COMPARISON OF FLIGHT DELAYS AND PASSENGER TRIP DELAYS IN THE NATIONAL AIRSPACE SYSTEM (NAS)

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Abstract:

The primary objective of the National Airspace System (NAS) is the transportation of passengers and cargo. It is no surprise, therefore, that passenger trip time performance is positively correlated with passenger satisfaction, airfare elasticity, and airline profits. Regulatory consumer information available to airline passengers provides measures of trip performance using only flight data (and not passenger trip data). Previously, researchers, using a small set of proprietary airline data, demonstrated that trip delays experienced by passengers due to missed connections, cancelled flights, and delayed flights are not negligible. Further they showed that flight delay data cannot be used as a proxy for passenger trip delays.

This paper describes a comparative statistical analysis between flight delay data and passenger trip delay data for one year's worth of flights on the 1030 single segment routes between the OEP-35 airports. The passenger trip data is derived from publicly available data-bases and accounts for delays experienced by passengers on single segment routes due to cancelled flights as well as delayed flights. The statistical analysis indicates that: (i) the percentage of on-time flights is statistically equivalent to the percentage of on-time passengers, (ii) the average passenger trip delay is 34 minutes in excess of the average flight delay, and (iii) average passenger trip delay for the worst 5% of delayed passengers is 150 minutes in excess of the flight delay. The implications of these results for consumers and consumer protection are discussed.

1   INTRODUCTION

Passenger trip time is an important property of the air transportation system. Passenger trip time informs passenger choices of flights, airlines, and airports, and has been positively correlated with customer satisfaction and brand loyalty that drives airline profits [1, 2]. Conversely, poor service reliability on specific routes has been shown to lead to reduced airfares on these routes [3].

Contrary to popular opinion, the airlines are under no legal obligation to operate a scheduled flight on a given day and are not required to compensate passengers for "damages" when flights are delayed or canceled [7]. Passengers must apply *caveat emptor* in selecting airlines and airport-pairs while purchasing tickets.

The most complete consumer information is made available by the Department of Transportation (DOT) Office of Aviation Enforcement and Proceedings (OAEP) in a monthly report -. *Air Travel Consumer Report (ATCR).* This report is "designed to assist consumers with information on the quality of services provided by the airlines." In addition to data on mishandled bags, overbooking, and passenger complaints, the report includes measures of the percentage on-time performance (OTP) of arrivals of flights within 15 minutes of the schedule arrival time. This metric is known as the 15-OTP. The report also provides the percentage of cancelled flights. Similar consumer information can be found in the monthly Airline Quality Rating (AQR) Report [8] and in traveler survey data such as the J.D. Power Airport Satisfaction Report [12].

Researchers have shown that these types of "flight-based" metrics are poor proxies for the passenger trip experience [4, 5, 9, 10, 11]. First, these metrics fail to account for the trip delays experienced by passengers when they are re-booked on a later flight due to cancelled flight or missed connection. For example, Wang [5] estimated that 40% of the total trip delays accrued by passengers on single segment flights between OEP-35 airports in 2005 were the result of delays due to cancelled flights. The remaining 60% of total trip delays are attributed to flight delays.

Second, these metrics fail to describe the magnitude of delay experienced by the passenger when a flight is not on-time. Bratu & Barnhart [4] used proprietary airline data to study passenger trip times from the hub operations of a major U.S. airline. This study showed that that flight-based metrics are poor surrogates for passenger delays for hub-and-spoke airlines as they do not capture the effect of missed connections and flight cancellations. For example, for a 10 day period in August 2000, Bratu & Barnhart [4, page 14] cite that 85.7% of passengers that are not disrupted by missed connections and cancelled flights arrive within one hour of their scheduled arrival time and experience an average delay of 16 minutes. This is roughly equivalent to the average flight delay of 15.4 minutes for this period. In contrast, the 14.3% of the passengers that are disrupted by missed connections or cancelled flights experienced an average delay of 303 minutes.

