Total Delay Impact Study

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NEXTOR Research Symposium

Outline

- Background
- The Total Cost of Flight Delay
- Cost of Delay to Airlines
- Cost of Delay to Passengers
- Conclusions

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Flight Delay

- Flight delay is a critical metric for airports and aviation systems
- It is costly to airlines, air passengers, and society at large
- It is easy to measure and relatively easy to model and predict
- Most business cases and investment analyses for aviation infrastructure investments turn on the benefits from reduced delay

Cost of Flight Delay

- Scientific knowledge about the cost of flight delay is limited
- While converting flight delay and flight delay savings into money is a common practice
  - Methods are simplistic, and laden with untested assumptions
  - Important components of flight delay are not considered

Total Delay Impact (TDI) Study

- FAA-sponsored study to estimate to total economic impact of flight delay in 2007
- Unique aspects of the study include
  - Comprehensiveness
  - Methodological innovation
  - Breadth of participation

TDI Research Team

- University of California, Berkeley
- George Mason University
- Massachusetts Institute of Technology
- University of Maryland
- Virginia Polytechnic Institute
- Brattle Group

TDI Goals

- Provide a frame of reference for decision makers to assess the magnitude of the flight delay problem and the need for initiatives to address it
- Assess the relative magnitude of different flight delay cost components
- Provide a benchmark for assessing the accuracy of more traditional and simple methods for costing delay

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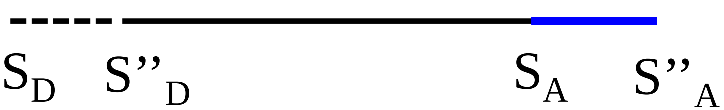
Flight Delay Taxonomy (I)

Ideal flight

- Leaves and arrives on schedule
- Duration is unimpeded flight time
- Schedule reflects air traveler preferences

Schedule padding

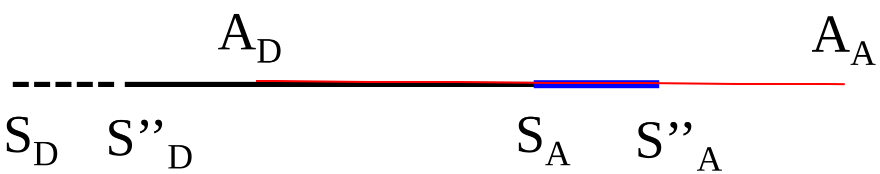
- Scheduled flight duration increases to absorb anticipated delay
- Reduces equipment utilization and passenger convenience



Capacity-induced schedule delay

- Flight schedule changed due to airport capacity constraints
- Reduces overall convenience of schedule to passengers

Flight Delay Taxonomy (II)



Delay against schedule

- Despite padding and schedule adjustments, the flight still does not arrive on time
- Strong association between arrival and departure due to traffic management initiatives and delay propagation
- Many cost-of-delay studies consider this form of delay only

Delay Cost Components Considered (I)

Component	Description	Methodology	Organ-ization
Airline costs	Increases in operating costs to airlines due to delay against schedule and schedule padding	Statistical cost models using firm level data	UCB
Passenger costs	Costs to passengers due to delay and disruption	Simulation using detailed pax itinerary and flight delay data	MIT, GMU, UCB
Capacity-induced schedule delay	Costs to passengers due to less convenient scheduling	Statistical analysis and optimization to find difference between capacity constrained and ideal schedule	UMD, UCB

Delay Cost Components Considered (II)

Component	Description	Methodology	Organ-ization
Passenger schedule adjustment costs	Costs to passengers from adjusting personal travel schedules to mitigate delay impacts	Analysis of airline CRS data to find relationship between trip timing and airport delay	Brattle Group
Lost demand	Welfare losses due to suppression of demand in delay-impacted markets and shifts to other modes	Econometric modeling	UMD,VPI
Indirect economic impacts	Macro-economic impacts of direct costs	Computable generalized equilibrium model	VPI, Brattle Group

