Flight Numbering Automation

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Your Speaker

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Jeff Warren works in product development at Sabre Labs and is a veteran OR professional in the aviation industry. He has worked primarily in forecasting and optimization applications within schedule planning.

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Agenda

01 Introduction

02 Numbering Needs

03 A Flight Numbering Tool

04 Modeling

05 Results & Conclusions

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Motivation

- Flights must be numbered
- Flight numbers should be organized
- Flight numbers should be stable
- Increases revenue?
- Decreases confusion in planning and operations
- Incurs opportunity cost in planning

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Our Story

- Large, multi-hub airline
- Has manual numbering process with automated assessment and reports
- We created an automatic tool that works alongside schedule software
- Renumbers flights according to several rules and preferences
- Big schedules required new modeling and solution techniques

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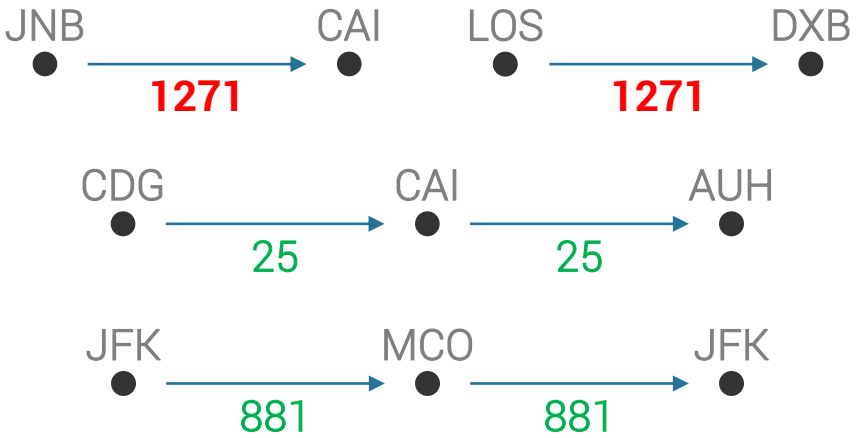
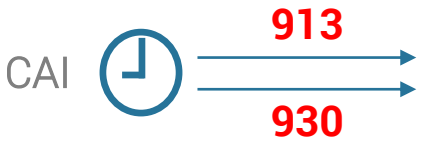
NUMBERING NEEDS

Flight Number Rules

- Don’t re-use flight numbers on the same day unless:
  - Approved through flight
  - Approved out-and-back flight



- Prevent similar-callsign violations



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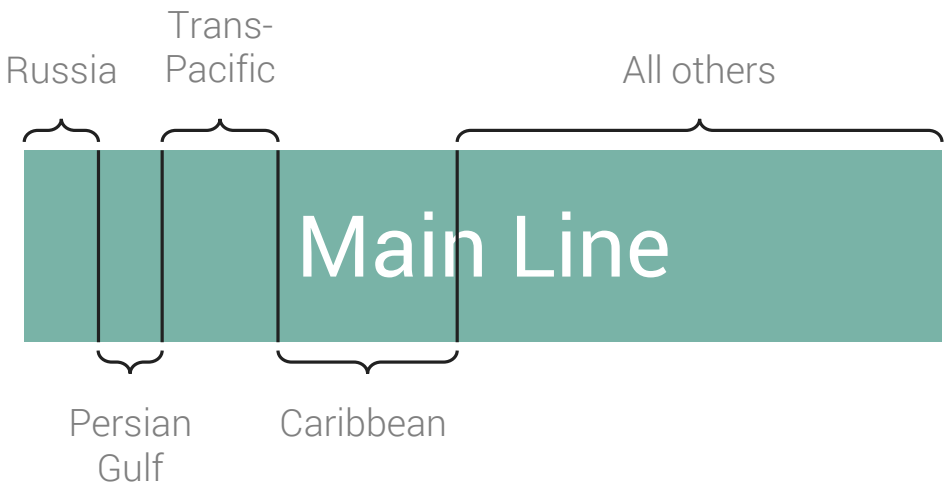
Flight Number Rules

- Respect operator ranges

- Respect sub-ranges



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Consistency

- Strongly prefer consistent numbering from schedule to schedule

May
1522 CAI 07:15 JFK
1801 CAI 10:00 JFK
2872 CAI 15:00 JFK

June
1522 CAI 07:20 JFK
1624 CAI 10:15 JFK
2872 CAI 15:10 JFK

- Prefer consistent numbering from day to day

Sun	Mon	Tue	Wed	Thu	Fri	Sat
817	817	817	817	**588**	**588**	817

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Compression

- Use fewer flight numbers for a given operator
- Prepare to transfer them to
  - The main line operator
  - Another regional operator
  - Codeshare use

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A FLIGHT NUMBERING TOOL

Previous Approach

- Smaller airline
  - Fewer flights
  - More flexibility
  - Greater requirements
- Only daily schedule
  - Didn’t address the trickiest numbering problems
  - Nearly useless late in scheduling process

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State of the Schedule

- Active Schedule
  - First OFS schedule
  - Carryovers correctly numbered; new flights arbitrarily numbered
  - Only close-in additions arbitrarily numbered

- Reference schedule
  - OFS schedule from previous time period
  - Updated OFS schedule from previous time period
  - Most recently published schedule from current time period
  - None

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Inputs

1	Active Schedule	Schedule to be renumbered
2	Reference Schedule	Schedule to provide historical numbers
3	Rules	Operator ranges, out-and-backs, etc.
4	Reference Data	Stations, countries, etc.

