System of Systems Engineering for the Airport Slot Allocation Problem

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ACCESS
APPLICATION OF AGENT-BASED COMPUTATIONAL ECONOMICS TO STRATEGIC SLOT ALLOCATION

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SoS Case Study

- **EU civil aviation**

Tackle an engineering issue for this SoS

- **(Multi-)Aiport Slot Allocation**

SoSE socio-economic approach

- **Auctions, Markets**

Motivation: airport capacity constraints

Airport categories

- Level 1 – not congested / not coordinated
- Level 2 – congested in periods / schedule facilitated
- Level 3 – congested / coordinated

Slot

- **Right for using airport resources to take-off or land during certain period of time**

Allocation Problem →

Administrative allocation

- EU regulation 95/93 + amendments
- Primary allocation:
  - Historical rights + use it or lose it
- Secondary trading:
  - Implicit/explicit economic factors

Current Slot allocation

ADVANTAGES

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

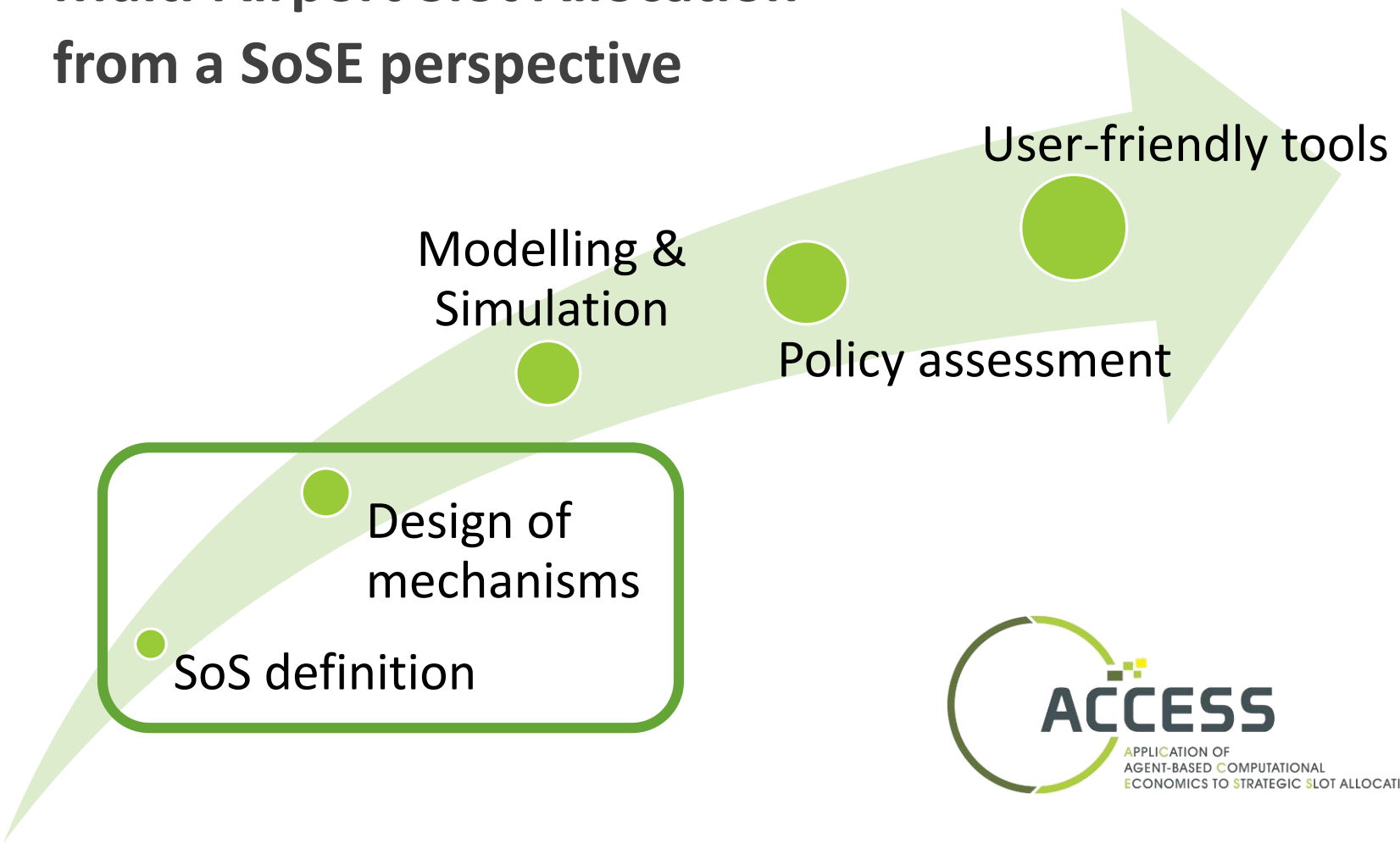
DRAWBACKS

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

What if we study the problem from a **SoSE perspective**?

