System of Systems Engineering for the Airport Slot Allocation Problem

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SoS Case Study
• EU civil aviation

Tackle an engineering issue for this SoS
• (Multi-)Airport 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

- SoS definition
- Design of mechanisms
- Modelling & Simulation
- Policy assessment
- User-friendly tools
Description of the SoS
SoS description: Constituent Systems

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<thead>
<tr>
<th>Regulators</th>
<th>Coordinators</th>
<th>Airlines</th>
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<tr>
<td>IATA</td>
<td>Airport coordinators</td>
<td>Network</td>
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<td>European Commission</td>
<td>Coordination committees</td>
<td>Low cost</td>
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<td>European Parliament</td>
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- **Regulators**
  - IATA
  - European Commission
  - European Parliament
  - European Council
  - Member States

- **Coordinators**
  - Airport coordinators
  - Coordination committees

- **Airlines**
  - Network
  - Low cost
  - Cargo
  - Regional
  - Charter

- **Airport operators**
  - Coordinated
  - Schedule facilitated

- **Final users**
  - Passengers

- **Inf. & Comm. Systems**
  - ICT platforms
  - Conferences & meetings
  - ‘Informal communications’
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
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
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SoSE Methodology
SoS Engineering Methodology

Are AUCTIONS suitable for SoSE?

Combinatorial Allocation Problem (CAP) → Analogy CAPs ↔ Markets → Auction Markets

- Problem fragmentation
- Pricing mechanisms
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

Experimental Economics
- Simulation

Market Experiment design
- \( I \times E \times A \)

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