Estimated U.S. Flight Delay Costs in 2007

Cost Component	*Cost in $ Billions*
Costs to Airlines	16.7
Costs to Passengers	18.0
Costs from Lost Demand	4.5
Total Delay Costs	**39.2**

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Previous Estimates of Cost of Delay to Airlines

Sources	Evaluation year	System-wide cost ($billion)	Methodology
JEC (2008)	2007	3.6-6.1	Cost factor approach
		12.2-23.4	Total cost approach
ATA (2008)	2007	6.9	Cost factor approach
Hansen et al. (2001)	1995-1997	1-4	Total cost approach
Hansen et al. (2000)	1995-1997	1.7-2.3	Total cost approach
Wingrove et al. (2005)	2015 (predicted)	3.3	Cost factor approach
	2025 (predicted)	13.14	
Citrenbaum and Juliano (1998)	1996	1.2	Cost factor approach
Odoni (1995)	1993	2-4	Cost factor approach
Geisinger (1988)	1986	1.8	Cost factor approach

Cost Factor Approach

- Single cost factor approach

$$(\text{Total delay cost}) = X\ \$/\text{min} * Y\ \text{min}$$

X: delay cost/min
Y: total delay minutes

- Category-based cost factor approach

$$(\text{Total delay cost}) = \sum_i (X_i\ \$/\text{min} * Y_i\ \text{min})$$

X_i: delay cost/min of the ith category of delay
Y_i: total delay minutes of the ith category of delay