Scope and Roadmap

Multi-Airport Slot Allocation from a SoSE perspective



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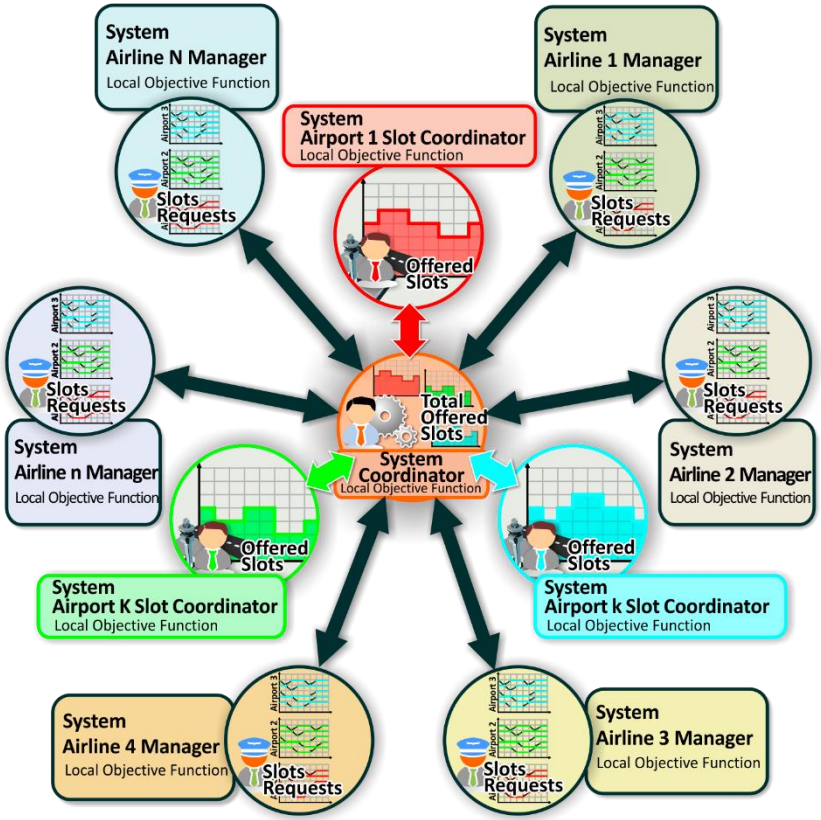
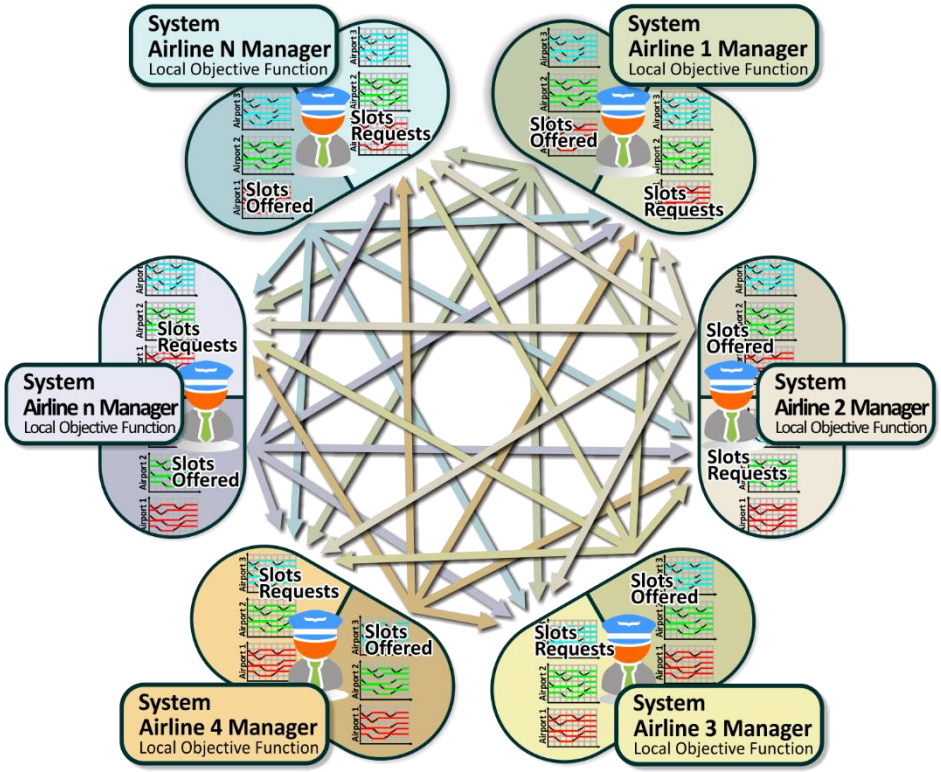