This paper describes the results of analysis using one years worth of data for all flights on the 1030 routes between OEP-35 airports. A statistical comparison of: the distributions of on-time percentage and delay magnitude for flights and passenger trips are summarized as follows:

- Percentage of On-Time: the mean of the distribution of "on-time percentage" for passenger trips is statistically the same as the mean of the distribution of "on-time percentage" for flights (i.e. the 15-OTP metric) with P-value 0.1858.
- Average Magnitude of Delays: the mean of the distribution of the average passenger trip delays experienced by passengers on delayed or cancelled flights is statistically 34 minutes in excess of the mean of the distribution of average delays for flight delays (P-value 0.9985).
- Average Worst-case Magnitude of Delays: the mean of the distribution of the worst 5% (excess of 95th percentile) passenger trip delays experienced by passengers scheduled on heavily delayed or cancelled flights is statistically 150 minutes (2.5 hours) in excess of the mean of the worst 5% flight delays (P-value 0.9704).

These results confirm that flight performance data is a poor proxy for passenger trip performance. Further, these results indicate that the average and worst-case trip delays experienced by passengers are not negligible and should be reported, in addition to percentage on-time, as part of consumer protection charter.

Section 2 of the paper provides an over of the properties of the distributions for flight delays and passenger trip delays. Section 3 describes the method for computing the flight delay and passenger trip delay metrics. Section 4 describes the results of an analysis of comparison of the flight delay and passenger trip delay metrics for 2005. Section 5 discusses the implications of these results and describes the proposed 15-POTP metric.

2   STATISTICS OF FLIGHT AND PASSENGER TRIP DELAYS

The underlying behavior of flight delays and passenger trip delays are represented by the right-tailed distribution (Figure 1). For the purpose of this paper there are three pairs of parameters used to characterize the delays:

1. Percentage of flights (or passengers) that arrive within 15 minutes of scheduled arrival time
2. Average delay for flights (or passengers) that arrive within 15 minutes of scheduled arrival time
3. Percentage of flights (or passengers) that arrive after 15 minutes of scheduled arrival time, but less than the time associated with 95th percentile delays (see #5 below).
4. Average delay for flights (or passengers) that arrive after 15 minutes of scheduled arrival time, but less than the time associated with 95th percentile delays (see #5 below).
5. 5% of flights (or passengers) that arrive after the 95th percentile delays
6. Average delay for flights (or passengers) that arrive after the 95th percentile delays

Passenger trip delays include the delays experienced by passengers due to delayed flight, plus the delays accrued by waiting to be re-booked on a later flight when a flight is cancelled. As a consequence, the distribution for passenger trip delays exhibits a longer right-tail. The question that is being resolved by this paper is: "Is the magnitude of the right-tail for passenger trip delay statistically significant when compared to the right tail of flight delays."

3   METHOD FOR COMPUTING PASSENGER TRIP DELAYS

The data used in this study was derived from two publicly available data-bases:

1. Airline On-Time Performance (AOTP) Database [6] – This database provides departure delays and arrival delays for non-stop domestic flights by major air carriers. The data also includes additional information such as origin and destination airports, flight numbers, cancelled or diverted flights. Each record
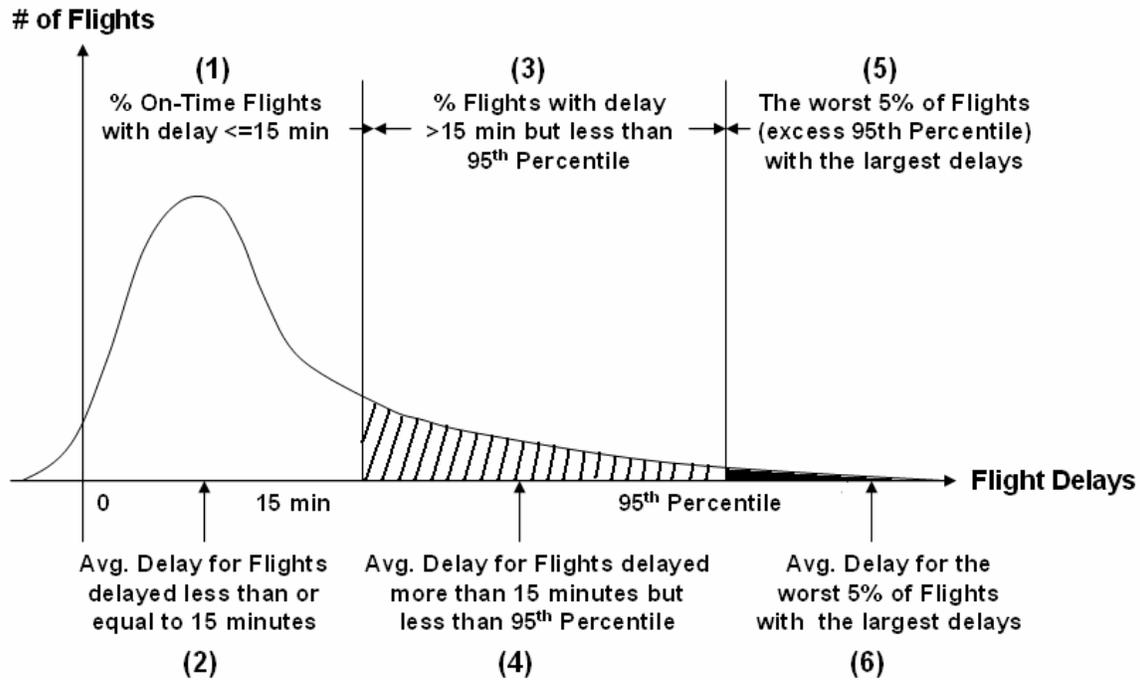
Right-tailed distribution of flight (or passenger) delays. Identifies 3 pairs of parameters used in this paper to characterize the distribution. Distribution for passenger trip delay has similar form with longer right-tail.
Figure 1:

in the data-base represents one flight.

2. Air Carrier Statistics (known as T-100) Database [6] – This database provides domestic non-stop segment data by aircraft type and service class for passengers, freight and mail transported. It also provides available capacity, scheduled departures, departures performed and aircraft hours. Each record in the data-base represents monthly aggregated data for a specific origin/destination segment.

One thousand and thirty routes were identified between OEP-35 airports. These routes each experienced in excess of 50 flights during the time period under investigation.

Calculating Flight Delays
Flight delay statistics for each route were generated from the Airline On-Time Performance (AOTP) Database:

- 15-OTP On-Time Flights Percentage
For each route, the number of on-time flights (with less than 15 minutes) is summed. This total is divided by the total number of scheduled flights on that route yielding the 15-OTP On-Time Percentage of Flights for the route.

- Average Magnitude of Flight Delays

For each route, the flight delays for delayed flights (with flight delay more than 15 minutes) are summed. This total is divided by the total number of delayed flights on that route yielding the Average Magnitude of Flight Delays for the route.

- Average Worst-Case Magnitude of Flight Delays

For each route, the top 5% flights with the largest flight delay are derived. Their flight delays are summed. This total is divided by the total number of these top 5% flights yielding the Average Magnitude of Flight Delays for the route.

Estimating Passenger Trip Delays

Passenger trip delays on each route were estimated using the algorithms to compute the Passenger Trip Delay for each passenger on single segments flights [5]. The algorithm includes trip delays that are a result of delays caused by re-booking passengers on later flights due to cancelled flights and/or delays incurred by flight delays.

Total Passenger Trip Delay (TPTD) is computed using two algorithms to process the data from the data-bases described above: (Algorithm 1) TPTD due to Delayed Flights, and (Algorithm 2) Estimated TPTD due to Cancelled Flights.

Algorithm 1: Total Passenger Trip Delay (TPTD) due to Delayed Flights

TPTD due to Delayed Flights is computed by processing the data for each flight in the AOTP database for a given route and specified period (e.g. 365 days) to compute the *delay time for the flight*. This time is them multiplied to the average number of passengers for this flight (from the T-100 data-base) to derive the *passenger delay time for the flight*. The *total passenger delay time for delayed flights* is computed by summing the *passenger delay time for the flight* for all the flight for the specified period.

Algorithm 2: Estimated Total Passenger Trip Delay (TPTD) due to Cancelled Flights

Estimated TPTD due to Cancelled Flights is computed based on the assumption that a passenger displaced by a cancellation will be rebooked on a subsequent flight operated by the same carrier with the same origin/destination pair. The passenger will experience a trip time that now includes both the flight delay of the re-booked flight plus the additional time the passengers must wait for the re-booked flight. The ability to re-book passengers on subsequent flights is determined by the load-factor and aircraft size of the subsequent flights. In general, passengers from a cancelled flight will be relocated to 2 or 3 different flights due to limited empty seats on each available flight.