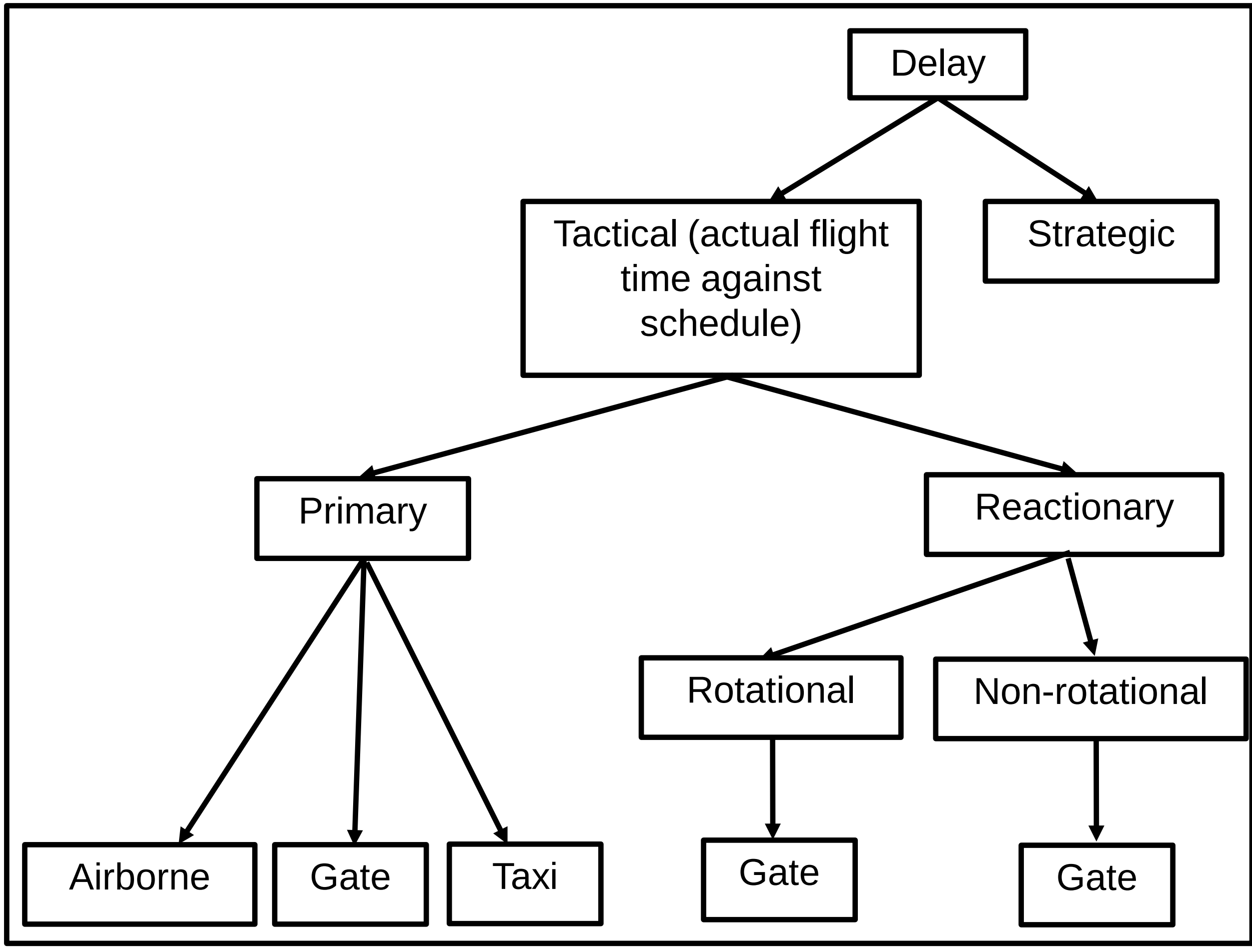
- Simple and straightforward, but …

Problems with the Cost Factor Approach

- Delay heterogeneity
- Cost factor uncertainty
- Untested assumptions about the form of the relationship

Delay Heterogeneity

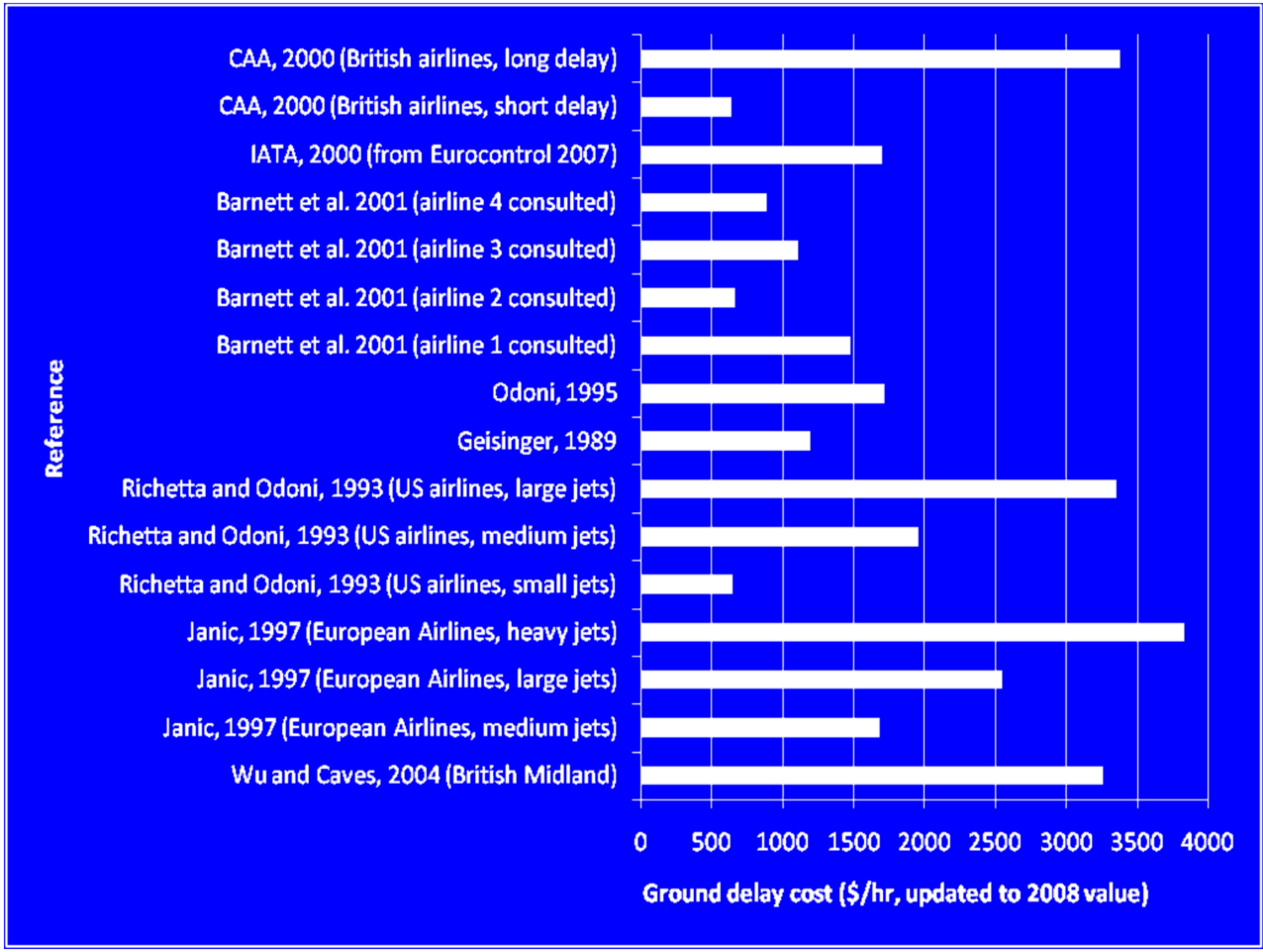
- Cost of delay is likely to vary according to
  - Where the delay is taken
  - Why the delay is taken (primary vs. reactionary)
- But to fully account for this requires
  - Detailed delay data
  - Cost factors for each category



