Integrated gate and bus assignment at Amsterdam Airport Schiphol

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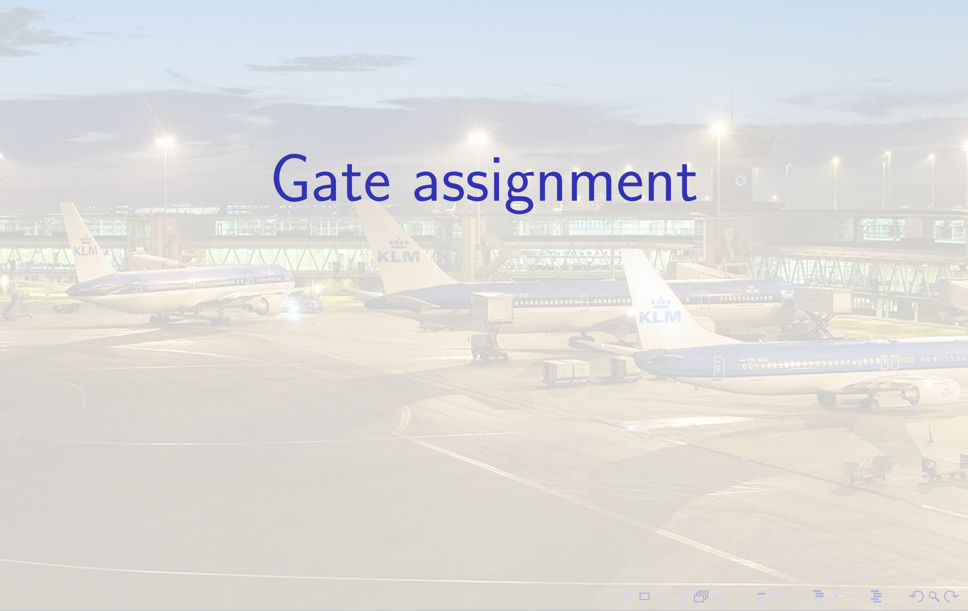
Gate assignment



Problem description

We have a set of flights:

- Arrival and departure time
- Type of aircraft
- Region of origin/destination (Schengen/EU/Non-EU)
- Preferences of airline
- Ground handler

And we have a set of gates

- Possible regions (Schengen/EU/Non-EU)
- Possible aircraft
- Possible ground handlers

Problem description (2)

Goal:

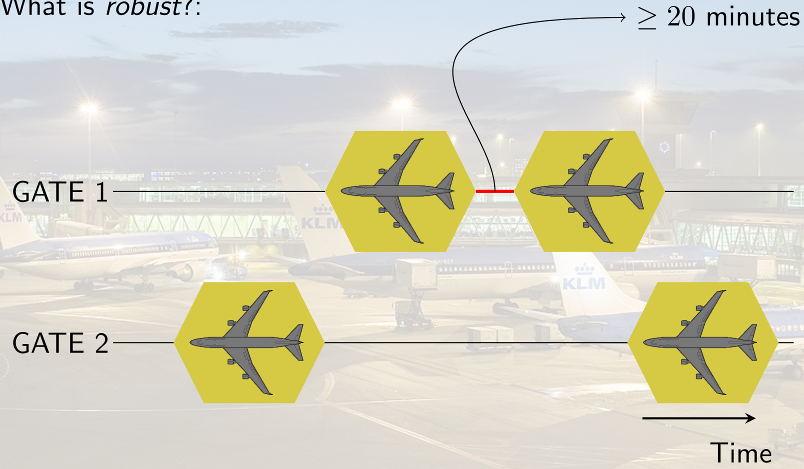
- find assignment one day ahead
- maximize *robustness*

that satisfies:

- region constraints
- aircraft constraints
- ground handler constraints
- time constraints
- preferences

Problem description (3)

What is *robust*?:



Problem description (3)

What is *robust*?:

Problem description (4)

Cost function: $c(t) = 100(\arctan(0.21(5 - t)\frac{\pi}{2})$

- High for small separation times
- Low for long separation times
- Descending steeply in beginning

Refinements:

- Certain combinations of flights are more desirable
- Certain assignments are less desirable

Gate plans

Distinguish only between gate types (not between individual gates)

Gate plan:

- Set of flights assigned to the same gate
- Designed for a given type of gate
- Cost of gate plan = cost due to corresponding separation times

Decision variable $x_i = 0/1$ if gate plan i is (not) selected.

We can incorporate all mentioned constraints within *valid* gate plans

The model

$$\text{Min.} \sum_{i=1}^{N} c_i x_i + \sum_{v=1}^{V} Q_v \text{UAF}_v \quad \text{s.t.}$$

$$\begin{aligned}
\text{UAF}_v + \sum_{i=1}^{N} g_{vi} x_i &= 1 \quad \text{for all flights } v \\
\sum_{i=1}^{N} e_{ia} x_i &= S_a \quad \text{for all gate types } a \\
\textit{Preferences are met} & \\
x_i &\in \{0, 1\}
\end{aligned}$$

Column genration: pricing problem

Create graph G_a for gate type a:

- Vertices: possible flights v
- Arc (v, v') if flight v' can be placed after flight v
- Set cost arc (v, v') to contribution flight v to reduced cost

Shortest path in Directed Acyclic Graph with topological order.

