The economic value of adding capacity at airports – a data-driven model

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Introduction

Objectives

- Contribute to SESAR Operational Focus Area 05.01.01 (Airport Operations Management).
- Assess the economic value of extra capacity at an airport.
- Better understand interdependencies of various KPIs.
- Assess existence and behaviour of an airport economic optimum, in a similar way to the early 2000s when estimating the economic en-route capacity optimum.
- Build a simple model but highly data-driven.
Introduction

Basic idea: capacity is costly, but brings higher revenues due to smaller delays.
Data

Collection of very different types of data, including:

- Traffic data (delay, capacity, number of passengers etc.),
- financial data of airports,
- cost of delay for airlines,
- satisfaction data,
- airport infrastructure,
- etc...
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⇒ consolidated database of heterogeneous data (note: Data from 2014, except financial data).
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⇒ Pre-data analysis aiming at guiding the modelling process.
Pre-data Analysis

- \( \sim 20 \) parameters
- Structure of Correlation
- Principal Component Analysis: reduction
- Cluster analysis (modularity) + robustness
- \( \Rightarrow \) Clusters roughly compatible with qualitative assessments of airports
Modelling guidelines

- Airline revenue primarily a function of ticket price and passenger volumes (excluding cargo).
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- Passengers’ choices determined by external factors (e.g. airport location, airline fare/service) ⇒ not modelled here.
- Passengers have different experiences at different airports, based on the delay at the airport, the quality of service at the airport, etc. ⇒ utility.
Relationships between variables

**Delay-capacity**

\[ \delta t \sim \exp \left( \frac{T}{C} \right) \]
Delay-capacity

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Cost of delay

\[ c_d = -7.0 \delta t - 0.18 \delta t^2 + (6.0 \delta t + 0.092 \delta t^2) \sqrt{MTOW} \]
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Probability of operating a route for airline

\[ P_A = \frac{2}{1 + e^{c_d/s}} \]
Relationships between variables

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**Probability of operating a route for airline**

\[ P_A = \frac{2}{1 + e^{c_d/s}} \]

**Cost of capacity**

\[ c_{\text{inf}} = \alpha(C - C_{\text{init}}) + c_{\text{init}} \]
Revenues of airport

\[ r_a = (P + l_f w) N_p A \]
Relationships between variables

Revenues of airport

\[ r_a = (P + l_f w) NP_A \]

Value of time for passengers

\[ v = v_I r_{lcc} + v_b (1 - r_{lcc}) , \]
Different steps of calibration

- **Direct calibration**: an input of the model is directly matched to some value extracted from the data. Ex: MTOW, typical traffic.

- **Post-calibration**: an output of the model is matched to some values from the data, sweeping input parameters. Ex: aeronautical revenues of airport.

- **Functional relationships**: independent on the specific airport and fitted from data or taken from literature. Ex: delay as a function of capacity.
Delay vs Traffic

\[ \delta t \sim \exp \left( \frac{T}{C} \right) \]
\[ c_d = -7.0 \delta t - 0.18 \delta t^2 + (6.0 \delta t + 0.092 \delta t^2) \sqrt{MTOW} \]

**Problem**

*Cost of average delay is not average cost of delay* because:

- Cost is not linear with delay,
- In particular air companies do not gain from negative delays (anticipated flights) in general.
Delay distribution – hourly pdf fit
Delay distribution – cost correction

- Cost in euros per flight vs. Average delay
- Data points and trend line indicating a positive correlation between delay and cost
Implicit equation of delay

- delay depends on traffic
- traffic depends on probability of operating the flight
- probability depends on the cost of delay
- cost of delay depends on delay

⇒ Implicit equation which fortunately had always a solution
⇒ Post-calibration of a “traffic multiplicator”, output traffic to be matched to data.
### Calibration (on CDG)

