PLANNING A RESILIENT AND SCALABLE AIR TRANSPORTATION SYSTEM IN A CLIMATE-IMPACTED FUTURE

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May/June 2014
Definitions

Resilience: Ability of system operations to recover from events

Extreme events and closures
Flooding of LGA gates by Hurricane Sandy (2012)

Routine severe weather events and congestion
Fog at SFO (Routine)

Scalable: Ability of the system to change in scale (operational, climate, etc.)
Era of Airline Consolidation: 2000s-2012

2004: Before mergers

- America West Airlines (HP)
- US Airways (US)
- Northwest Airlines (NW)
- Delta Airlines (DL)
- Continental Airlines (CO)
- United Airlines (UA)

2012: Post-mergers

- Delta Airlines (DL) (2010)
- United Airlines (UA) (2011)
- American Airlines (AA)

Penn University of Pennsylvania
USA Climate Change

Northeast Extremes in 1-Day Precipitation (Step 4*)
Annual (January-December) 1910-2013

Source: National Oceanic and Atmospheric Administration
USA Climate Change

Increases in Amounts of Very Heavy Precipitation (1958 to 2007)

The map shows percent increases in the amount falling in very heavy precipitation events (defined as the heaviest 1 percent of all daily events) from 1958 to 2007 for each region. There are clear trends toward more very heavy precipitation for the nation as a whole, and particularly in the Northeast and Midwest.

Projected Change in North American Precipitation by 2080-2099

The maps show projected future changes in precipitation relative to the recent past as simulated by 15 climate models. The simulations are for late this century, under a higher emissions scenario. For example, in the spring, climate models agree that northern areas are likely to get wetter, and southern areas drier. There is less confidence in exactly where the transition between wetter and drier areas will occur. Confidence in the projected changes is highest in the hatched areas.

Source: U.S. Global Change Research Program
International Climate Change

Extreme Weather Overall Vulnerability:
Physical Impacts Adjusted For Coping Ability

Source: Center for Global Development
Jet Fuel Prices

Kerosene-Type Jet Fuel Prices: U.S. Gulf Coast (WJFUELUSGULF)
Source: U.S. Department of Energy: Energy Information Administration

- $3.00/gal
- $0.50/gal

Shaded areas indicate US recessions.
2013 research.stlouisfed.org
Tutorial Overview

Introduction

How do airlines currently plan their operations due to the threat of events?: An investigation of airline fuel uplift

Managing a major hub airport outage through passenger-centric diversion strategies
PLANNING FOR RESILIENCE AND THE COST TO CARRY FUEL FOR CONTINGENCIES

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Mark Hansen, Michael Seelhorst & Lu Hao
Department of Civil and Environmental Engineering
University of California, Berkeley

Thanks to:
What is the Cost of Planning for Contingencies?

We looked at this in two ways:

• First, indirectly, by relating schedule padding to additional fuel consumption

• Next, directly, by collecting data on fuel loaded for contingencies and calculating the fuel consumption attributed to carrying this fuel
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Data

Airline data: Flight-level fuel and operating statistics for 28,000 US and international flights on a major US-carrier in November 2010

FAA NASPAC Model

FAA ASPM Database: Hourly meteorological condition at the origin and destination airport at the scheduled arrival and departure time

Consider two aircraft types commonly used for domestic operations

Boeing 737-800

- Seats 162 to 189

Boeing 757-200

- Seats 186 to 289
## Approach: Statistical Model of Actual Fuel Consumption

\[
f_{it} = \alpha + \beta_{\ell_d} \ell_{it}^d + \beta_{\ell_r} \ell_{it}^r + \beta_{o_{it}} o_{it}^d + \beta_{c_{it}} c_{it} + \beta_{c_{it} o_{it}} o_{it}^a + \sum_{\gamma_o} \gamma_o \phi_{\gamma_o} + \sum_{\gamma_d} \gamma_d \phi_{\gamma_d} \\
+ \sum_{w_o} w_o \gamma_o \phi_{w_o} + \sum_{w_d} w_d \gamma_d \phi_{w_d} + \varepsilon_{it}
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Where:

- \( \ell^d \) = Departure delay
- \( \ell^r \) = Airborne delay
- \( \ell^p \) = Padding
- \( o^d \) = Take-off weight difference
- \( o^a \) = Actual take-off weight
- \( c \) = Flight-plan cruise fuel consumed
- \( y_o \) = Origin airport
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- \( w_o \) = Origin weather
- \( w_d \) = Destination weather

**Unimpeded flight time**

\( T_0 \)

**Schedule pad**

\( T_p \)

**Airborne delay**

\( T_a \)

\[ Scheduled \ time = T_0 + T_p \]

\[ Delay \ time = T_p + T_a \]
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### Model Estimation

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<th>B757-200</th>
<th>B737-800</th>
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<tr>
<td></td>
<td>Estimate (Std. error)</td>
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</tr>
<tr>
<td><strong>Intercept</strong></td>
<td>7371.087 (121.129)</td>
<td>5010.300 (79.393)</td>
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<tr>
<td><strong>Departure delay</strong></td>
<td>4.395 (1.018)</td>
<td>2.413 (0.890)</td>
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<td>59.156 (3.271)</td>
<td>49.860 (3.089)</td>
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<tr>
<td><strong>Schedule padding</strong></td>
<td>11.755 (3.038)</td>
<td>5.390 (2.113)</td>
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<tr>
<td><strong>TOW Difference</strong></td>
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<td>0.031 (0.004)</td>
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<tr>
<td><strong>FAA Airborne fuel</strong></td>
<td>0.148 (0.046)</td>
<td>0.493 (0.055)</td>
</tr>
<tr>
<td><strong>FAA Airborne fuel * Actual TOW</strong></td>
<td>3.51<em>10^{-6} (2.16</em>10^{-7})</td>
<td>3.000<em>10^{-6} (3.47</em>10^{-7})</td>
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<tr>
<td><strong>R^2</strong></td>
<td>0.9901</td>
<td>0.9930</td>
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<tr>
<td><strong>N</strong></td>
<td>4000</td>
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All coefficients are significant at the 1% level.
## Model Estimation

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- 1 min of airborne delay = 50-60 lbs of fuel
- 1 min of schedule padding = 6-12 lbs of fuel

One minute of airborne delay is equivalent to 6 minutes (B752) or 10 minutes (B738) of schedule padding.

There is a *measurable cost* for planning for resilience because excess fuel is loaded for *contingencies*.

All coefficients are significant at the 1% level.
Fuel Savings From Reducing Delay

For all reported operations, consider that all positive delays are eliminated, and all negative delays are maintained as savings.

Potential savings in fuel:

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<td>25th</td>
<td>0.97%</td>
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<td>50th</td>
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<tr>
<td>75th</td>
<td>2.89%</td>
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<td>Maximum Value</td>
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<td>Average Value</td>
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Flights could save on average 2% of fuel consumption by not padding their schedules and by avoiding airborne delays.

There appears to be a cost attributed to fuel uplift – we now investigate this directly.
Direct Cost to Carry Estimation

In the flight planning process, airline dispatchers load contingency fuel to prepare in case of possible events

- Airport outages
- Weather events
- Possible re-routes

While some of this contingency fuel is federally mandated, some of it is discretionary

Does some of this discretionary fuel indicate over-fueling, and what is the cost of carrying this additional fuel?
Who Makes Fuel Decisions?

Flight dispatchers

- Airline employees, responsible for planning and monitoring all flights for an airline
- Act as point of contact for pilots during flight
  - Coordinate between groups for maintenance issues
  - Speak with air traffic control and airport personnel
- Determine characteristics of flight plan
  - Actual routing from origin to destination
  - How much fuel to load, including extra fuel for contingencies

Operational Control Center (OCC)

- ~200 people, working in a single room at a company’s headquarters
Flight Planning Basics

Timeline of dispatcher duties for a single flight

- Flight plan is created
- Look at weather, choose routing, determine fuel loads
- Revise flight plan if necessary based on last-minute info
- Monitor flight while en-route, update pilots with necessary info

