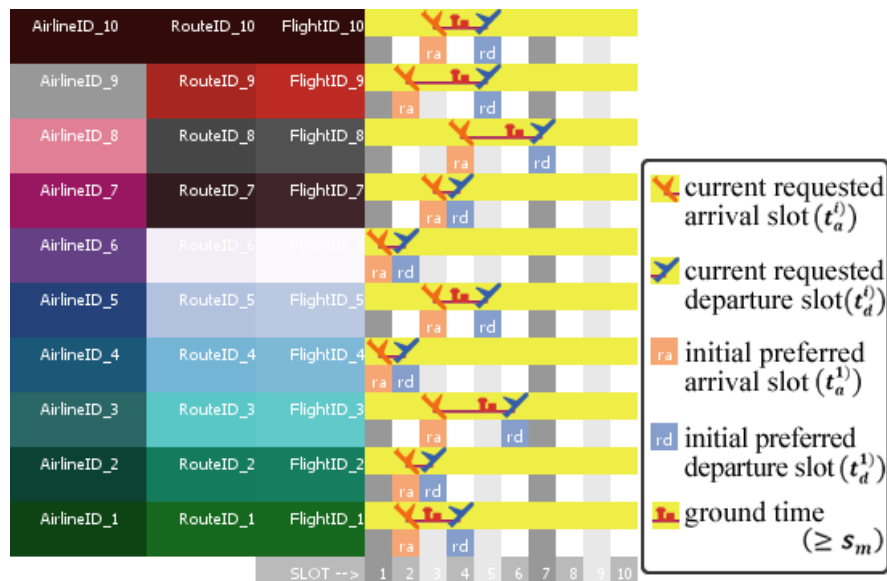
Airlines

Airline ID (m)	t_a^1	t_d^1	w_a	w_d	s_m	$U(t_a^1, t_d^1)$
1	2	4	1	1	1	30
2	2	3	1,5	1,8	1	30
3	3	6	1,1	1,2	2	40
4	1	2	0,3	0,5	1	50
5	3	5	0,5	0,9	1	30
6	1	2	2	1,9	1	40
7	3	4	1,4	1,3	1	20
8	4	7	0,2	0,1	2	30
9	2	5	2	1	1	50
10	3	5	1	1,2	2	30

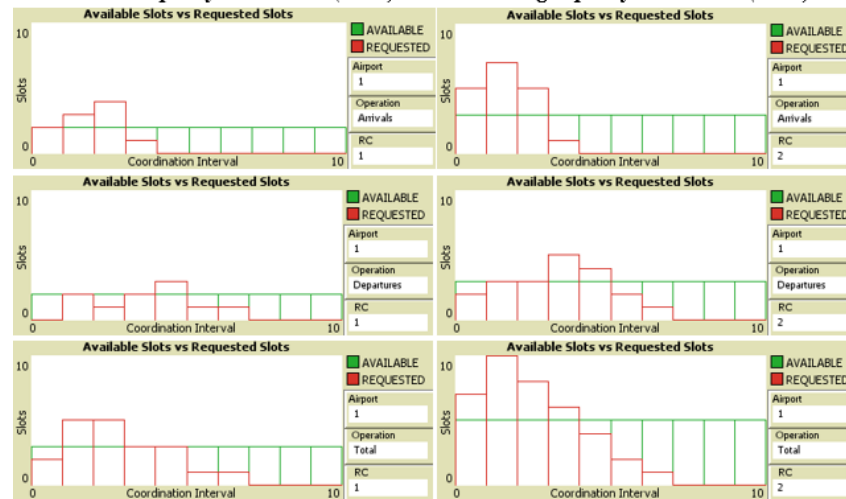
Shift costs: $SC^i(f^1 \rightarrow f^i) = |\overline{t_a^i} - \overline{t_a^1}| \cdot w_a + |\overline{t_d^i} - \overline{t_d^1}| \cdot w_d$

Payment function: $P_m^i(f^i)$ for current slot prices $(\overline{P_{at}^i}, \overline{P_{dt}^i})$

Pilot Simulation (initialisation)



Nominal capacity constraints ($h = 1$)

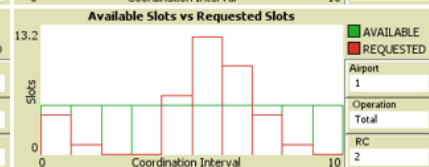
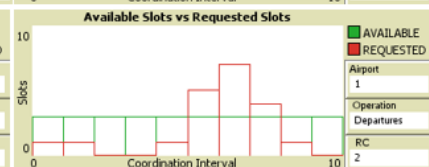
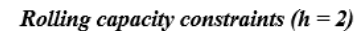
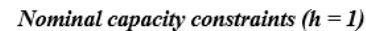
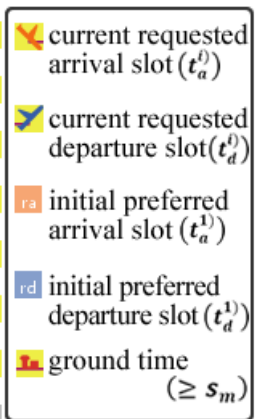


Rolling capacity constraints ($h = 2$)

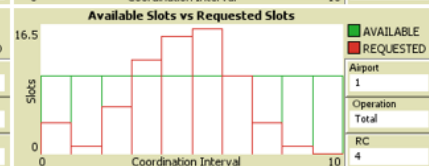
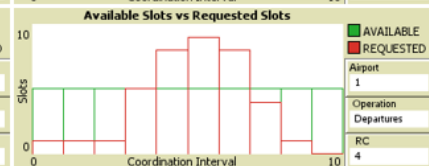
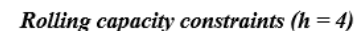
Rolling capacity constraints ($h = 3$)