<table>
<thead>
<tr>
<th>Name of parameter</th>
<th>Short description</th>
<th>Type of parameter</th>
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<tbody>
<tr>
<td>$\sqrt{MTOW}$</td>
<td>Max. take-off weight</td>
<td>DC</td>
</tr>
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<td>$l_f$</td>
<td>Load factor</td>
<td>DC</td>
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<td>$P$</td>
<td>Airport charges</td>
<td>DC</td>
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<td>$C_{init}$</td>
<td>(Departure) capacity</td>
<td>DC</td>
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<td>$cc$</td>
<td>Delay at zero traffic</td>
<td>DC</td>
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<tr>
<td>$v$</td>
<td>Value of time</td>
<td>DC</td>
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<tr>
<td>$T$</td>
<td>Distribution of traffic</td>
<td>DC</td>
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<tr>
<td>$w$</td>
<td>Average revenue per passenger</td>
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<td>$c_{init}$</td>
<td>total initial cost</td>
<td>DC</td>
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<tr>
<td>$\beta$</td>
<td>Traffic multiplier (demand)</td>
<td>PC</td>
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<tr>
<td>$\alpha$</td>
<td>Marginal cost of capacity</td>
<td>FP</td>
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<tr>
<td>$s$</td>
<td>Smoothness</td>
<td>FP</td>
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</table>
Results – fixed marginal cost

Graphs illustrating the relationship between revenues per pax, cost per pax, income per Pax, and average delay (Avg. Delay) as a function of C.
Results – fixed marginal cost

- Cost Delay vs. C
- Operated/Demand vs. C
- Nb. flights vs. C
- Net Inc. vs. C
Results – different airports comparison

![Graph showing the relationship between profitable marginal cost and number of passengers for different airports. Each airport is represented by a point on the graph, with the x-axis representing the number of passengers and the y-axis representing the profitable marginal cost. The airports are labeled with their respective IATA codes.]

G. Gurtner (Uni. of Westminster)
More exploratory model

Variable indirect revenues per passenger

\[ w(\delta t) = w_{\text{init}} + w_{\text{shop}}(\delta t) + w_{\text{sat}}(\delta t). \]
More exploratory model

Variable indirect revenues per passenger

\[ w(\delta t) = w_{\text{init}} + w_{\text{shop}}(\delta t) + w_{\text{sat}}(\delta t). \]

More shopping time

\[ w_{\text{shop}}(\delta t) = t_e \frac{\delta t - \delta t_{\text{init}}}{120} w_{\text{init}}, \]
Variable indirect revenues per passenger

\[ w(\delta t) = w_{\text{init}} + w_{\text{shop}}(\delta t) + w_{\text{sat}}(\delta t). \]

More shopping time

\[ w_{\text{shop}}(\delta t) = t_e \frac{\delta t - \delta t_{\text{init}}}{120} w_{\text{init}}, \]

Worse shopping time

\[ w_{\text{sat}}(\delta t) = \begin{cases} s_e \left( \frac{\delta t - \delta t_{\text{init}}}{120} \right)^2 w_{\text{init}} & \text{if } \delta t < \delta t_{\text{init}} \\ -s_e \left( \frac{\delta t - \delta t_{\text{init}}}{120} \right)^2 w_{\text{init}} & \text{else}. \end{cases} \]
Variable indirect revenues per passenger
More exploratory results
More exploratory results
GUI

AEV-model v0.9.2b

Airport NBU

Airline NBU

2D-contour

X-axes

Y-axes

P (Airport fees)

C (Airport capacity)

N° (Number of Pax/flight)

a (Cost per unit of capacity)

b (Cost per minute of delay)

r, ind (Indirect revenues per pax)

Airport cluster

Airline cluster

Modal info

Using default models

G. Gurtner  (Uni. of Westminster)  
Airport Economic Value

SID – Nov. 2016
Conclusions

- Simple but highly data-driven model.
- Data come from different sources, hard to consolidate.
- Data analysis shows main differences in airports is size, then business models.
- Calibrated model: presence of an optimum in capacity, depending on the marginal cost of capacity: not always reachable.
- Profitability threshold is different among airports.
- More complex indirect passengers revenues: presence on local minima, complexification of the cost analysis.
Future Work

- More Data!
- Further liaisons with ACI on joint modelling initiatives.
- Further liaisons with Heathrow in particular on PAX satisfaction.
- The work on AirPort Operation Concept will continue as part of its Project 04: additional variables, closer interaction with interested airports.
Thank you for your attention
Cluster analysis

Categorisation of the airports, likely to have different functional relationships for different types (hubs, etc.).

- Used Modularity-based method, coming from network science. Louvain algorithm maximises the modularity.
- Network-based method: construction of a system where airports are nodes and links are weighted with Euclidean distance.
- Distance is based on the four components from PCA + weighting of variance share:

  \[ d_{ij}^2 = v_0^2(c_0^i - c_0^j)^2 + v_1^2(c_1^i - c_1^j)^2 + ... \]

- Scaling sweep with Modularity to discover the different clusters level in the data.
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<th>Airport Name</th>
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