Based on: Cook et al. (2004)

Cost Factor Uncertainty

- Approaches to date based on
  - Analyst judgment
  - Interviews with airport and airline staff
- Validity is questionable
  - Lack of detailed operational knowledge
  - Lack of global perspective on airline costs
  - Accounting relationships vs, causal relationships
  - Lack of agreement among published values



Untested Assumptions about the Form of the Relationship

- Additive separability
  - The total cost of flight delay to an airline can be obtained by adding the costs of delays to individual flights
  - Ignores interaction effects
- Linearity
  - Cost of an individual delay event is linear in the duration of the delay
  - Non-linearity widely recognized, but accounting for it is difficult

Total Cost Approach

- Based on relationship between flight delay and the total costs incurred by an airline
- A simple version (JEC, 2008)

  (Total delay cost) = (Total opr. cost) * p

  p = (delay time)/(total operation time)

- Statistical cost estimation
  - Include delay metrics as arguments in airline cost functions
  - Estimate the functions econometrically, using well-established methods

General Cost Function Specification

$$\mathrm{COST}_{it} = f(\vec{W}_{it}, \vec{Y}_{it})$$

Cost of airline *i* in time period *t*

Factor prices for airline *i* in time period *t* for fuel, labor, etc

Outputs of airline *i* in time period *t* (e.g. revenue ton-miles)

- Assumes that airline is cost-minimizer
- Reflects underlying technology, i.e. ability to efficiently transform inputs into outputs

Cost Function Used in this Research

$$(\mathrm{COST})_{it} = f(\vec{W}_{it}, S_{it}, \Phi(Y_{it}, \vec{Z}_{it}, \vec{N}_{it}))$$

Operating cost of airline *i* in time period *t*

Capital inputs of airline *i* in time period *t*

Hedonic output function
- *Y*—Out quantity
- *Z*—Output characteristics
- *N*—Operational performance variables

- Capital inputs cannot be adjusted to optimal levels instantaneously
- Uses hedonic output function
- Adds performance variables as new arguments