- Domestic dispatchers plan and monitor up to 40 flights in one ~9hr shift
Mission fuel: Choose a route (econ, other alternative route) and calculate necessary fuel

Federal Aviation Regulations (FAR) Reserve Fuel: Fuel to hold for 30 minutes plus fuel to fly to an alternate airport (under specific wx conditions)

Alternate airports: when adverse weather conditions are in forecast, extra fuel is allocated in the case the aircraft must divert

- Vis < 3 mi and Ceiling < 2000 ft require an alternate
- T-Storms in forecast require an alternate
- Alternates can be added at any time, however

Taxi fuel: fuel used to taxi prior to takeoff

Contingency fuel: fuel used at any time to account for unexpected conditions
Domestic Flight Planning Basics: Fueling Decisions

Mission fuel: Choose a route (econ, other alternative route) and calculate necessary fuel

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Taxi fuel: fuel used to taxi prior to takeoff

Contingency fuel: fuel used at any time to account for unexpected conditions
Statistical contingency fuel (SCF)

For domestic flights, dispatchers are presented with two suggested numbers for contingency fuel. The numbers are based on the historical distribution of additional fuel burn (beyond mission fuel) required for similar flights. The 95th and 99th percentile are shown to dispatchers: SCF95 & SCF99. These numbers are sometimes ignored (for a variety of reasons) and the contingency fuel load is higher than SCF99.
Fueling Example

ATL to JFK flight:

SCF95: 18 min, SCF99: 22 min
Weather is clear, no congestion:
   25 minutes of contingency fuel (CF)
Low ceilings at destination:
   40 minutes of contingency fuel
   30 minutes of contingency fuel and TEB listed as alternate (equivalent to adding 15 min more CF)
Thunderstorms at destination and congestion
   45 minutes of contingency fuel and ALB listed as alternate (equivalent to adding 20 min more CF)
What is the Cost to Carry “Additional” Fuel?
Dataset for Analysis

All domestic and international flights for a year (June 2012 to May 2013)

Flight statistics

Fueling information (mission fuel, reserve fuel, tankering fuel, contingency fuel, suggested contingency fuel (SCF95/SCF99), alternate fuel – but not if an alternate is required, just if it’s present)

Actual weather at the time of schedule arrival (not forecast)
What is the Cost to Carry “Additional” Fuel?

What is “additional” fuel?

A portion of a flight’s contingency fuel

Any contingency fuel added above SCF 99

Non-required alternate fuel

All 2nd alternates
All 1st alternates added when not required by wx conditions
Domestic Analysis “Additional Fuel” Definition & SCF

For flights in the dataset with an SCF present, additional fuel is any fuel above SCF99.

For flights in our dataset without an SCF present, additional fuel is any fuel above our calculated SCF.

Calculating SCF: Using 14 months of historical data we calculated a new SCF value.

Per O-D pair, per time bank, but the following modifications were made:

- 4-hour time bank instead of 2-hour
- SCF segregated by equipment type
- Forward and backward looking over time (strong proxy for 1 year back)
- Use the same filters as currently used to filter out bad data.
A Rationale for SCF by Equipment
(Examples like this exist in the historical data for single Origin-Destination Pairs served by multiple aircraft types)

![Graph showing occurrences of under/overburn for different equipment types](image)

- All MD88
- 320s/737-800

# of occurrences

Under/Overburn Min
What is the Cost to Carry “Additional” Fuel?

What is “additional” fuel?

What is the burn attributed with carrying this “additional” fuel?
Estimate Cost To Carry Factors

• We calculated our own “cost to carry” factors which capture the fuel burned per pound of fuel carried per mile

• Special recognition for: icct

• There is a cost to carry this additional fuel in terms of additional fuel burned

• Delta has their own numbers, but these are less useful in a research context
Estimate Cost To Carry Factors

- Using PIANO, estimate block fuel consumption ($b$) by varying take-off mass ($m$) and distance ($d$) for a range of a/c types
- Use the outputs to gather coefficients for cost to carry calculation

\[ b_i(a, d, m) = \beta_o + \beta_mm + \beta_dd + \beta_mdmi \]

\[ ctc(a, d, m) = \frac{\beta_m}{d} + \beta_md \]
## Cost to Carry Overall Statistics

<table>
<thead>
<tr>
<th>Category</th>
<th>Average per operation (gallons)</th>
<th>Cost to carry fuel over entire airline for 1 year (gallons)</th>
</tr>
</thead>
<tbody>
<tr>
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<td>15.18</td>
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<td>All flights with good weather at destination airport</td>
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We will focus on these high density airports for Delta as well as overall stats.

