Performance Improvements Through Trajectory Feedback in the Future Collaborative Flight Planning Environment

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Stéphane Mondoloni, Ph.D., Sheng Liu, Daniel Kirk, Ph.D.
Overview

- **Background on the future collaborative flight planning environment**
  - Provides trajectory feedback in flight planning process:

- **Describe & investigate two benefits mechanisms for AUs to use feedback to**
  1. Optimize route selection
  2. Absorb delay on the ground in lieu of airborne holding
Background on the Future Collaborative Flight Planning Environment
Background on Flight Planning Changes

ICAO tasks a study group to modernize the ICAO flight planning provisions

Nov. 2004

ICAO flight planning provisions


Farther term (FF-ICE)

Meeting “expressed its full support for the concept and agreed there was a need for all partners to support a single concept of operations using FF-ICE”

Richer set of information exchange required for advanced capabilities

Seek extensible (XML) format allowing new items to be incorporated with shorter lead times

Air Traffic Management Requirement and Performance Panel (ATMRPP)
Flight and Flow Information for a Collaborative Environment (FF-ICE)
Flight Information Exchange Model (FIXM)
Flight Plan Study Group (FPLSG)

Images: ICAO, fixm.aero
Timeline from ASBU FICE Thread

- **2015**
  - FF-ICE/1
  - Ready for Implementation

- **2016**
  - ICAO

- **2017**
  - v4.0
  - v4.0 supports B1-FICE provisions

- **2018**
  - B1-FICE
  - FIXM exchange pre-departure
  - GUFI (Globally Unique Flight ID)
  - Supports Operator-provided 4DT
  - Update to flight information

- **2019**
  - B2-FICE
  - FIXM exchange during execution
  - Internationally Interoperable Flight Object
  - Use of system wide information management (SWIM)
  - 4DT exchange & support for TBO

- **2020**
  - B3-FICE

- **2021**
  - ASBU: Aviation System Block Upgrade

- **2022**
  - ASBU FICE: ASBU FF/ICE Thread

FIXM core is intended to be “globally applicable”

FIXM allows for Regional Extensions which are not in FIXM core

**This effort focuses on some pre-departure benefits that could be delivered in Block 1**
## Pre-Departure 4DT Exchange Overview

<table>
<thead>
<tr>
<th>Pre-negotiation</th>
<th>Negotiation</th>
<th>Agreement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early Information (e.g. scheduling)</td>
<td>Flight Information &amp; Desired 4DT</td>
<td>Plan filing and acceptance</td>
</tr>
<tr>
<td>Constraint Publication</td>
<td>Feedback on 4DT (Negotiating)</td>
<td></td>
</tr>
<tr>
<td>- Adaptation Information Exchange Model (AIXM)</td>
<td>- e.g. speed and altitude restrictions, re-routes</td>
<td></td>
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</tbody>
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- Optional – ICAO Provisions do not describe
- ICAO Provisions will describe
Using Feedback to Optimize Route Selection (Pre-departure)
Feedback on 4DT

- **Constraints:**
  - Location of constraint
  - Altitude, speed or time values
  - Value type: AT, AT OR GREATER, AT OR LESS, BETWEEN
  - Activation type
    - Point at which the constraint is met, or
    - Point at which transition is initiated

- **Lateral Path:**
  - Modified route
  - Indication of which points were modified

Profile affected by constraints
**4DT Feedback for Route Optimization**

- Feedback enables AU to select optimal trajectory while meeting operational objectives
  - FIXM supports parallel negotiations on multiple route-trajectory options

![Graph showing 4DT feedback for route optimization with planned and ATC intended routes.](image)

**Route 1**
- As planned
- With ATC intents

**Route 2**
- As planned
- With ATC intents

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Planned 4DT | ATC Intended (i.e., lateral and altitude restrictions)
Approach

- Cost of a trajectory for each of the N routes for a city pair

\[ C_i = c_i + \varepsilon_i + \eta_i \quad \text{where} \quad i \in [1,N] \quad (1) \]

- Selecting the least costly route

  - Without feedback: \[ C^* = \min_i \{c_i + E(\varepsilon_i + \eta_i)\} \quad (2) \]
  - With: \[ C^* = \min_i \{c_i + \varepsilon_i + E(\eta_i|\text{feedback})\} \quad (3) \]

  Difference between (3) and (2) is the benefit of 4DT feedback.
\( \epsilon \), cost of known perturbation

