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

Mario Ramírez Ferrero
mario@inisoc.org

Félix Villafáñez Cardeñoso
villafafelix@yahoo.es

Alberto Araúzo Araúzo
arauzo@eii.uva.es

Adolfo López Paredes
adolfo@inisoc.org

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

Analysis of the current airport allocation system

Review of auction types and market designs

Performance framework

Simulation model

Data analysis and visualisation tools

Assessment of different market mechanisms at European level
Alternative allocation mechanisms

- Mathematical optimisation
- Market mechanisms

ACCESS methodology

- Agent-Based Modelling (ABM)
- Experiment design

Multi-Airport Slot Allocation

- Combinatorial Price-setting Auctions
- \( I \times E \times A \)

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

ACCESS

Primary allocation
- Mathematical Optimisation
- Auction Markets
- Hybrid approaches
- Administrative + Optimisation
- Administrative + Auction Markets

Secondary allocation
- Centralised markets
- Monetary exchanges
- Decentralised markets
- Monetary exchanges
- Non-monetary exchanges
Roadmap status

Alternative Multi-Airport Slot Allocation

- Literature review
- Design of mechanisms
- Modelling & Simulation
- Policy assessment
- User-friendly tools
- Validation & testing
- Simulation toolset
- Pilot model

26/11/2014
ACCESS methodology

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

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

26/11/2014
Experiment Design

Inputs

Mechanisms
(auction types, etc.)

Simulation

Scenarios (Δ Parameters)

1 2 3 ... S

Experiment

MODEL

U_i(...,...,...)

Replicas

Outputs

KPIs

V_1, V_2, V_3, ..., V_N
(Δ Variables)

Others

Statistical Analysis
Combinatorial Price-Setting Auctions for Multi-Airport Slot Allocation – Pilot Model
Auctions for primary allocation

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)
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

### Coordinator

#### Slot prices (arrivals/departures): \( \overline{P_a^i}, \overline{P_d^i} \), initially set to 0

### Airlines

<table>
<thead>
<tr>
<th>Airline ID (m)</th>
<th>( t_a^1 )</th>
<th>( t_d^1 )</th>
<th>( w_a )</th>
<th>( w_d )</th>
<th>( s_m )</th>
<th>( U(t_a^1, t_d^1) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>30</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>3</td>
<td>1,5</td>
<td>1,8</td>
<td>1</td>
<td>30</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>6</td>
<td>1,1</td>
<td>1,2</td>
<td>2</td>
<td>40</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>2</td>
<td>0,3</td>
<td>0,5</td>
<td>1</td>
<td>50</td>
</tr>
<tr>
<td>5</td>
<td>3</td>
<td>5</td>
<td>0,5</td>
<td>0,9</td>
<td>1</td>
<td>30</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>1,9</td>
<td>1</td>
<td>40</td>
</tr>
<tr>
<td>7</td>
<td>3</td>
<td>4</td>
<td>1,4</td>
<td>1,3</td>
<td>1</td>
<td>20</td>
</tr>
<tr>
<td>8</td>
<td>4</td>
<td>7</td>
<td>0,2</td>
<td>0,1</td>
<td>2</td>
<td>30</td>
</tr>
<tr>
<td>9</td>
<td>2</td>
<td>5</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>50</td>
</tr>
<tr>
<td>10</td>
<td>3</td>
<td>5</td>
<td>1</td>
<td>1,2</td>
<td>2</td>
<td>30</td>
</tr>
</tbody>
</table>

### Shift costs:
\[ SC^i (f^1 \rightarrow f^i) = |t_a^i - t_a^1| \cdot w_a + |t_d^i - t_d^1| \cdot w_d \]

### Payment function:
\[ P_m^i (f^i) \] for current slot prices \( \overline{P_a^i}, \overline{P_d^i} \)
Pilot Simulation (initialisation)

Nominal capacity constraints ($h = 1$)  
Rolling capacity constraints ($h = 2$)  
Rolling capacity constraints ($h = 3$)  
Rolling capacity constraints ($h = 4$)  

Slot Prices

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

26/11/2014
Pilot Simulation (evolution)

<table>
<thead>
<tr>
<th>AirlineID</th>
<th>RouteID</th>
<th>FlightID</th>
<th>Slot</th>
<th>ra</th>
<th>rd</th>
</tr>
</thead>
<tbody>
<tr>
<td>AirlineID_10</td>
<td>RouteID_10</td>
<td>FlightID_10</td>
<td>Slot_1</td>
<td>ra</td>
<td>rd</td>
</tr>
<tr>
<td>AirlineID_9</td>
<td>RouteID_9</td>
<td>FlightID_9</td>
<td>Slot_2</td>
<td>ra</td>
<td>rd</td>
</tr>
<tr>
<td>AirlineID_8</td>
<td>RouteID_8</td>
<td>FlightID_8</td>
<td>Slot_3</td>
<td>ra</td>
<td>rd</td>
</tr>
<tr>
<td>AirlineID_7</td>
<td>RouteID_7</td>
<td>FlightID_7</td>
<td>Slot_4</td>
<td>ra</td>
<td>rd</td>
</tr>
<tr>
<td>AirlineID_6</td>
<td>RouteID_6</td>
<td>FlightID_6</td>
<td>Slot_5</td>
<td>ra</td>
<td>rd</td>
</tr>
<tr>
<td>AirlineID_5</td>
<td>RouteID_5</td>
<td>FlightID_5</td>
<td>Slot_6</td>
<td>ra</td>
<td>rd</td>
</tr>
<tr>
<td>AirlineID_4</td>
<td>RouteID_4</td>
<td>FlightID_4</td>
<td>Slot_7</td>
<td>ra</td>
<td>rd</td>
</tr>
<tr>
<td>AirlineID_3</td>
<td>RouteID_3</td>
<td>FlightID_3</td>
<td>Slot_8</td>
<td>ra</td>
<td>rd</td>
</tr>
<tr>
<td>AirlineID_2</td>
<td>RouteID_2</td>
<td>FlightID_2</td>
<td>Slot_9</td>
<td>ra</td>
<td>rd</td>
</tr>
<tr>
<td>AirlineID_1</td>
<td>RouteID_1</td>
<td>FlightID_1</td>
<td>Slot_10</td>
<td>ra</td>
<td>rd</td>
</tr>
</tbody>
</table>

Nominal capacity constraints ($h = 1$)

Rolling capacity constraints ($h = 2$)

Rolling capacity constraints ($h = 3$)

Rolling capacity constraints ($h = 4$)

Slot Prices

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

26/11/2014
Pilot Simulation (market clearance)

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

| 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

SESAR INNOVATION DAYS 2014

www.access-sesar.eu