Description of the SoS

SoS description: Constituent Systems

- IATA
- European Commission
- European Parliament
- European Council
- Member States

Regulators

- Airport coordinators
- Coordination committees

Coordinators

- Network
- Low cost
- Cargo
- Regional
- Charter

Airlines

- Coordinated
- Schedule facilitated

Airport operators

- Passengers

Final users

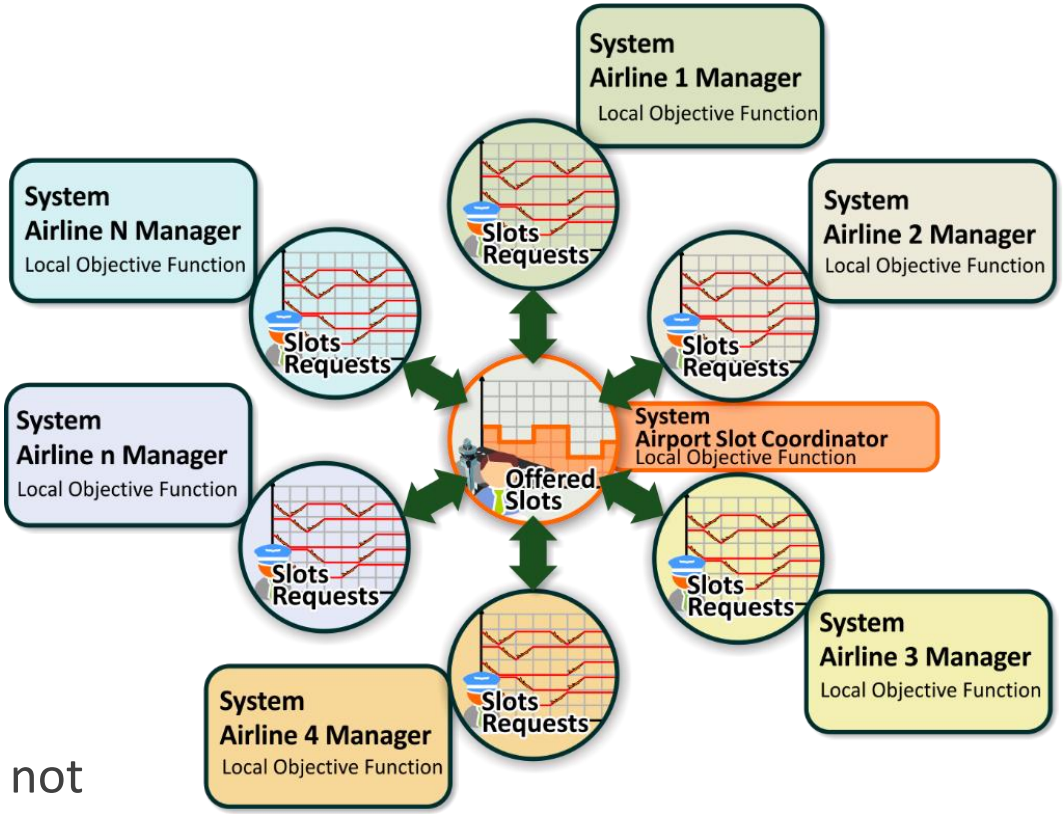
- ICT platforms
- Conferences & meetings
- 'Informal communications'

Inf. & Comm. Systems

SoS for Primary Allocation (single airport)