- \( \epsilon = \text{cost of ATC intended} - \text{cost of planned 4DT} \)

- Estimated Cost Index (CI) was used to combine the fuel and time costs
- CI was estimated by perturbing speed on the desired 4DT and obtaining resulting fuel and time perturbations

LAX-DFW and ORD-BWI flights were frequently subjected to ATC changes
Benefits are City-Pair Dependent

- Benefit = cost difference between best routes selected with and w/o feedback
  - Using the distribution of $\varepsilon$ for each route

Frequently no alternative plans between ORD-BWI
Cost Savings from Trajectory Feedback

- Average savings of 0.2% in planned flight cost
  - 0.19% saving in fuel consumption when CI set to 0

- Average savings in planned flight cost is reduced but still at 0.15%
  - Shows it is more beneficial to use trajectory feedback than to guess with the past knowledge
Using Feedback to Absorb Delay on the Ground versus Airborne Holding

Using pre-departure exchange between a flight operator and a downstream ANSP
4DT Feedback for Delay Optimization

- Enables downstream ASP-AU dialogue on ATFM constraints†
  - AU may choose the best delay absorbing strategy (e.g. ground delay, speed control)

As an example, this paper estimates benefits of AU taking portions of delays on the ground

†Many alternative strategies could be developed using FF-ICE as enabler
Approach

- Two Monte Carlo simulations were developed to estimate delays
  a. Tactical airborne delays
     - Arrival spacing based on airport capacity and First-Come-First-Serve (FCFS) approach
  b. Absorbing some of the airborne delays on the ground
     - Multi-layer Monte Carlo simulation, detail as follows

\[ t_{arr} = t_{sched} + \epsilon_{dep} + t_{flight} + \epsilon_{EET} \]

- Distribution obtained from operational data
- Similar approach to departure time error (simulation did not condition on departure airport)
Multi-layer Monte Carlo Simulation Illustrated

Outer layer, each run produces a departure schedule for the simulation

- **Departure Schedule**
  - 123
  - 334
  - 823
  - 237
  - 157
  - 541

Inner layer calculates $N$ arrival sequences based on the departure schedule & uncertainties

- **Arrival sequences**
  - 123
  - 334
  - 823
  - 237
  - 157
  - 541

- **Time**
  - 0
  - 3
  - -1
  - ... $N$

- **Flight 157’s expected airborne delays**

- **Airborne at the time of prediction of current flight**
- **Not yet departed at the time of prediction of current flight**

Pick ground delay at a fixed percentile

Airborne delay distribution

Sponsored by the Federal Aviation Administration, NextGen Office (ANG)
Absorbing Delays on the Ground

- Credit system that honors delay taken on the ground
  - FCFS assignment modified by ground delay credit

- Ground delay threshold
  - Only take minimal airborne delay on the ground to prevent missing arrival slots (i.e., the deterministic component of the delay distribution)
  - Future search: consider the probability of system-wide delay instead of the single-flight delay
Simulation Results

- Total delay – flights sometimes do better, other times not
- Airborne delay – majority of flights get a reduction

- 4.1 minutes of airborne delay (with ground delay) vs 6.4 minutes airborne delay (without)
- Ground delay averages 2.6 minutes, when taken
Impact of Uncertainty

- Illustrates impact of improving trajectory prediction
- Improved airborne uncertainty allows greater certainty of delay prediction
- Total delay remains approximately constant
- Eliminating EET uncertainty results in 50% reduction in airborne delay
Conclusions

- **Pre-departure feedback on automation-imposed re-routes and altitude/speed constraints:**
  - Allows users to pick a more optimal plan → 0.2% improvement in planned cost of flight
  - Applying historical impacts → 0.15% improvement in planned cost of flight
  - Across major US carriers, these cost changes are on the order of $100 million per annum
  - Further evaluation to include estimates of as-flown perturbations ($\eta$) is necessary

- **Use of pre-departure feedback to enable improved ground/airborne allocation**
  - Recognize this is an example of a benefit that may have significant operational challenges
  - Illustrates one way in which FF-ICE/1 allows one ASP to influence flights earlier for benefits:
    - In our example: 138 flights potentially could save ~ 5-13 million kg of fuel per annum at one airport
  - Other mechanisms (e.g. linear holding) could be applied post-departure (FF-ICE, ASBU Block 2)

- **Further exploration of FF-ICE/1 benefits through pre-departure flight-specific feedback is needed**
Thank you