Functional Form—Translog Model

$$
\begin{aligned}
\ln(COST_{it}) = {} & \alpha_i + \alpha_T t + \beta \ln(Y_{it}) + \sum_j \gamma_j \ln(W_{jit}) + \sum_j \delta_j \ln(Z_{jit}) + \sum_j \omega_j N_{jit} + \kappa \ln S_{it} \\
& + \frac{1}{2}\eta_{YY}[\ln(Y_{it})]^2 + \frac{1}{2}\sum_j\sum_k \phi_{jk}\ln(W_{jit})\ln(W_{kit}) + \frac{1}{2}\sum_j\sum_k \mu_{jk}\ln(Z_{jit})\ln(Z_{kit}) \\
& + \frac{1}{2}\sum_j\sum_k \varphi_{jk} N_{jit} N_{kit} + \frac{1}{2}\lambda_{SS}[\ln S_{it}]^2 + \sum_k \theta_{Yk}\ln(Y_{it})\ln(W_{kit}) \\
& + \sum_j\sum_k \rho_k \ln(Y_{it})\ln(Z_{kit}) + \sum_j\sum_k \sigma_{jk}\ln(Y_{it})N_{kit} + \varsigma_{YS}\ln(Y_{it})\ln S_{it} \\
& + \sum_j\sum_k \tau_{jk}\ln(W_{jit})\ln(Z_{kit}) + \sum_j\sum_k \upsilon_{jk}\ln(W_{jit})N_{kit} + \sum_j \xi_{jS}\ln(W_{jit})\ln S_{it} \\
& + \sum_j\sum_k \psi_{jk}\ln(Z_{jit})N_{kit} + \sum_j \zeta_{jS}\ln(Z_{jit})\ln S_{it} + \sum_j d_{jS} N_{jit}\ln S_{it} + \varepsilon_{it}
\end{aligned}
$$

Where: $OCOST_{it}$: airline operating expense; Y_{it} : quantity of output;

$\vec{W}_{it}$: input price; S_{it} : capital service; $\vec{Z}_{it}$: operating characteristics;

$\vec{N}_{it}$: performance measures;

Operational Performance Metrics

- Average positive delay against schedule
  - Widely accepted measure
  - Other moments (e.g. average squared positive delay) considered, but first moment worked best
- Average schedule buffer
  - Less commonly measured
  - Difference between scheduled block time and "unimpeded" block time
  - "Unimpeded time" operationized as 5th, 10th, 20th percentile of actual block time for segment
  - Averaged across all flights

Data

- Firm level financial and operational information for DOT Form 41
- Operational data from BTS
- Panel data
  - Time span: 1995.1-2007.4
  - Cross section: 9 major US air carriers

    (American, Alaska, Continental, Delta, American West, Northwestern, United, US Airways, Southwest)

Model estimation

- Joint estimation with:
  - Input cost share functions: following Shephard's Lemma
  - Capital service function: short-run cost minimization that w.r.t. capital service
- Additional constraints: cost functions must be homogeneous of degree one
- Seemingly unrelated regression (SUR): takes into account contemporaneous correlations among the error terms

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Estimation Results (1st Order Terms)

	Model 1		Model 2		Model 3	
	Est.	Std. Err.	Est.	Std. Err.	Est.	Std. Err.
Output (RTM)	0.4875	0.0369	0.4831	0.0362	0.4783	0.0356
Fuel price	0.2016	0.0016	0.2014	0.0016	0.2010	0.0016
Labor price	0.3858	0.0022	0.3856	0.0022	0.3853	0.0022
Materials price	0.4126	0.0032	0.4130	0.0032	0.4136	0.0032
Capital service	-0.0547	0.0009	-0.0546	0.0009	-0.0544	0.0009
Stage length	-0.2172	0.0837	-0.2071	0.0838	-0.1913	0.0835
Points served	0.6650	0.0573	0.6685	0.0571	0.6720	0.0569
Avg. arr. delay	**0.0060**	0.0014	**0.0059**	0.0014	**0.0057**	0.0015
Avg. buffer5	**0.0070**	0.0027				
Avg. buffer10			**0.0066**	0.0029		
Avg. buffer20					**0.0057**	0.0031
R^2	0.9902		0.9901		0.9900	

- The relative magnitude of buffer wrt delay is sensitive to its definition
- Model 1 is preferred: higher R^2 and significance of buffer coefficient, used in subsequent cost estimation

