

Estimating Costs of Flight Delay for Air Cargo Operations

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Outline

- Introduction
- Impact of Flight Delay to Late Deliveries
- Cost of Late Deliveries
- Estimating the Cost of Flight Delay
- Conclusions

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- **Introduction**
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Background

- Why Concern About Cargo Carriers?
 - FAA is seeking to understand how flight delay impacts on cargo carriers' late deliveries, and estimate the specific costs of flight delay result from late deliveries (value of freight time);
 - Many researches are concerning about operating costs or delay costs for passenger flights, but very few literatures focus on estimating the cost of flight delay for air cargo operations;
 - Many cargo carriers claim that they should have more priorities when FAA launches traffic management initiatives, because they are vulnerable to flight delays, and suffer from a much higher delay cost. Should they?

Carriers On-time Delivery Performance

- On-time delivery performance for three major carriers in US
 - Sent 14,400 overnight packages from 24 origins to 20 destinations by three carriers in 10 consecutive days in July, 2006;
 - Does not reveal the impact of flight delay.



Midwest	92.83% (1)	92.83% (1)	88.58% (3)
Northeast	94.08% (1)	92.08% (2)	89.25% (3)
South	89.41% (1)	85.41% (2)	84.41% (2)
West	93.00% (1)	91.35% (1)	84.83% (3)

Key	DHL	FedEx	UPS
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Source: PA consulting group, U.S. Domestic 10:30 am Delivery Performance Study, Benchmark of Express Carriers in the U.S. September 2006.

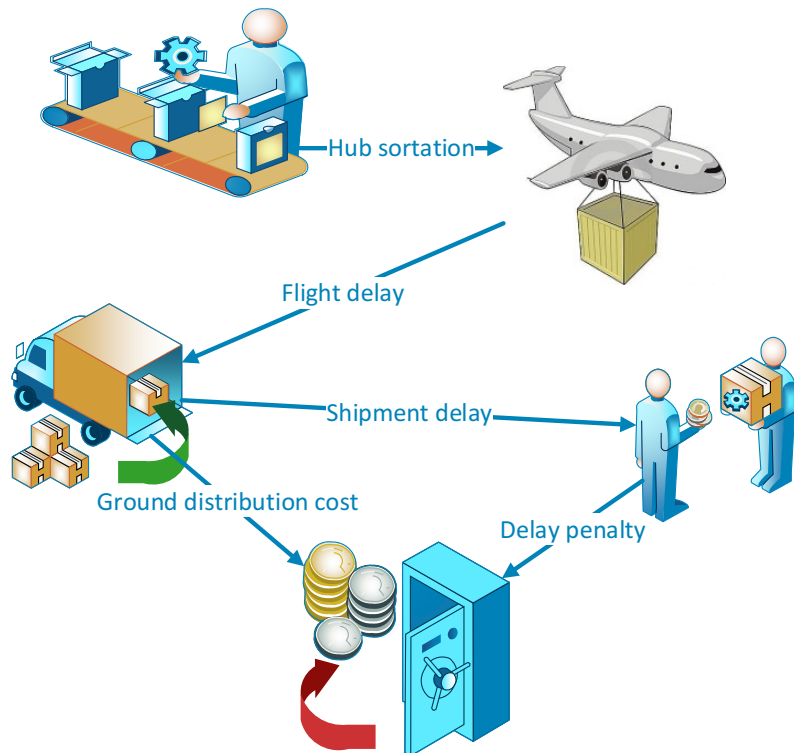
Costs for Air Cargo Operations

- Flight Operating Costs (Estimated by GRA Inc.)
 - \$5,922/ block hour (Large Carriers, in 2002 USD)
 - \$3,938/ block hour (Regional Carriers, in 2002 USD)
- Ground Distribution Costs
 - Fixed costs (fleets, sortation)
 - Operating costs (gasoline, crew, maintenance...)
- Costs of Late Deliveries
 - Caused both by flight delay and ground distribution
 - No reference estimations

Costs of Late Deliveries

- Hard Cost

- Refund
- Real money to carriers



- Soft Cost

- Loss of brand loyalty or good will
- Degraded value of services



Project Goals

- Understand how flight delay influences air cargo carriers' on-time delivery;
- Quantify the contributions of flight delay to package late deliveries;
- Estimate the costs of flight delay that result from late deliveries for air cargo operations;
- Focus on FedEx.

FedEx Delivery Services

- Service Types
 - FedEx offers various types of services ranging from one-day (FedEx SameDay) to one-week delivery (FedEx Ground)

