A Model for Determining SFO GDP End Times Using a Probabilistic Forecast of Stratus Clearing

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Background

- Low altitude cloud layer (marine stratus) fills the SFO bay area during the night, and frequently does not burn off before the first bank of SFO arrivals.
- SFO arrival capacity is reduced from 60 to 30 aircraft per hour (no simultaneous operations on parallel runways).
- Ground Delay Program (GDP) required which delays flights at departure airports.

![Cumulative Count of SFO GDPs by Year](image-url)
SFO GDP Statistics

400 GDPs from Jan 2005 – Dec 2007
(37% of the days)

• Average Statistics
  – Initial Planned Duration = 5:07
  – Final Planned Duration = 6:09
  – Actual Duration = 4:10
  – Early Cancellation = 1:59

Corresponds to ATCSCC SFO GDP Guidelines used at that time:
“The recommended length of the program is burn-off time plus two hours.”
SFO Stratus Forecast System
MIT Lincoln Labs

Run at:

CONSENSUS FORECAST

Model Run
16z
Approach Clear At
17:39 GMT

Confidence Good

Probability of Clearing By:
17Z 18Z 19Z 20Z
30% 80% 90% 95%

COMPONENT FORECASTS

Run Model Fcst Wgt
16:00 COBEL 17:53 0.21
16:00 Local 17:43 0.36
16:00 Regional 17:07 0.13
16:00 Satellite 17:57 0.31

Hourly Forecast Summary

Note: not all components are available for a given run

Used mid-May to mid-October
Probabilistic elements of forecast
Wgt based on type of day and hour of run

Physics-Based Model
Statistical Models

MOSAIC ATM
Using Forecast Uncertainty

- The 4 cumulative clearing probabilities (17Z-20Z) are based on the CDF of historic prediction errors, and are rounded to a precision of 5%.
- One hour resolution is arbitrary, and not precise enough to properly evaluate the risks to aviation imposed by forecast error.
- With a more precise CDF of forecast error, we can model (simulate) the risks of forecast error on any proposed GDP.

*We use the empirical CDF of forecast error, classified by forecast confidence and run period.*
Model Overview – Selecting GDP End Time

Min Cost = Optimal GDP End Time

GDP Scen 1
1600-End 1

GDP Scen 2
1600-End 2

GDP Scen m
1600-End m

GDP Cnx Time 1
GDP Cnx Time 2
GDP Cnx Time 3
...n. Clearing Time

Metric Set 1
Metric Set 2
Metric Set 3
...Metric Set n

Scen 1 Probable Metric Set

Scen 2 Probable Metric Set

Scen m Probable Metric Set

Min Cost = Optimal GDP End Time

Scen 1 Cost

Scen 2 Cost

Scen 3 Cost

1. Clearing Time
2. Clearing Time
3. Clearing Time
4. Clearing Time
...n. Clearing Time

CDF

Prob

Clearing Time

function

function

function

function

avg

avg

avg

avg
Metrics Evaluated for Objective Function

**Competing Goals:** Some metrics increase in cost with later end times, while others decrease. Must balance the risks of users (excess delay) and ATC provider (excess demand).
GDP End Time Model Objective Function

\[ Z(t, \xi) = E_\xi \{ w_1 U(t, \xi) + w_2 H(t, \xi) + e^{k \left( upm(F,t,\xi) \right)} + w_3 T(t, \xi) \} \]

where:
- \( t \) is the chosen GDP end time, and
- \( \xi \) is the probability distribution of clearing time, and
- \( E_\xi \) is the expectation over the distribution of clearing times, and
- \( U \) is the total unnecessary ground delay in minutes issued to the non-exempt flights in the GDP, and
- \( H \) is the total airborne holding after the GDP end time, and
- \( F \) is the max flights inholding after the GDP end time, and
- \( w_1 \) is the weighting coefficient for unnecessary ground delay, and
- \( w_2 \) is the weighting coefficient for airborne holding after the GDP end time, and
- \( w_3 \) is an arbitrarily large weighting coefficient, and
- \( k \) is the risk controlling coefficient, and
- \( T \) is equal to 1 if the number of exempt flights in the first new hour if the GDP extended at 1600Z exceeds a threshold, 0 otherwise.

Balancing both NAS Users and Service Providers Goals/Risks
SFO GDP Scope

- Scope is a less critical decision at SFO
  - Issued in mornings with predominantly short haul arrivals
  - Shorter duration programs
  - Very few flights typically added when increasing scope
GDP Scope Model Objective Function

\[ Z(s, \xi) = E_p \{ w_1 A(s, \xi) + w_2 U(s, \xi) + w_3 V(s, \xi) + w_4 T_1(s, \xi) + w_4 T_2(s, \xi) + w_4 T_3(s, \xi) \} \]

where:
- \( s \) is the chosen GDP scope, and
- \( \xi \) is the probability distribution of clearing time, and
- \( E_p \) is the expectation over the distribution of clearing times, and
- \( A \) is the average delay per flight, and
- \( U \) is the total unnecessary ground delay in minutes issued to the nonexempt flights in the GDP, and
- \( V \) is the delay variability across carriers, and
- \( T_1 \) is equal to 1 if the number of exempt flights in the first new hour if the GDP extended at 1500Z exceeds a threshold, 0 otherwise, and
- \( T_2 \) is equal to 1 if the EMA threshold is violated, 0 otherwise, and
- \( T_3 \) is equal to 1 if the EMF threshold is violated, 0 otherwise, and
- \( w_1 \) is the weighting coefficient for the average delay, and
- \( w_2 \) is the weighting coefficient for unnecessary ground delay, and
- \( w_3 \) is the weighting coefficient for delay variability, and
- \( w_4 \) is a very large weighting coefficient.
Sensitivity of Scope Objective Function Parameters

- Variety of combinations of weights/thresholds tested
- Objective function not very sensitive to weights/thresholds, except for extreme cases
Benefits of using the SFO Stratus Forecast System

**Goal:** Use probabilistic forecast information from an existing system for predicting stratus burn-off at SFO and show benefits of improved decision making using these data

- Benefits Analysis
  - Approach:
    - Translated probabilistic forecast information into optimal GDP parameters, using our stochastic model
    - Gathered actual GDP data
    - Analyzed the reductions in unnecessary ground delay and flights affected using GDP parameters recommended by model
Model Benefits

Annual Estimated Savings: $2,830,000 per severe weather season

* Assumes $60.46 per minute delay, 77 GDPs per season

- 61% (88 minutes) reduction in excess planned GDP minutes. From 143 minutes to 55 minutes.
- Model still selected an end time later than clearing time 86% of the time.
- Model selected better end time 91% of the time.
Next Steps

- Developing the model as a real-time operational system
- Field trials planned for severe weather season 2010
- Future research:
  - Apply model to other airports with probabilistic forecasts or capacity scenarios
  - Investigate additional possible benefits for the NextGen timeframe from using a new GDP algorithm to replace RBS
Questions?

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