We will focus on a few key statistics:

- Total Cost To Carry
- Cost to Carry per Operation
- Cost to Carry per Mile
- % of Fuel Consumed per Operation Attributed to Carrying Additional Fuel
Total Cost to Carry Over 1 Year

- JFK Destination
- Atlanta Destination
- LGA Destination

CTC total (gallons)

Month

CTC total (gallons)

Month

- All Days in Dataset
- Good WX Days Only
Avg. CTC per Operation for Select Destinations
CTC per Mile for Select Destinations
CTC per Mile

ATL

JFK

LGA
Flights on good wx days
Flights on bad wx days
Bottom Line: Domestic CTC

There is a significant peak in CTC in the summer months.

Flights destined for JFK and LGA have a higher CTC per operation compared with flights destined for ATL or the average flight; per mile, ATL has the highest.

Flights (at least, flights on Delta Airlines) consume between .04 and .3 lbs of fuel per every lb carried.

About 0.5%-1.0% of fuel consumed per domestic operation is due to carrying “additional” fuel.

- The magnitude of the potential savings is commensurate with the potential savings from taxi fuel reduction.
- The average flight consumes 1-2% in taxi in and about 4% in taxi out.
International Analysis “Additional Fuel” Definition

International dispatch has release types rather than contingency fuel

Straight Release: The fuel reserve quantity for SR is 10% of the en route fuel plus 30 minutes of hold at the destination

B43: Fuel reserve is 10% of the en route fuel where the aircraft is planned to be in Class 2 airspace (rule of thumb: over the ocean), plus forty-five minutes of hold at the destination.

B44: Fuel reserve is the minimum of two quantities: 10% of the en route time from the re-dispatch point to destination airport and 10% of the en route time from origin to intermediate airport minus the fuel burn from intermediate airport to destination.

Fuel loading: B44 < B43 < Straight Release
International Analysis “Additional Fuel” Definition

Target Gate Arrival Fuel (TGAF): The amount of fuel an aircraft has on arrival assuming all goes as *planned* -- *not ideal, but planned*

We use TGAF to define and estimate the “additional fuel”

The “additional fuel” for any flight is $\text{max}(\text{TGAF} - 25^{\text{th}} \text{ Percentile of TGAF}, 0)$

Any flight with TGAF over the $25^{\text{th}}$ percentile is carrying “additional” fuel
The Cost to Carry estimate for international flights for a year is 174-195 million lbs (26-29 million gallons)

The average Cost to Carry for a flight is about 2300 lbs (340 gallons)
The percent of total fuel consumed due to the burn from carrying “additional” fuel is mostly around 2-3%.
What is the Benefit of B44?

Assume that all B43 and Straight Release flights could be released as B44. Additional fuel is the fuel that could have been saved if the average of B44 fuel for that OD pair had been utilized.
The percent of total fuel consumed due to the burn from carrying “additional” fuel is mostly around 2%.

In short, if all flights were released with a B44, fuel consumption per flight would be reduced by 5%.
Summary

How large is the problem?

About 45 million gallons per year ≈ $135 million a year
250 dispatchers responsible for all fuel loading decisions
$550,000 per dispatcher

How do the savings compare to other initiatives?

Implementing and maintaining NextGen initiatives is expected to cost the FAA and aircraft operators $37 billion through the year 2030, while generating $106 billion in total benefits over that same time period.

About $7B benefits per year over all carriers; approximately $700 million for Delta Airlines

Going forward: policy, investments to improve predictability, airline diversion plans to reduce the penalty of diversions
Thanks to:

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