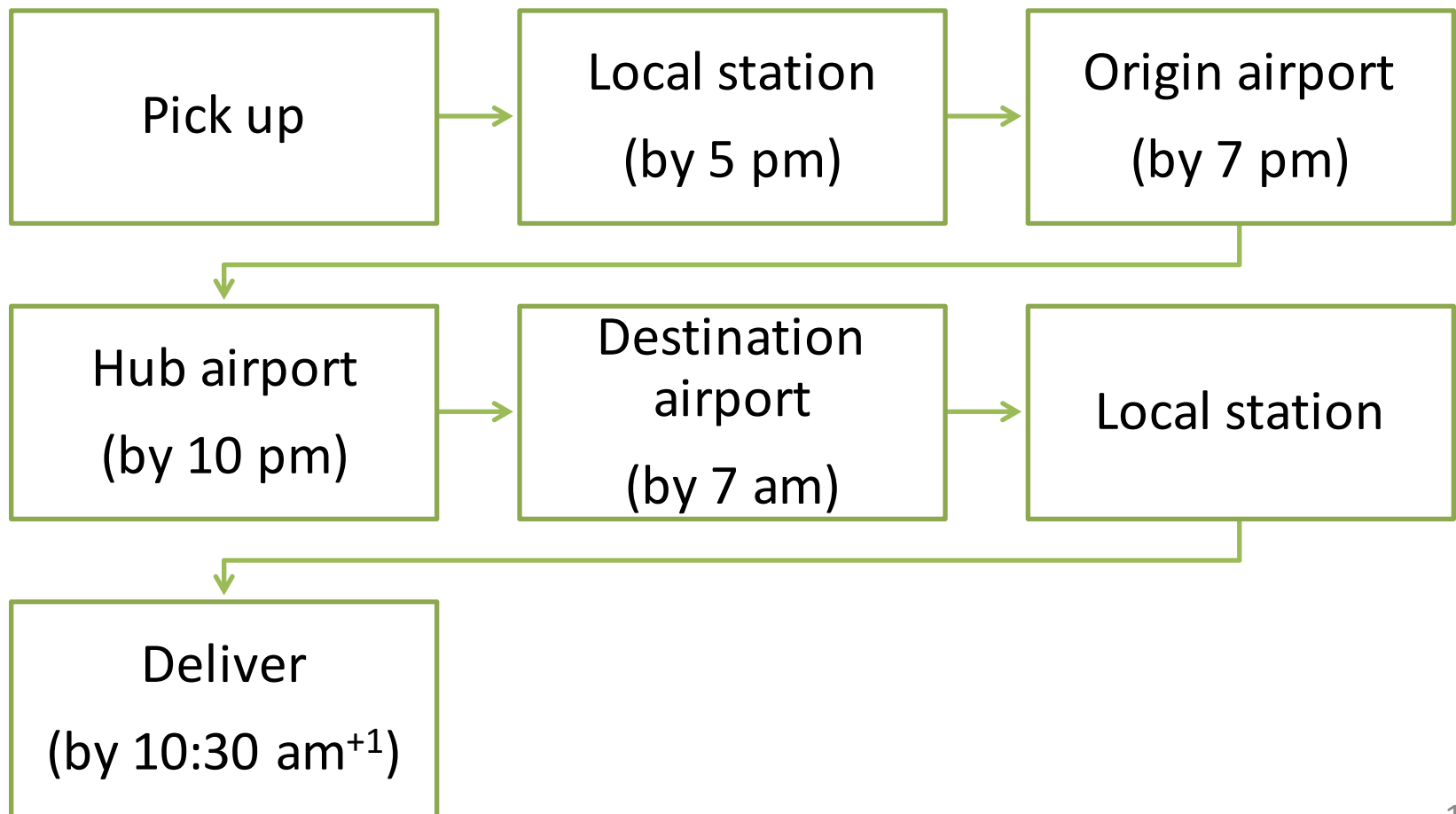
Delivery commitment		FedEx service
Same Day	Delivery time based on flight availability	FedEx SameDay
	<i>Delivery by 8:00 am</i>	<i>FedEx First Overnight</i>
<i>Overnight</i>	<i>Delivery by 10:30 am</i>	<i>FedEx Priority Overnight</i>
	<i>Delivery by 3:00 pm</i>	<i>FedEx Standard Overnight</i>
2 Business Days	Delivery by 4:30 pm	FedEx 2Day
3 Business Days	Delivery by 4:30 pm	FedEx Express Saver
1–5 Business Days	Delivery day based on distance to destination	FedEx Ground
	Delivery day based on distance to destination	FedEx Home Delivery

FedEx Delivery Services

- FedEx Priority Overnight (PO) Service
 - Packages are typically guaranteed to be delivered by next day 10:30 am to most areas, and by noon, 1:30 pm or 4:30 pm on Saturdays;
 - Packages are transported by air cargo flights;
 - PO service is vulnerable to flight delays, due to the small delivery time window.