Systemwide Cost of Delay

- Evaluation year: 2007
- Improved scenario:
  - Delay reduced to zero
  - Buffer reduced to the min level since 2002 (more realistic considering high opportunity cost when delays appear)
- System-wide extrapolation is performed based on the proportion of available seat miles (ASM)

	Delay Against Schedule	*Buffer*	*Total*
7 major airlines	5.7	6.1	11.8
Industry wide	8.1	8.6	16.7

Comparison with previous studies

Sources	Evaluation year	System-wide cost ($ billion)	Note
Our model	2007	16.7	Total cost approach
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Task 2, TDI Project: Quantify Passenger Delays

MIT: Cynthia Barnhart, Douglas Fearing, Amedeo Odoni, Nitish Umang, Vikrant Vaze

GMU: Lance Sherry

Objectives

1. Obtain as accurate an estimate as possible of passenger delays – and their breakdown by cause – in 2007.
2. Use this exercise to improve and “automate” the process of passenger delay computation.

Causes of Passenger Delays
(Relative to Scheduled Arrival at Destination)

1. Late arrival of flight on which passenger was originally booked
2. Late arrival of flight originally booked due to diversion of flight to another airport, prior to reaching destination
3. Late arrival due to cancellation of originally booked flight and re-booking on later flight
4. Passenger arrives late, when the passenger is denied boarding on the ticketed flight due to over-booking and is re-booked on a later flight
5. Passenger misses connection at a transfer airport (plus possible unavailability of seats on one or more subsequent flights)

Passenger Delays in 2007

- Problem: Whereas flight delays are recorded and are publicly available, passenger delays are not. How does one estimate these delays using only publicly available databases?
- GMU's (Passenger Trip Delay Algorithm) and MIT's (Passenger Delay Calculator) have been developed for this purpose
- Until this study, the above approaches were missing a method for computing delays due to missed connections

Delays Due to Missed Connections

- An important new tool: Algorithm for estimating passenger delays due to missed connections using only publicly available data
  1. Estimate load factors and aircraft size for all scheduled flights on a day-of-week and time-of-day basis
  2. Develop itineraries for passengers that fly with connections at transfer airports
  3. Use 1 and 2, plus flight delay data to compute passenger delays due to missed connections

Data Sources for Algorithms

- T-100 Domestic Segments Data (U.S. Carriers) – domestic segment data aggregated by month
- DB1B Coupons Data – a 10% sample of domestic itinerary data aggregated by quarter
- Flight On-Time Performance Data (ASQP) – daily on-time arrival data for domestic flights operated by major U.S. carriers
- Innovata Flight Offerings Data – expected flight offerings for 2007
- FAA Aircraft Registry – seating capacities by carrier and aircraft type

Also:

- Continental Proprietary Passenger Bookings Data – proprietary bookings data for Q4 2007 (used for the purpose of validating the proposed approach)

Passenger Delays: 2007 Estimates

- Total passenger delay in 2007:
  - 270 million passenger hours or
  - 135,000 person-years (2000 hours per year)
- Approximate distribution of delays by cause:
  - 50% delayed flights [includes only delays >15 minutes]
  - 35% cancellations
  - 15% missed connections
- Note: Cancellations and connections double the amount of annual passenger delay

Passenger Delay Cost*: 2007

	Cost (million $)
Delayed flight	**5,008**
Denied boarding (overbooking)	**8**
Flight cancellation	**3,722**
Diverted flight	**64**
Missed connection	**1,478**
Total	**10,280**

$37.60 per passenger hour [DOT (2003), inflated to 2007 $]

Conclusions

- We have estimated cost of delay to airlines by modeling relationship between airline total cost and operational performance metrics
- We have estimated cost of delay to passengers through careful analysis of how flight delays and cancellations beget passengers delays and disruptions
- Our estimated costs to airlines and passengers are each on the order of $\$10^{10}$ for 2007
- We have identified two important cost drivers that are not widely recognized
  - Schedule padding
  - Disruption of other itineraries
- Our study also considers other mechanisms by which delay generates cost, including lost demand and induced overnight stays

Thank you!