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Outputs

- Diagnostic Mode
  - Violations needing correction
  - Use of flight numbers by operating carrier
- Optimization Mode
  - Renumbered Schedule
  - Diagnostic reports on renumbered schedule

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MODELING

How to Model?

- An assignment-style problem with a few side constraints
  - Each day has 9999 buckets
  - Each flight goes in one of the buckets for its day
  - Each bucket holds one flight (mostly)
  - Some pairs of flight numbers cannot be used by some pairs of flights
  - Some flights on different days should get the same flight number

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MIP Model

Minimize

$$\sum_{f \in F} \sum_{n \in N} c_{fn} x_{fn}$$

Subject to

$$\sum_{n \in N} x_{fn} = 1$$

Coverage

$$\sum_{f \in F_d} x_{fn} \leq 1$$

No reuse of n on day d

$$x_{fn} + x_{\hat{f}\hat{n}} \leq 1$$

Callsign conflicts

Hopelessly intractable!!

Still lacks consistency, throughs, and out-and-backs!!

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Heuristic

For each flight

Assign the best available flight number

We like MIP solvers because they reduce these risks!

- In what order should we take the flights?
- What happens when no number is found for a flight?
  What happens when one choice precludes a later good choice?
  - Backtrack?
  - Identify a small swap?

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Our Approach

- Aggregate assignment
  - Multiple flights in a single group
  - Multiple groups contain a given flight
- Limited re-numbering options for each flight
- Front-end analysis
  - Needed fixes
  - Potential for consistency
- Split into two MIPs
  - MIP 1: flight number ranges, uniqueness, consistency, reducing flight-number use
  - MIP 2: callsign conflicts, compression

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Flight Number MIP 1

Minimize

$$p_1 \sum_f y_f + p_2 \sum_{n,d} R_{nd} + \sum_{g,n} p_{gn} x_{gn} - \sum_{g,n} r_{gn} x_{gn}$$

Subject to

$$\sum_{g \in G_f} \sum_{n \in N_g} x_{gn} = 1$$

Coverage for g

$$\sum_{g \in G_d} x_{gn} \leq 1 + R_{nd}$$

Count reuse of n on day d

$$\sum_{n \in N_B} z_{Bn} = 1$$

Preferred number for bloc B

$$\sum_{g \in G_f} x_{gn} + y_f \geq z_{Bn}$$

Flights match their bloc or are penalized (for each f and n)

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Flight Number MIP 2

Minimize

$$p\sum_{Q} y_Q - \sum_{g}\sum_{n} r_{gn}x_{gn} \boxed{- r\sum_{n} w_n}$$

Only for g, n of the operator subject to compression

Regional 1

Subject to

$$\sum_{n\in N_g} x_{gn} = 1$$

Coverage for g

$$\sum_{g\in G_n} x_{gn} \leq 1$$

No re-use of n

$$x_{gn} + x_{\hat{g}\hat{n}} \leq 1 + y_Q$$

Callsign conflict Q

$$\boxed{\begin{aligned} v_n &\geq x_{gn} \\ w_n &\leq 1 - v_n \\ w_{n_i} &\leq w_{n_{i+1}} \end{aligned}}$$

Indicate use of n by g

Use precludes terminal non-use

Use of higher number precludes terminal non-use

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RESULTS AND CONCLUSIONS

Results

- MIP 1 eliminates almost all rule violations in a few minutes
- Compression makes MIP 1 expensive
- MIP 2 can be large and costly when proximity windows are wide
- For hardest problems, some callsign conflicts remain after a few minutes

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Results

Optimization

	Week-long Schedule		Month-long Schedule	
	Before	**After**	**Before**	**After**
Range violations	0	0	22	0
Uniqueness violations	2	0	39	0
Call-sign violations	1076	13	4746	95

Optimization with Compression

	Week-long Schedule		Month-long Schedule	
	Before	**After**	**Before**	**After**
Free numbers	120	115	53	54
Consecutive free	6	109	5	20

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Results

Optimization

	Uniqueness Challenge		9999 Challenge	
	Before	**After**	**Before**	**After**
Range violations	0	0	All	0
Uniqueness violations	807	0	-	0
Call-sign violations	2604	108	-	76

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Summary

- Naïve MIPs don’t work for:
  - Fully-dated schedules
  - Largest airlines
- Heuristics are risky
- Multiple, carefully restricted MIPs:
  - Can address all major requirements
  - Provide good numberings
  - Run quickly
- A tool like this can save hours of work per schedule

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Future Work

- Finer control of consistency settings
- Enhanced intra-market numbering
- Enhanced through-flight generation
- Better pre-processing and optimization techniques
- Hierarchy of callsign conflicts

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Thank You

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