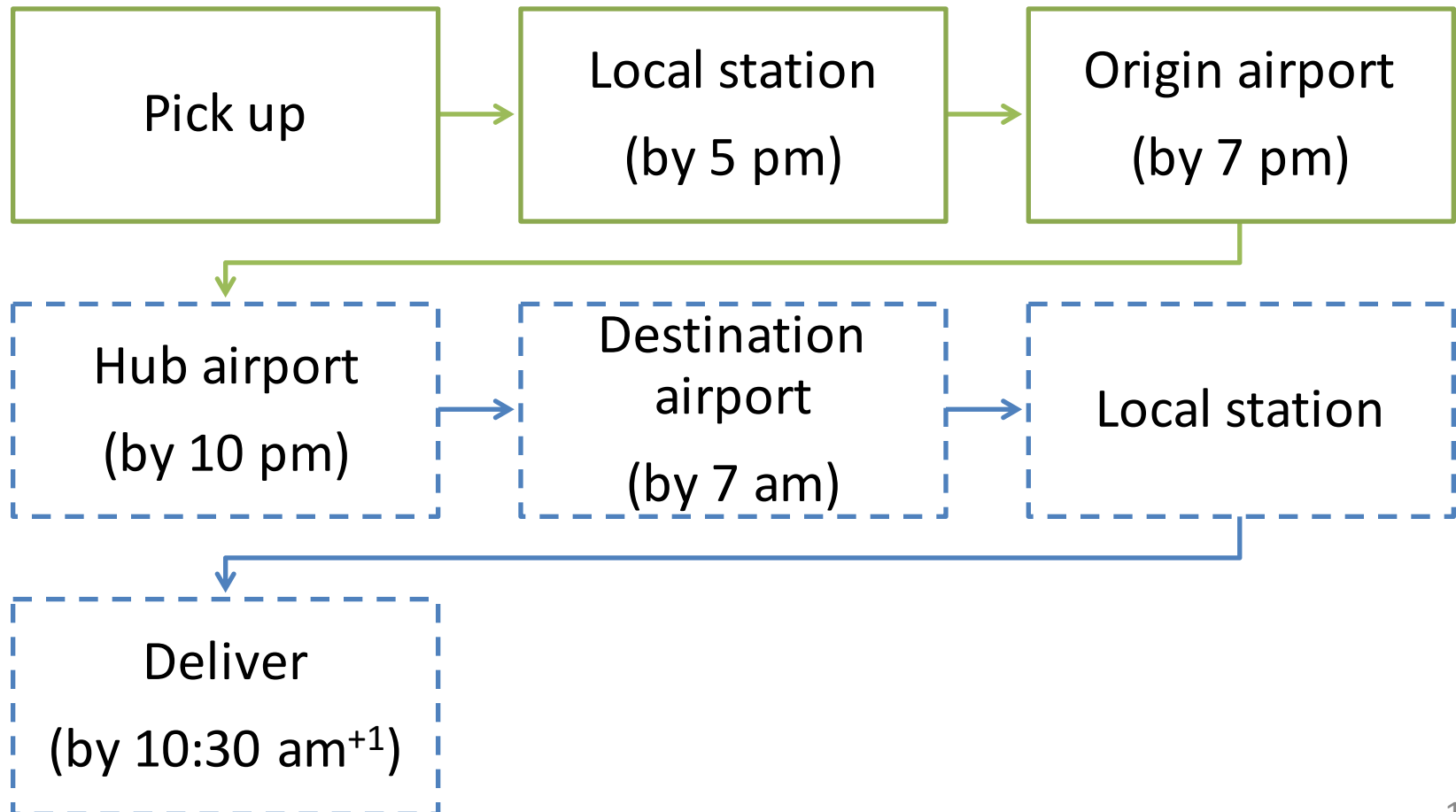
Package Delivery Procedure

- Delivery practice



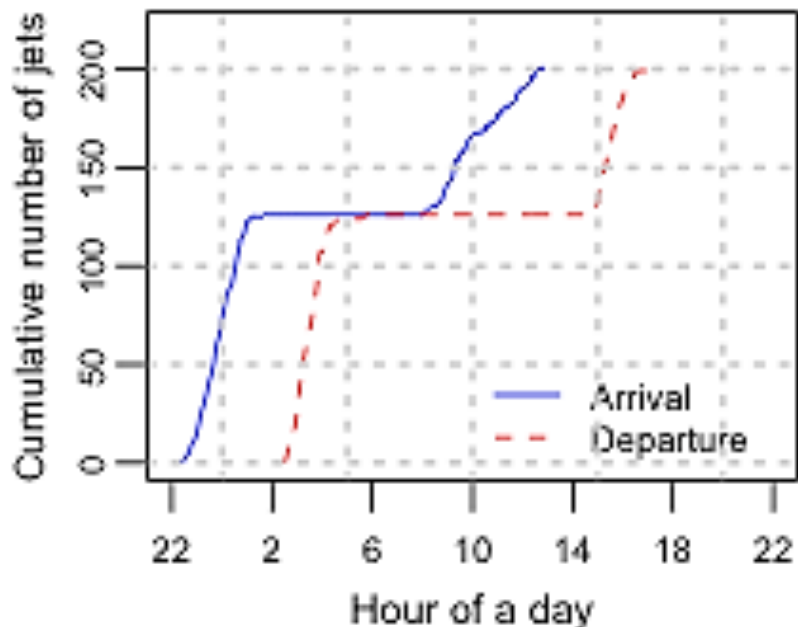
Package Delivery Procedure

- Delivery practice



Package Delivery Procedure

FedEx flights into/out of MEM on Jun 13th, 2012



- Hub Operations

- Inbound flights usually arrive at hub airport by 10 pm, and outbound flights usually depart at 2 am.
- Within a four-hour period, packages will be sorted and transferred to outbound flights at an amazing speed;
- Computerized sortation speed goes up to 500,000 packages/hour for UPS, and 160,000 packages/hour for FedEx

Overview of Research Methods

- Apply mixed logit regression technique to FedEx on-time delivery data;
- Predict contributions of flight delay to late deliveries;
- Apply hedonic regression to several cargo carriers' service rates data;
- Estimate the Costs of late deliveries based on mixed logit model and hedonic model.

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Logit Regression

- Odds Ratio (OR)
 - Ratio of probability that an event happens (late delivery) to probability that an event not happens (on-time delivery)
- Binary Logit Model
 - $\ln(OR_i) = V_i + \varepsilon_i$; $\varepsilon_i \sim i.i.d. \text{ Gumbel distribution}$;
 - $P_i = 1/(1 + \ln(OR_i)) = 1/(1 + e^{-V_i})$;
 - Closed form, easy to estimate;
 - Unable to capture heterogeneities across observations.
- Mixed Logit Model
 - $\ln(OR_i) = V_i(\beta) + \xi_i + \varepsilon_i$; $\beta, \xi \sim \text{could follow any distributions}$;
 - $\varepsilon_i \sim i.i.d. \text{ Gumbel distribution}$;
 - $P_i = \int L_i(\beta) \cdot f(\beta) d\beta$; $L_i(\beta) = 1/(1 + e^{-V_i(\beta)})$;
 - No closed form. Need simulation to estimate;
 - Can capture heterogeneities across observations.

Model Specification

- Model Selected
 - Mixed logit model
 - Better captures regional and airport heterogeneities.
- Dependent Variable y
 - Package late delivery.
 - 1 if package is delayed, 0 otherwise.
- Independent Variables x
 - Flight on-time performance attributes
 - Delivery attributes
 - Regional effects

Model Specification

- Explanatory Variables

- Flight on-time performance

- AvgDelay: Average hour of flights delay at destination airport; (+)
 - AvgSchArr: Average scheduled arrival time (numerated as hours after midnight) of overnight flights. (+)

