**Scheduled Fleet Demand, No Delay**

- PIT USA1776 -> DFW USA1492 -> ORD USA1177 -> PHL USA1212
- DFW USA1345 -> MKE USA2312 -> CLT USA1825 -> ORD
- DFW USA2316 -> MEM USA2145 -> CLT USA353 -> ERI
- SNA USA7887 -> DFW USA6423 -> ORD USA2145 -> LGA USA7216

- 16:00 18:00 20:00 22:00 00:00 02:00

**Scheduled Fleet Demand, 30 Minutes Delay on an Aircraft**

- PIT USA1776 -> DFW USA1492 -> ORD USA1177 -> PHL USA1212
- DFW USA1345 -> MKE USA2312 -> CLT USA1825 -> ORD
- DFW USA2316 -> MEM USA2145 -> CLT USA353 -> ERI
- SNA USA7887 -> DFW USA6423 -> ORD USA2145 -> LGA USA7216

- 16:00 18:00 20:00 22:00 00:00 02:00
Scheduled Fleet Demand, 90 Minutes Delay on an Aircraft

Equity (Fairness)
- Delay distributions
- Distribution of circular holding
- Pop up model validation
- Long-haul Vs. Short Haul
- Regional Vs. Major
- GA Vs. Scheduled
- Overhead Vs. Departure
- Carrier Vs. Carrier
- Arrivals Vs. Departures
- Flight Vs. Flight
The Big Effect of a Small Uncertainty

4.5% of GDP arrival demand is unanticipated “pop-ups”

1.9 pop-ups per hour are inserted into the queue

- 7.7 minutes of delay added per GDP flight
- 1,757 minutes of delay added per GDP
- 3,890,000 minutes of delay added over all airports
- Compare with 14,000,000 minutes of compression savings

Assigning Arrival Slots: many multiple optima

Each flight \( i \) has a reported arrival time \( t_i \)
Let \( x_{i,j} = 1 \) if flight \( i \) assigned to slot \( j \), 0 otherwise

Solve to minimize total delay
Minimize \( \sum_{i,j} x_{i,j} (s_i - t_i) \)

subject to
\[
\sum_j x_{i,j} \leq 1 \text{ for } j = 1, \ldots, m
\]
(each slot is assigned at most one flight),
\[
\sum_i x_{i,j} = 1 \text{ for } i = 1, \ldots, n
\]
(each flight is assigned to one slot),
\[
x_{i,j} = 0 \text{ if } s_i < t_i
\]
(no flight is assigned before its current arrival time).
Controlling only city pair flights within a 1400 nmi radius

Controlling all demand to deal with a given situation can reduce average delays amongst all parties and spread delay to all users.

Controlling only city pair flights within a 1200 nmi radius

Approximately 65% of delayed traffic is NWA

Initiatives that control more flights increase chances of spreading delay, which decreases delay for principle users.
Controlling only city pair flights within a 1000 nmi radius

Options that control more flights can create smaller deviations between flights average delays.

Controlling only city pair flights within a 800 nmi radius

Controlling flights from a carrier’s hub without controlling all carriers may create inequities.
Controlling only city pair flights within a 600 nmi radius

Carriers with few operations may be issued inequitable delay, if the initiative does not consider all demand.

Controlling only city pair flights within a 400 nmi radius

Increasing the scope allows more carriers to be subject to the initiative.

Still there exists a number of carriers, that will not be subject to delay.
Controlling only city pair flights within a 200 nmi radius

100% of delayed traffic is NWA

Average delay of 88 minutes per flight

Uncertainty: Sector Warning Time Distribution

Less than 1 hour notice for:

- 15% (56 of 362) of the flights
- 23% (61 of 260) of the flights
- 35% (103 of 196) of the flights

Data Set: Tube Flts April 9-30 2002
The conceptual: trying to re-generate demand

2nd Tier DTW GS not released soon enough Causes Gap in Demand

Flights Delayed on the ground an average of 30 min. (Potentially could have left earlier to fill gap)
Measuring En Route Delays

Average: 15.5 minutes
Average: 12.6 minutes

Fallacy of Averages

\[ E[f(x)] \neq f(EX) \]
There is Always a Trade-off in Delaying Actions

As the time of the event approaches, certainty goes up but possible options are reduced.

Interactive Flight Planning: What are the incentives?
CDM the Philosophic:
It’s very, very difficult

- Challenging assumptions: collections of networks not flights
- Confronting culture: avoid flight specific initiatives (MIT, Ground Stops, etc…)
- A network of networks (system of systems) viewpoint
- Economics: the allocation of scarce public resources and user flexibility

Economic Themes and CDM

- Options: the users (e.g., airlines) manage transportation networks
- Equity: Fairness must be perceived
- Incentives: to produce desired behavior
“Economics is that way of understanding behavior that starts from the assumption that people have objectives and tend to choose the correct way to achieve them.”


Read the first edition free (it’s better anyway):
http://www.daviddfriedman.com/Academic/Price_Theory/PThy_ToC.html

Economics is about choices and incentives, not money

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**Market Research and ATM**

- Balancing supply and demand
- Establishing property rights
- Assessing value of a resource
  - Price based on cost when demand less than capacity
  - Price based on demand for scarce resource, otherwise
- Extensions to trading mechanisms (critical to optimal throughput)
It’s easy to ignore the complexities

- Conflicts between equity and efficiency
- Conflicts between predictability and flexibility
- Uncertainty and interdependencies
- Gaming
- Conflicting signals
- Economic implications of TFM

NGATS: pre-negotiated trajectories: TFM all the time
Once upon a time...
There were two quaint little villages on a lake.

Then Urban Sprawl Sprang Up
65 min from city to city

60 min @ 1 car/min
5 min @ 1 car/min
So Someone Built a Bridge

Land: 65 min from city to city
Bridge: 15 min from city to city

Then Everyone Started Using the Bridge

The village streets became clogged.
Land: 110 min from city to city
Bridge: 105 min from city to city

Daniel H. Wagner Associates
So They Tore Down the Bridge

65 min from city to city

60 min @ 1 car/min

5 min @ 1 car/min

Lessons from Braess

- Attend to “System” equilibrium
- The demand side of the equation is “the market”
- Don’t just push a technology approach: establish the right market conditions and make it part of the debate
CDM/TFM Challenges and NGATS

- The changing face of demand
  - Confluence of new technologies
  - Smaller aircraft and more point to point
- What are the congestion implications?
- What is the economic foundation and what are the incentives?