Column generation

Extra columns:

- Solving pricing problem resulted in shortest path
- Disable flights from this new gate plan one by one and solve shortest path again

Column deletion:

- if reduced cost exceed threshold

Solving: ILP

- Add the unique columns to the ILP problem:
  - Tremendous speed up
  - Better solutions
- Gamble for small integrality gap (0.35 %).
- Aggressive CPLEX settings

Summary gate assignment

1. Assigning flights to gate plans:
   - Colum generation
   - Fast (some minutes for solving complete day)
   - Small integrality gap
2. Assigning gate plans to gates:
   - Every single gate is separate type: done
   - Solve small assignment problems

Bus planning

Problem description

- Some stands don't have air bridge
- Flights at platform require bus trips
- Correspondance to gate assignment model:

Flight	$\longrightarrow$	Trip
Gate type	$\longrightarrow$	Shift
Gate plan	$\longrightarrow$	Bus plan

- Differences:
  - Bus drivers must get some breaks during shift
  - There are two types of buses

The model

- Decision variable $y_j = 0/1$ if bus plan j is (not) selected.
- Cost function based on robustness
- Each trip in exactly one bus plan
- Correct number of bus plans per shift type
- Incorporate breaks in pricing problem

Integrating the two problems

Integrating the two problems

Some advantages:

- Possibility of feed-back from bus planning to gate planning
- Better overall robustness
- Reducing number of buses needed

But:

- Unknown which trips need to be driven
- Problem size increases enormously

The model

Minimize robustness cost function

Subject to:

- gate assignment constraints
- correct number of bus plans per shift type
- correct bus trips are driven:

$$\mathrm{NNT}_t + \mathrm{UAT}_t + \sum_{j=1}^{M} h_{tj} y_j = 1 \qquad \text{for all trips } t$$

- coupling constraints:

$$\mathrm{NNT}_t + \sum_{i=1}^{N} \sum_{v=1}^{V} t_{tvi} r_i x_i = 1 \qquad \text{for all trips } t$$

Solving LP

- Pricing is finding shortest path, coupling constraint 'incorporated' in finding gate plans
- Pricing for gates and buses in each iteration

Fight degeneracy

- Extra columns are added during column generation (up to 20.000)
- Stabilized column generation
  - Add bounded surplus and slack variables with positive coefficient in objective function
- Column deletion

Solving ILP

Additional constraints for ILP:

- rounding heuristic
- fix flight on type of gate or bus on type of shift

Gamble for small integrality gap of 0,5 %

Test instances

Gates:

- Three high-season days at AAS: 600 flights, 1000 possible arrival/departure events for platform flights
- Three low-season days at AAS: 500 flights, 900 possible arrival/departure events for platform flights

Buses:

- Thirty days with 20 shifts and 60 buses

LP results

Instance	Time LP (s) Average	Avg iter	Avg time (s)/iter RMP	Pricing
HS1-GG	1129.6	161.67	2.8	3.9
HS1-SG	2070.1	171.90	4.8	6.8
HS2-GG	973.9	148.27	2.6	3.7
HS2-SG	1847.4	163.07	4.4	6.5
HS3-GG	1142.6	157.50	3.2	4.0
HS3-SG	2575.2	212.77	4.6	7.2
LS1-GG	658.5	165.17	1.1	2.7
LS1-SG	1235.8	175.17	1.9	4.8
LS2-GG	710.0	161.90	1.3	2.8
LS2-SG	1383.4	175.87	2.5	5.0
LS3-GG	595.0	141.37	1.2	2.8
LS3-SG	1125.1	151.70	2.2	4.9

ILP results

Instance	Average additional constraints: Flight constraints	Average additional constraints: Trip constraints	Average solving time ILP (s)
HS1-GG	121.4	57.6	43.5
HS1-SG	103.4	57.9	54.1
HS2-GG	117.8	57.1	42.0
HS2-SG	105.4	57.7	103.3
HS3-GG	119.3	57.2	82.7
HS3-SG	108.7	57.5	95.2
LS1-GG	108.9	58.4	86.5
LS1-SG	91.0	59.0	271.0
LS2-GG	107.0	59.1	45.8
LS2-SG	84.2	59.3	170.6
LS3-GG	118.5	59.9	20.6
LS3-SG	105.6	59.6	29.5

Conclusion

- Integrated model to optimize robustness
- Realistic constraints can be incorporated
- Computation times are quite good:
  - Gate assignment can be solved within a few minutes
  - Bus planning with one minute
  - Integrated problem within one hour

Questions?