- Delivery attributes

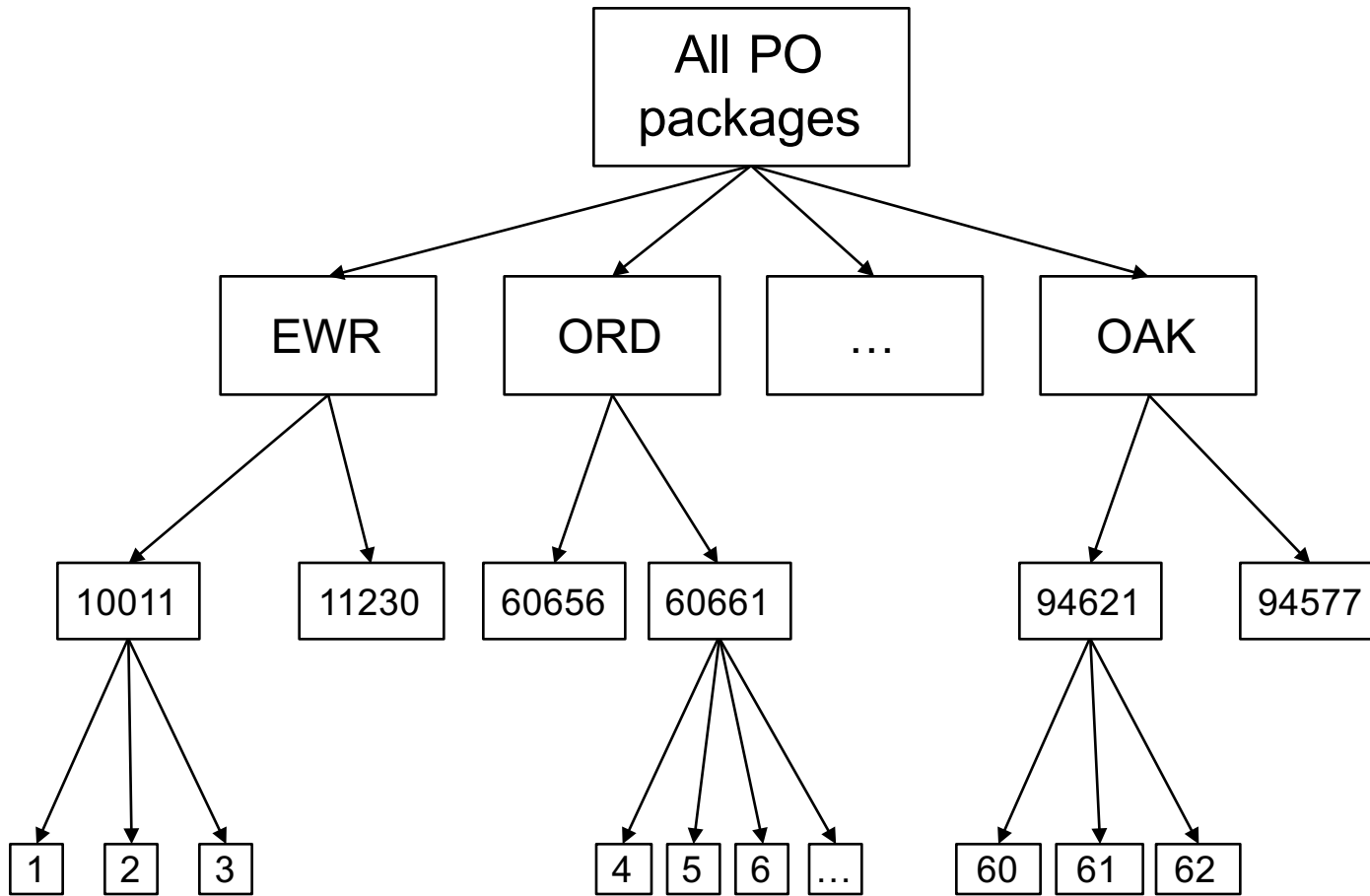
- Shipping cost: Shipping cost of each package; (-)
 - Distance: Great circle distance from destination airport to destination zip code centroid. (+)

- Regional congestion effects

- MSA: population density of the airport associated MSA; (+)
 - County: population density of the airport associated county; (+)

Model Structure

- Three-layer nested structure



Level 3:
Airport k

Level 2:
Zip Code n

Level 1:
Package i

Formulation

- Mixed Logit Model

- $V_{i,n,k} = \sum_j (\beta_j + \zeta_{kj}) \cdot x_{ij} + \sum_{j'} \beta_{j'} \cdot x_{ij'} + (\beta_0 + \eta_k + \xi_n)$

- $P_{i,n,k} = Pr(Y_{i,n,k} = 1) = \int \left[\frac{1}{1 + e^{-V_{i,n,k}}} \right] \cdot f(\zeta_{kj}, \xi_n, \eta_k) d\zeta_{kj} d\xi_n d\eta_k$

- $P_{i,n,k}$ is the probability of late delivery for package i , which is delivered to zip code n covered by airport k .

- x_{ij} are independent variables (e.g., flight delay), and β_j are the associated coefficients;

- ζ_{kj} is the random part of parameter β_j within group k (aka., airport);

- ξ_n is the random part in intercept β_0 within group n (aka., zip code);

- Both random coefficients are assumed to be Gaussian distributed with zero mean and variance σ^2 to be estimated

Data

- Freight Auditing Company
 - FedEx package delivery data, including service type, guaranteed and actual delivery time, origin and destination zip codes and etc.;
 - Only tracks packages that customers have signed up for;
 - Records are from February 18th, 2014 to May 21st, 2014.
- FAA ASPM
 - Flights scheduling data;
 - Flights actual arrival/ departure time data.
- BTS
 - Aggregated monthly freight data.

Data Preprocessing

- Data Extracting

- Only keep non-weekend 10:30 am guaranteed *Priority Service* records;
- Exclude packages having more than one day lateness or delivered to Alaska and Hawaii.
- We treat records having exactly the same destination zip code and actual delivery time as a single delivery with shipping costs combined.

- Data Fusion

- Integrate delivery data with flight data;
- We assume packages will be flown firstly to MEM and then to the FedEx-served airport closest to the centroid of the destination zip code.

- Final Dataset

- 12190 records from 03/17/2014 – 05/21/2014, scattered around 98 airports;
- 1890 (15.5%) packages were late. (Higher than 11.98%)

Summary Statistics

Variable	Mean	Std.	Min	Max
Package late delivery (binary)	0.155	0.362	0	1
Distance (miles) †	20.88	22.68	0.30	226.8
Shipping cost (USD)	36.2	86.8	5.0	2842.0
Multiple flight (dummy)	0.573	0.495	0	1
<i>Average flight actual arrival time</i>	<i>5:44 am</i>	<i>40.6 min</i>	<i>3:56 am</i>	<i>7:57 am</i>
<i>Average flight scheduled arrival time</i>	<i>5:30 am</i>	<i>39.5 min</i>	<i>4:03 am</i>	<i>6:59 am</i>
<i>Average flight delay (in min)</i>	<i>14</i>	<i>15.8</i>	<i>-19.6</i>	<i>133.7</i>

†: Distance is the great circle distance from destination airport to the centroid of zip code

Estimation Results

Variable name	Estimates	Standard Error
AvgDelay	0.812***	0.174
AvgSchArr	0.191*	0.089
Distance	0.336***	0.109
Shipping Cost	-0.105*	0.054
County Population density	0.055*	0.035
MSA Population density	0.259***	0.073
Distance Squared	-0.056**	0.023
AvgDelay × Distance	0.416***	0.134
Constant	-3.999***	0.503
<i>Random effect: σ (Level 2, grouped by airports. 98 groups in total)</i>		
AvgDelay	0.517 †	
AvgSchArr	0.311 †	
Constant	1.529 †	
<i>Random effect: σ (Level 3, grouped by zip codes. 3465 sub-grouped in total)</i>		
Constant	0.821 †	
<i>Observations</i>	<i>12190</i>	