Scenario

- One airport
- Several airlines request a set of slots



Observations

- Slots might be interrelated or not
- Single airport coordination authority

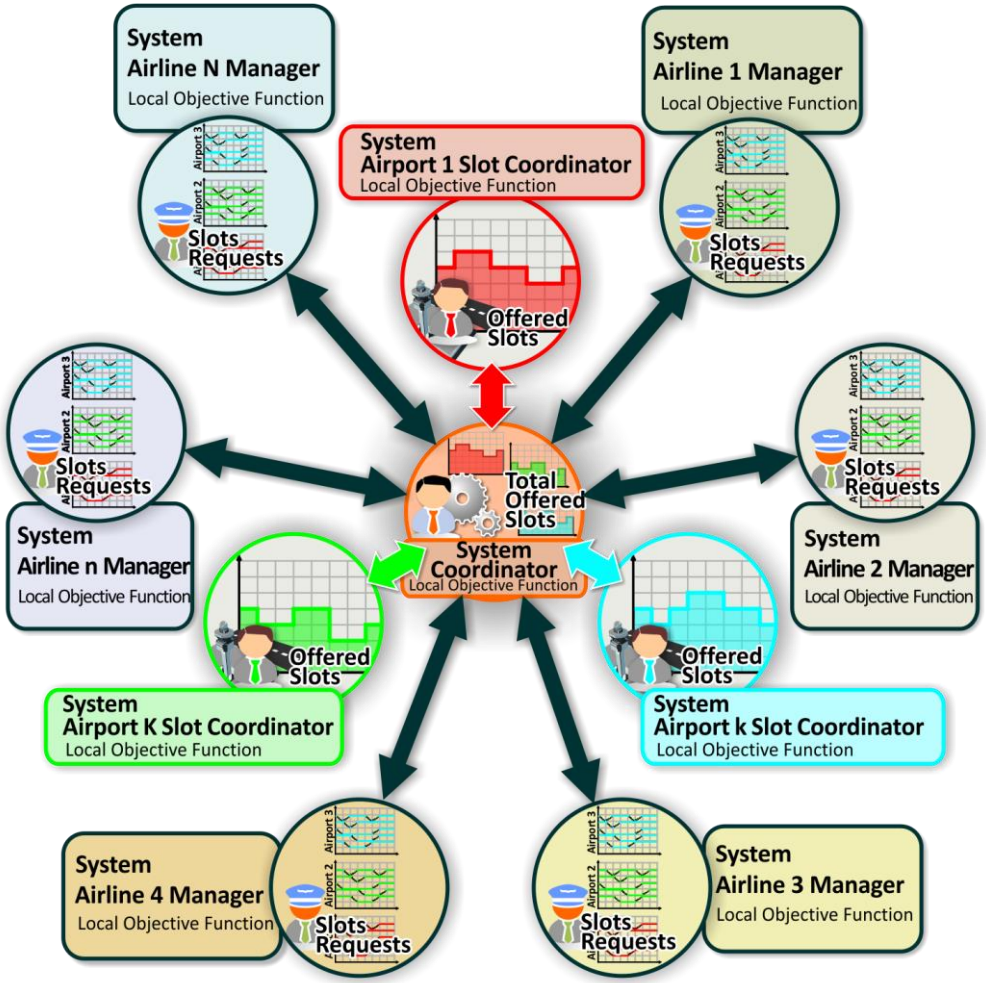
SoS for Primary Allocation (multiple airports)

Scenario

- Several airports and airlines
- Airlines request slots at several airports
  - Currently not at the same time
  - ACCESS will study simultaneous allocation

Observations

- Slots at different airports are interrelated (departure + arrival) → Combinatorial Allocation Problem
- Different airport coordinators
- Uncertainty increases



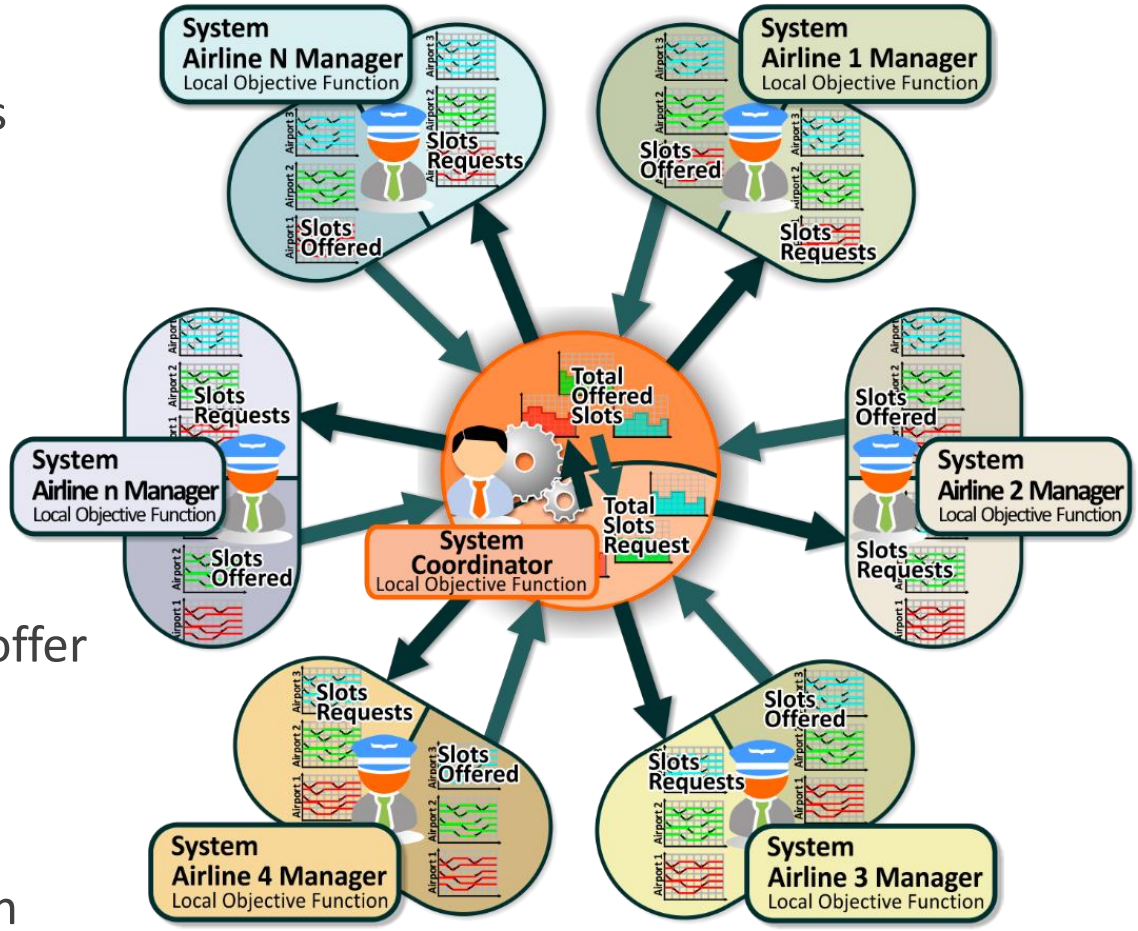
SoS for Secondary Allocation (multiple airports)