Rolling capacity constraints ($h = 4$)

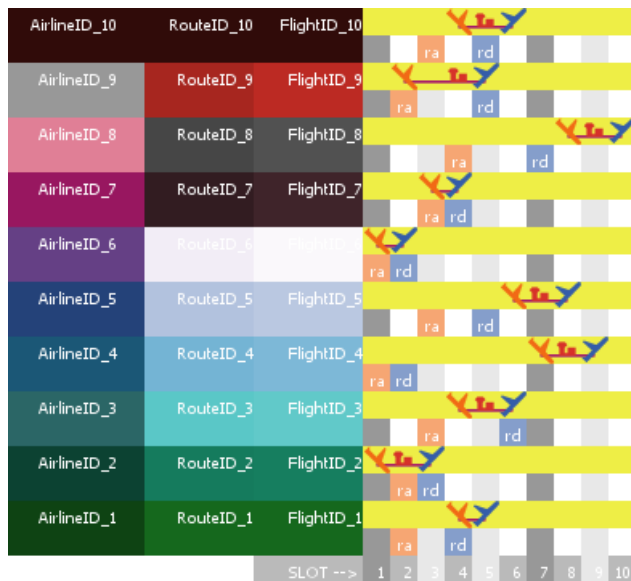




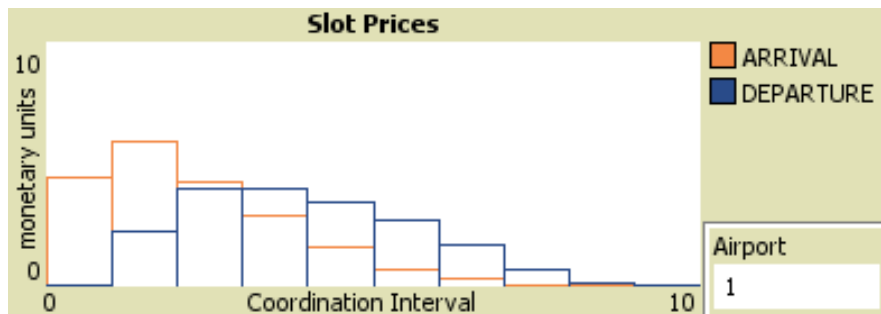
Rolling capacity constraints ($h = 3$)



Pilot Simulation (market clearance)



current requested arrival slot (t_a^i)
 current requested departure slot (t_d^i)
 initial preferred arrival slot (t_a^1)
 initial preferred departure slot (t_d^1)
 ground time ($\geq s_m$)



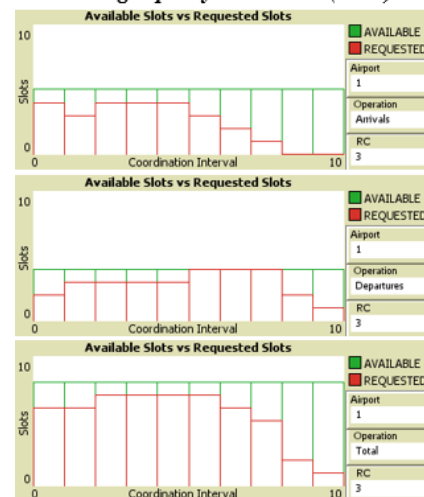
Nominal capacity constraints ($h = 1$)



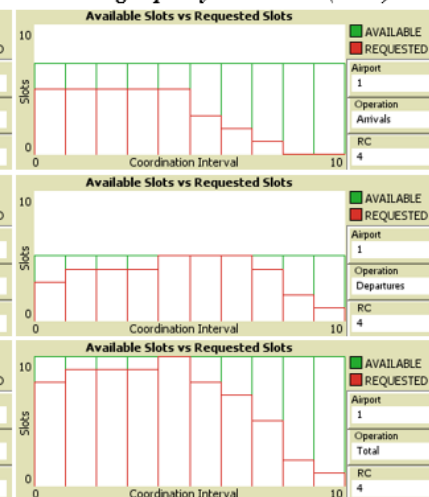
Rolling capacity constraints ($h = 2$)



Rolling capacity constraints ($h = 3$)



Rolling capacity constraints ($h = 4$)





Conclusions

Conclusions

ACCESS Methodology

- Agent-Based Modelling (Bottom-Up approach)
- Experiment Design
- Simulation and Testing

Combinatorial Auction Markets for Primary Allocation

- Non disclosure of private information
- Value of slots: socio-economics factors become explicit
- Rolling slot constraints consideration
- Maximisation of the overall surplus

Simulation (Experimental Economics)

- Explore uncertainty and emergent behaviour
- Convergence speed: initial prices + auction parameterisation (pricing) + rolling slot constraints
- Can provide validation and testing

Slot Allocation Mechanisms

- Primary + Secondary, multi-airport
- Hybrid approaches (partial slot auctioning + other)
- Several consecutive seasons

Auction Markets

- Several types of auctions/parameterisations
- Convergence speed studies
- Market protection mechanisms

Agent-Based Models

- More realistic airports & airlines
- Passengers demand
- Fuel prices

Simulation Environment

- Fully-featured simulation toolset (multi-airport)
- Definition of Experiments and Simulation Scenarios
- Analysis, comparison and assessment

Questions?

Thanks for your attention



AGENT-BASED PILOT MODEL FOR
ALTERNATIVE PRIMARY AIRPORT SLOT ALLOCATION
WITH PRICE-SETTING AUCTIONS

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26/11/2014