Note: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

†: Log likelihood Ratio Test shows the significance of such random effects

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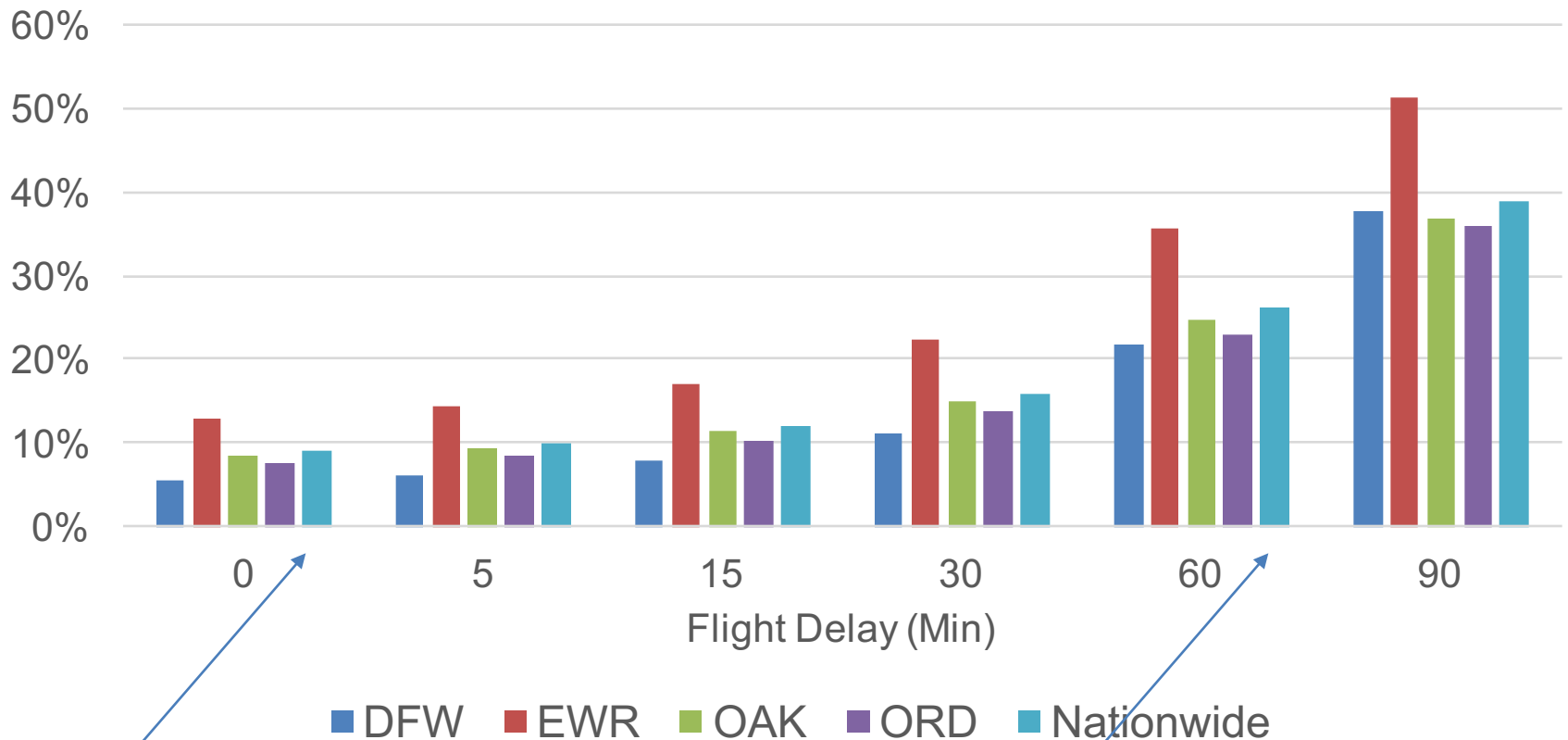
Offset by
 $\text{Ln}(15.5/11.98)$

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Contributions of Flight Delay to Late Deliveries

Package Late Probability



9% of late delivery probability even under zero flight delay

26% of late delivery probability under 60-min flight delay. Ground distribution absorbs much of the flight delay

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Hedonic Regression Model

- Estimate the contributory value of characteristics that constitute a product;
- Assumes that the price of a product reflects its constituent characteristics;
- $P_{product} = P_{attribute1} + P_{attribute2} + \dots$

Cargo Carrier Pricing Strategy

- Shipping cost of a package is mainly determined by OD distance, service type, carriers brand and value-added features;
- On-time guarantee service is a value-added feature, and usually comes “bundled” with certain services;
- While FedEx offers the on-time guarantee service on all its express services, USPS offers some services with such guarantee feature and some without;
- *Value of Guarantee* (VOG) can then be estimated by comparing the service prices of the two carriers.

Carriers Service Attributes

Carrier	Service Type	Delivery Commitment	Priority Service	One-day Service	Guarantee service
FedEx	Priority Overnight	Next day 10:30 am	Yes	Yes	Yes
FedEx	Standard Overnight	Next day 3:00 pm	Yes	Yes	Yes
FedEx	FedEx 2Day	2 business days	No	No	Yes
USPS	Priority Mail Express	Next day 3:00 pm	Yes	Yes	Yes
USPS	Priority Mail	2 business days	No	No	No

Data

- We construct a dataset to estimate the effects of delivery service attributes on service price;
- A 500-package random sample from the pool of 12190 delivery records
 - Only keep OD zip codes and great circle distance;
 - Randomly assign each record to one of the five service types
 - Calculate the shipping cost based on 2014 FedEx and USPS Service Guide.