Scenario

- Several airports and airlines
- Slots are already assigned
- Some airlines are willing to trade
- Central coordinator?

Observations

- Airlines may both request/offer slots at the same time
- Monetary / non-monetary exchanges
- Slots ownership information



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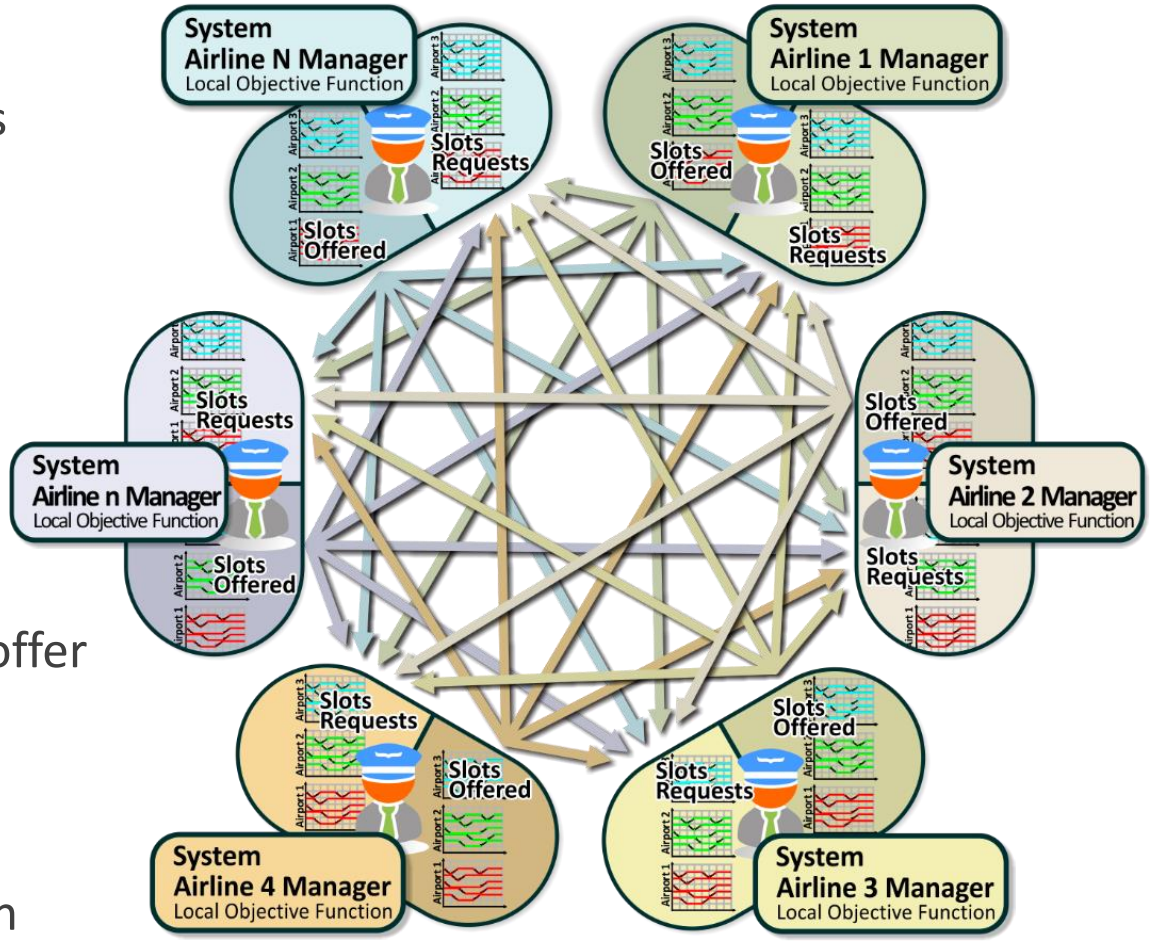


SoSE Methodology

SoS Engineering Methodology

Combinatorial Allocation Problem (CAP)

Analogy
CAPs ↔ Markets

Auction Markets

- Problem fragmentation
- Pricing mechanisms

Are AUCTIONS suitable for SoSE?