Model Specification

- We treat each package delivery as a product, and is constituted of delivering distance, carrier brand, priority feature, one-day feature and on-time guarantee feature;
- $\ln(\text{Price}) = \beta_1 \cdot \ln(\text{Distance}) + \beta_2 \cdot \text{Carrier} + \beta_3 \cdot \text{Priority} + \beta_4 \cdot \text{OneDay} + \beta_4 \cdot \text{Guarantee}$

Estimation Results

Log(price)	Est./ Std.
Log(distance)	0.09855*** (0.0036)
FedEx	0.32365*** (0.0209)
Priority	0.09800*** (0.0209)
One-day delivery	0.78745** (0.0209)
Guarantee	0.71608*** (0.0295)
Constant	1.24579*** (0.0252)
<i>Adjusted R²</i>	0.9602
<i>Observation</i>	500

- Effects of guarantee is highly significant;
- A shipment with a guarantee almost doubles the price than that without. (+71.6%)

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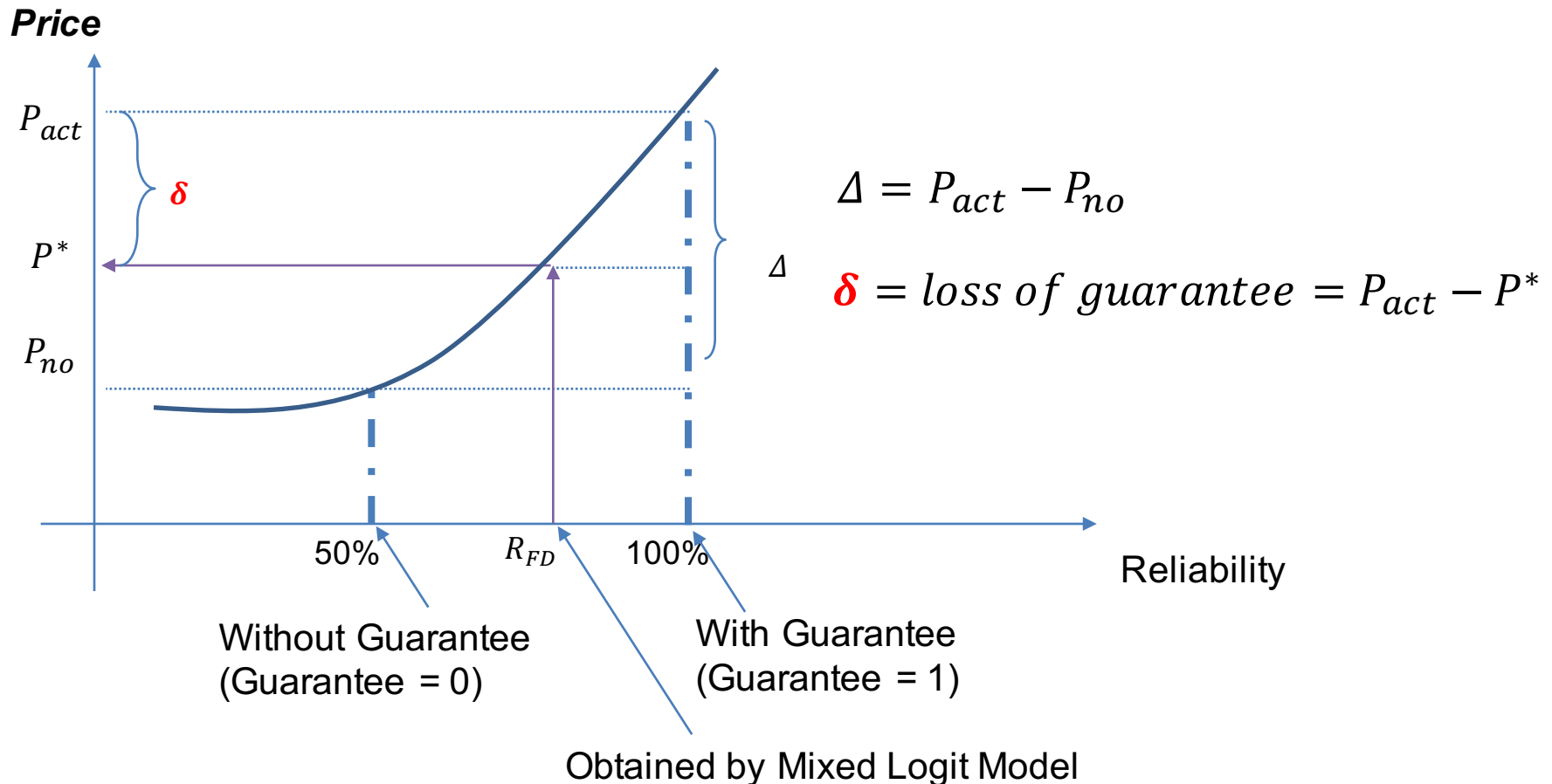
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Linkage Between Logit and Hedonic Regression Model

- Delivery Reliability
 - The probability of on-time delivery.
- Guarantee Service
 - We assume that service with a guarantee will provide 100% of on-time delivery reliability, and 50% without.
- Linkage
 - Mixed Logit Model: Given a flight delay, we can estimate the delivery reliability for each package;
 - Difference between estimated delivery reliability and guaranteed reliability degrades the service, and generates costs to carriers and customers;
 - Hedonic Model: Estimate the degraded value of service (a.k.a., loss of guarantee).

Loss of Guarantee

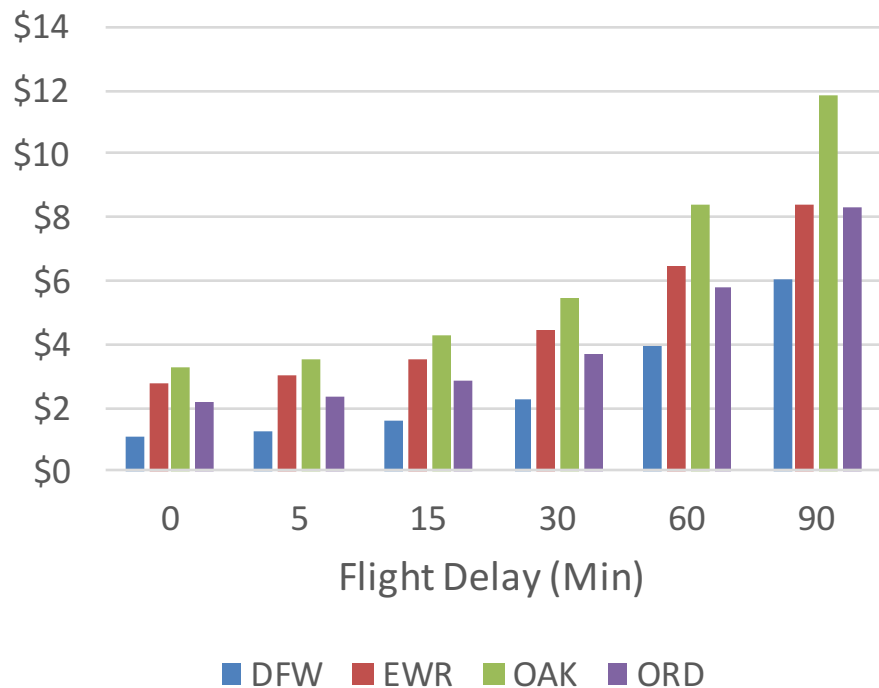
- Degraded value of guarantee service
 - Difference in Actual Price and Intrinsic Value of a shipment