Auctions for SoSE

Iterative Combinatorial Price-setting Auctions

- Price-setting: provide prices for slots
- Combinatorial: allow airlines to bid for combinations of slots
- Iterative: rounds improve the results

Decentralisation

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

SoS Engineering Methodology

Combinatorial Allocation Problem (CAP)

Analogy
CAPs ↔ Markets

Auction Markets
- Problem fragmentation
- Pricing mechanisms

Auction Engineering
- Price-setting auctions
- Iterative auctions
- Combinatorial auctions

Market Experiment design
- I × E × A

Experimental Economics
- Simulation

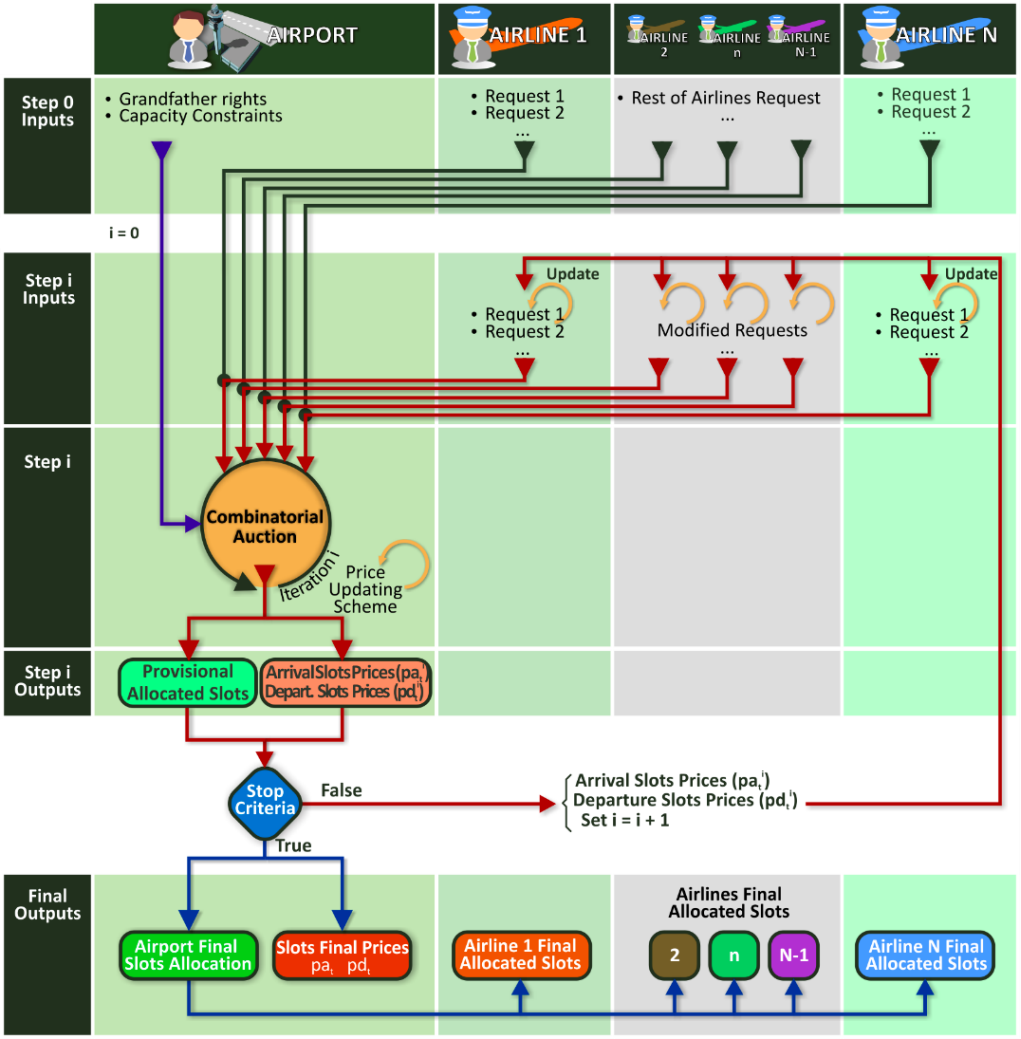
Single Airport Primary Allocation

Auction process

- Auctioneer sets initial prices
- Airlines request slots depending on price
- Auctioneer matches supply and demand and modifies prices for next round

Auction ends when…

- Round limit
- Prices converge
- Capacity not over-demanded
- Etc.