Cost of Flight Delay per Package

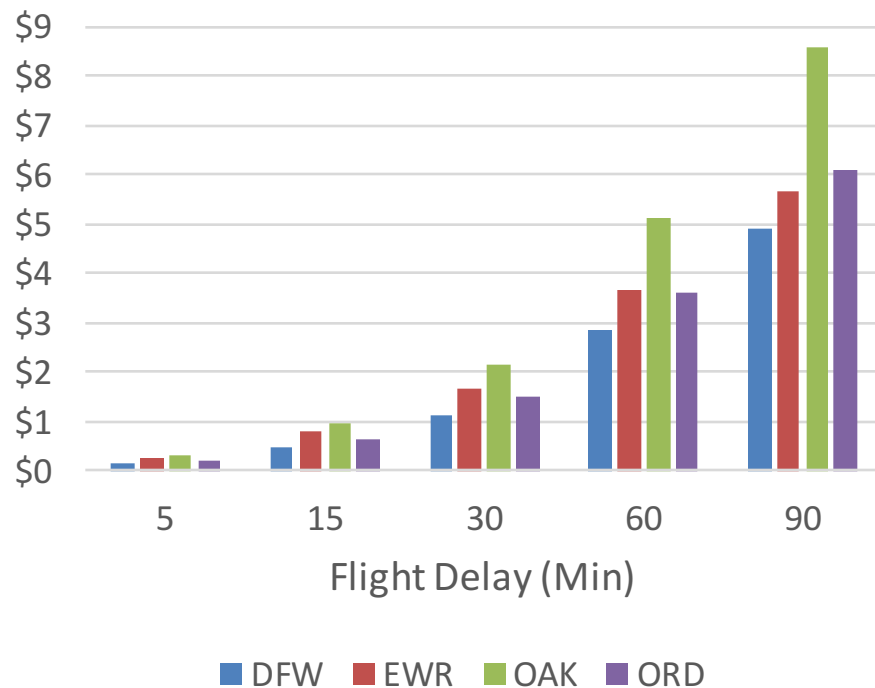
All factors considered

Cost of Delay per Package



Specifically attributable to flight delay

Cost of Delay per Package



Cost of Flight Delay per Aircraft

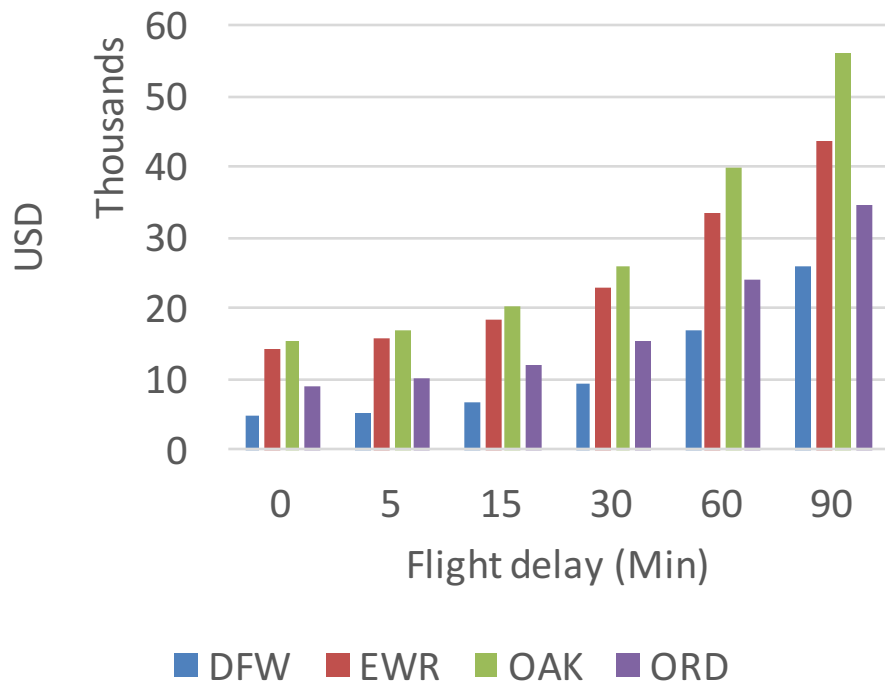
- BTS provides the aggregated monthly FedEx freight data;
- Average weight of domestic package by FedEx is 10.6 lbs.

Airport	Metrics	Month			PO Packages per aircraft
		Mar	Apr	May	
DFW	Number of Packages	163612	181389	168509	4279
	Overnight Cargo Flights	38	42	40	
EWR	Number of Packages	197522	218921	201364	5148
	Overnight Cargo Flights	37	42	40	
OAK	Number of Packages	208740	215480	216653	4747
	Overnight Cargo Flights	43	46	46	
ORD	Number of Packages	168715	182411	178310	4202
	Overnight Cargo Flights	46	42	39	

Cost of Flight Delay per Aircraft

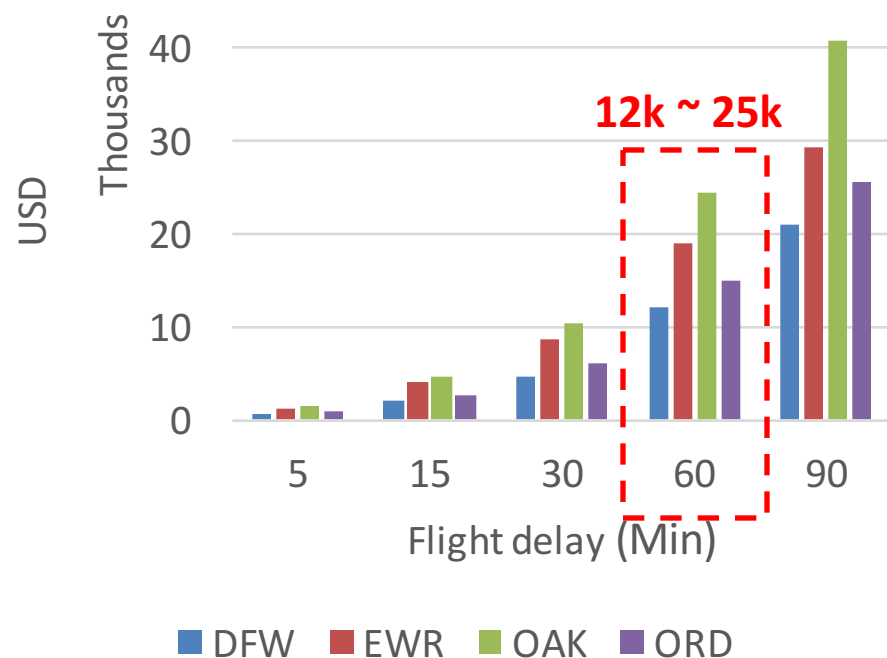
All factors considered

Costs of flight delay per aircraft



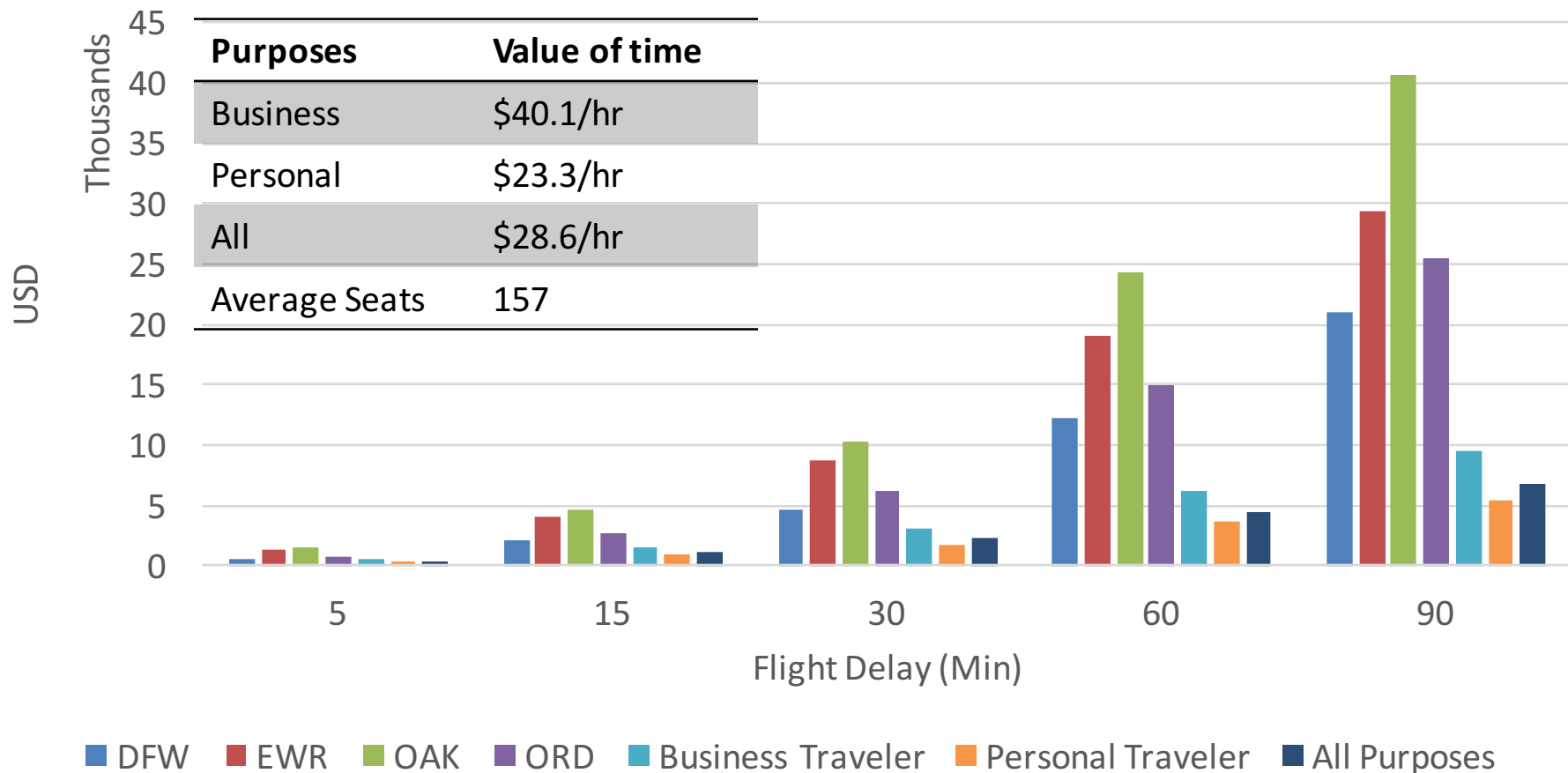
Specifically attributable to flight delay

Costs of flight delay per aircraft



Cost of Flight Delay for Cargo vs. Passengers

Costs of flight delay per aircraft



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Conclusions

- Flight delay has a significant impact on package late delivery. On average, the late delivery probability under a 15-minute delay increased by 30% comparing to that without flight delay;
- There are significant heterogeneities across airports and zip codes. Packages delivered to airports such as ATL and MIA are more sensitive to flight delay;
- Ground distribution also makes a significant difference. Longer distance away from destination airport increases the probability of late delivery;

Conclusions

- The value-added guarantee service increases the shipping price by 72%;
- On average, the cost of flight delay per package is \$0.77 for a 15-minute flight delay, and \$3.92 for a 60-minute flight delay;
- The cost of flight delay per package differs across airports. For example, the cost of delay to packages delivered to OAK almost doubles those to DFW (\$5.1/hr vs. \$2.8/hr)
- The costs of flight delay per aircraft that result from late deliveries ranges from \$12 to \$25 thousand per hour, which is a lot higher than passenger delay cost, or operating costs per block hour.

Acknowledgment

- We thank Joseph Post, the Director of Systems Analysis & Modeling at FAA, for his great support to our work;
- We also thank the officials of FedEx at Oakland station for their help and judgement to our work.

Thank you!

Q&A