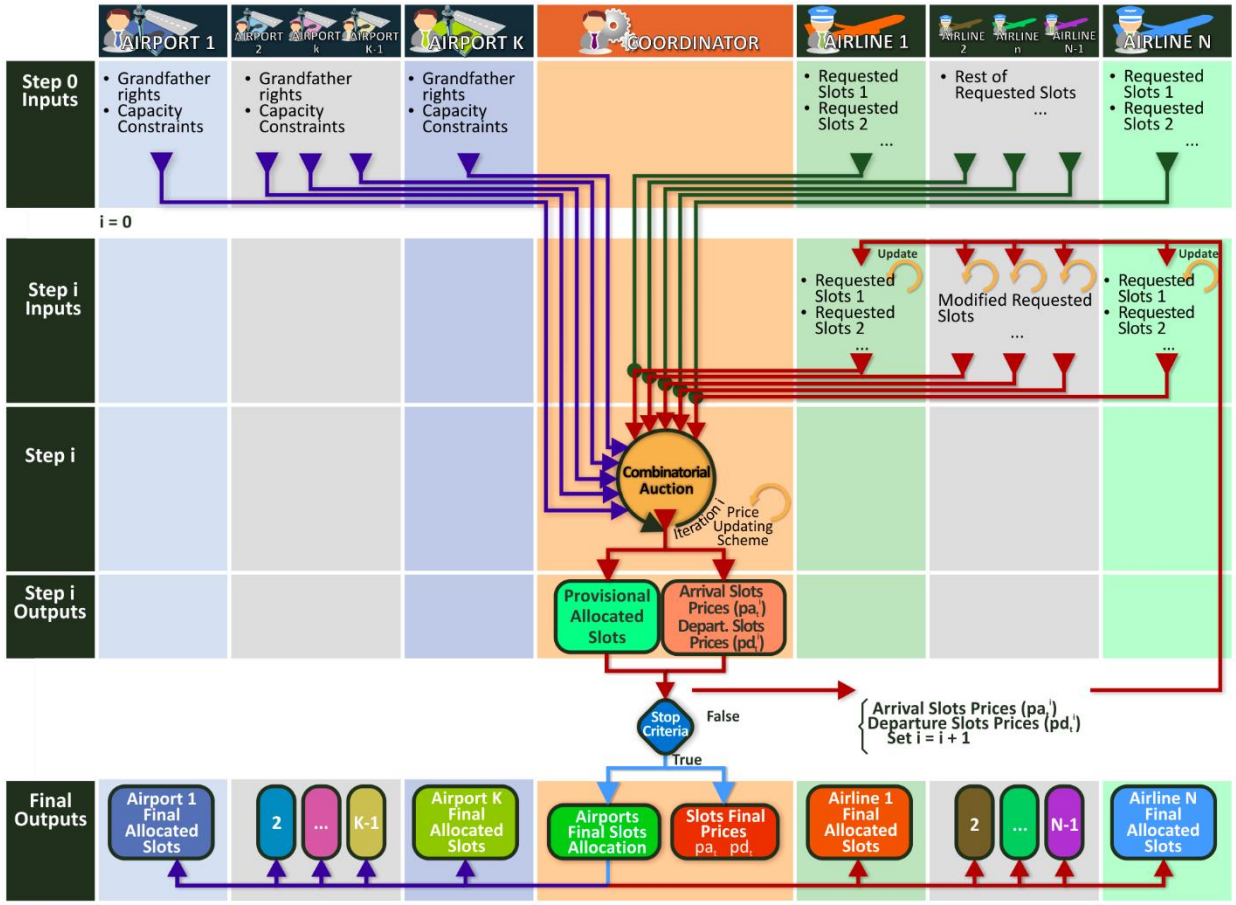


Multi-Airport Primary Allocation

Complexity increases

- Combinatorial requests
- Multi-airport capacity restriction analysis
- Feasibility of solutions

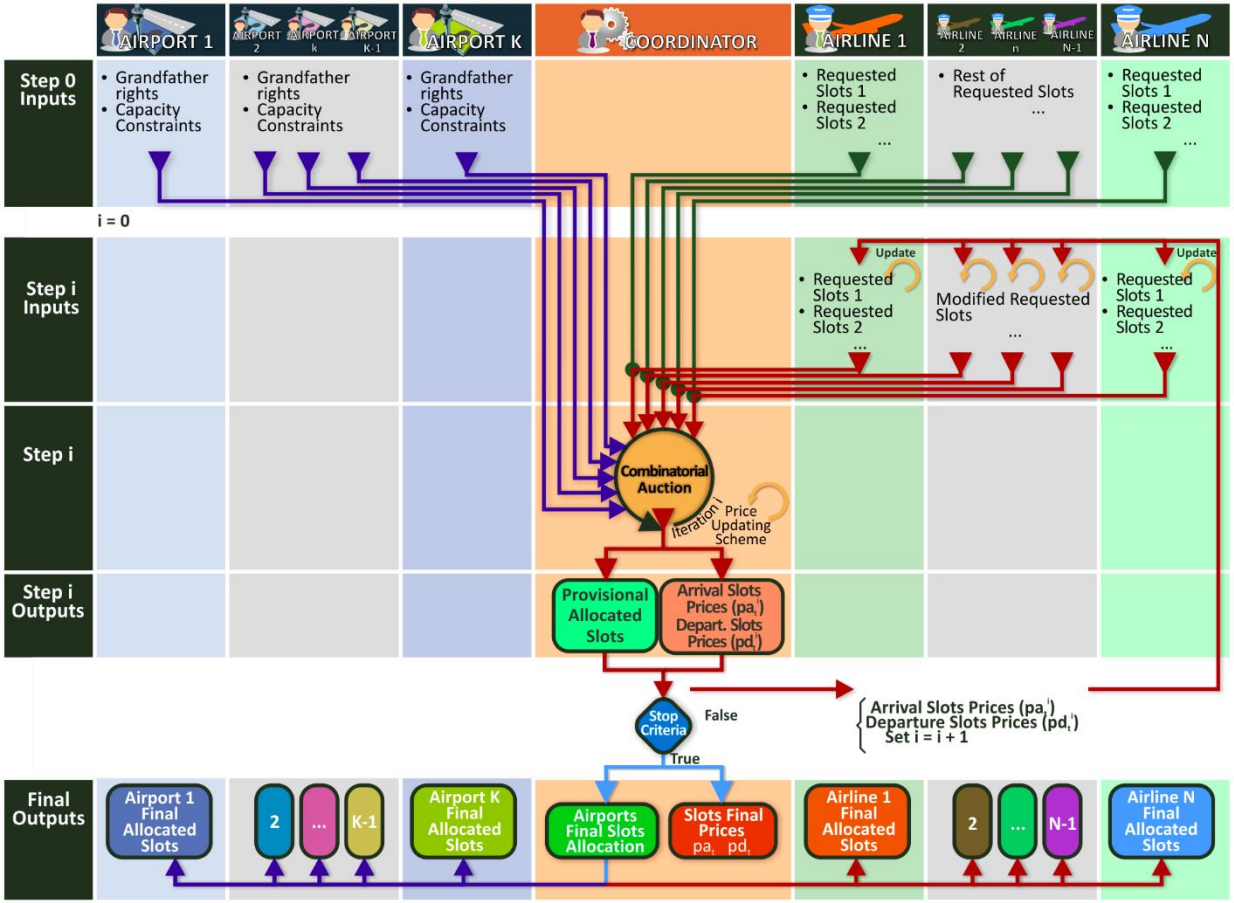
SoS complexity impacts on CS complexity



Secondary Allocation

Slight changes

- Airlines are buyers and sellers
- Market coordinator?
- Public information may change
  → CS may change their behaviour



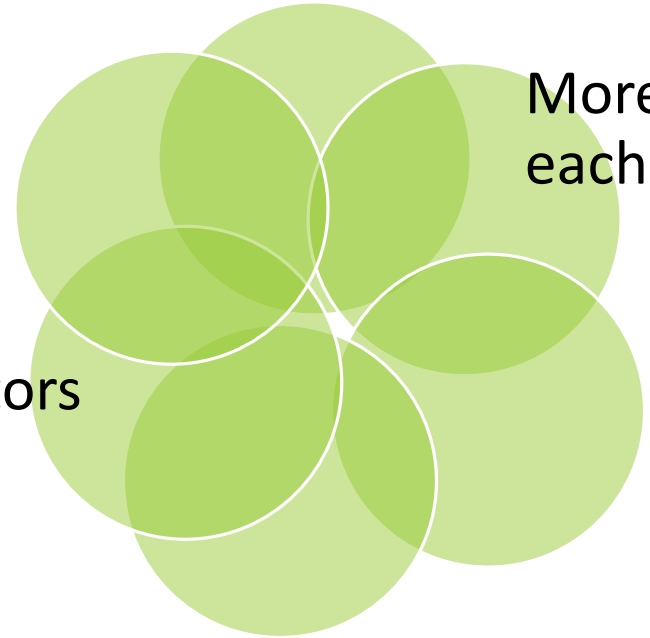
Impact and Conclusions

Some expected impacts of Auctions

Higher efficiency in the short run

Rejection: lack of willingness to pay

More intelligence in each CS



Explicit economic factors → Uncertainty

- Costs
- Revenues

Proof of slot value

Signals for policy makers

Conclusions

SoS paradigm suits Airport Slot Allocation

- Conceptualisation
- Modelling
- Communication requirements

Auction Markets are suitable for SoSE

- Negotiation capabilities for the SoS
- Implicit socio-economics factors become explicit
- Provide resilience, flexibility and self-reconfiguration

High impact on SoS/CS

- Benefits in the short run
- Uncertainty and rejection

Auction Engineering + Experimental Economics

- Explore uncertainty and emergent behaviour
- Provide SoS testing, validation and testing