The process is as follows. The algorithm processes data for each flight in the AOTP database for a given route and a specified period (e.g. 365 days). For each flight that is listed as cancelled, the algorithm checks the T-100 data-base for the average aircraft size and average passengers loaded for the cancelled flight as well as the aircraft size and load factor for the next available flights operated by the same carrier on the same route segment. Passengers for the cancelled flight are then "re-booked" on these subsequent available flights up to 15 hours from the scheduled departure time of the

cancelled flight. The 15 hours upper-bound is derived from Bratu & Barnhart (2005) and reflects an estimate of the upper bound of passenger trip delays due to cancelled flights. Also it should be noted that the algorithm described in this paper allows passengers to be re-booked on flights operated by subsidiary airlines (e.g. American Airline (AA) and it's subsidiary American Eagle (MQ)), but not on other airlines. The delay time accrued by waiting for the re-booked flight is added to the delay time for the re-booked flight.

- 15-POTP Passenger On-Time Percentage
  For each route, the number of passengers that are schedule on on-time flights (with flight delay less than 15 minutes) is summed. This total is divided by the total number of passengers on that route yielding the 15-POTP On-Time Percentage for Passenger for the route.

- Average Magnitude of Passenger Trip Delays
  For each route, the TPTP is first calculated, and then divided by the total number of disrupted passengers (with PaxDelay more than 15 minutes) on that route yielding the Average Magnitude of Passenger Trip Delays for the route.

- Average Worst-Case Magnitude of Passenger Trip Delays
  For each route, the top 5% passengers with the largest passenger trip delay are derived. Their passenger trip delays are summed. This total is divided by the total number of the top 5% passengers yielding the Average Magnitude of Passenger Trip Delays for the route.

Approximations in Algorithm

The original research on passenger trip time by Bratu & Barnhart [4] was conducted using data from a major U.S. airline that included the exact itinerary of individual passengers and the load factors of each flight. This data is proprietary to the airline and is also subject to civil liberties laws. To overcome this limitation, the algorithm developed by Wang [5] makes three assumptions:

(1)   The algorithm estimates passenger load factors based on publicly available monthly average data for each flight on each route. When the algorithm "re-books" passengers from cancelled flights it assumes the load factor for each flight is the average load factor for that flight for that month. Analysis of a sample of cancelled flights indicates that the average load factor on cancelled flights is equal to the average load factors on non-cancelled flights and that this assumption is statistically valid.

(2)   The algorithm only re-books passengers on single segment flights. The algorithm does not re-book passengers with a connecting flight to their original destination. Accounting for alternative routing would be possible but adds significant complexity to the algorithm. This is a subject for further research.

(3)   The algorithm only re-books passengers on flights operated by the same airline or its subsidiaries. Accounting for re-booking on other airlines is possible within the constraints of the existing algorithm but is not consistently practiced. For

example, it is understood that some Low Cost Carriers do not have the infrastructure to handle coupons from other airlines. At this time, the algorithm sets an upper-bound for delays due to cancelled flights of 15 hours. This value was chosen based on previous work by Bratu & Barnhart and reflects the behavior that passengers with extensive delays would be re-booked on other airlines. This is an area for future research.

Sample Route Statistics

Table 1 provides a sample of Flight Delay statistics and Passenger Trip Delay statistics generated by this analysis.

ORIGIN	DEST	Flights			Passengers		
		15-OTP	Avg. Magnitude of Flight Delays	Avg. Worst-Case Magnitude of Flight Delays	15-POTP	Avg. Magnitude of PaxDelays	Avg. Worst-Case Magnitude of PaxDelays
ORD	ATL	67%	66	158	68%	112	424
ORD	BOS	69%	67	159	69%	120	467
ORD	CLE	69%	59	146	70%	116	465
ORD	CLT	75%	56	133	75%	88	298
ORD	CVG	74%	55	127	75%	110	370
ORD	DCA	77%	64	138	77%	104	337
ORD	DEN	74%	55	130	73%	81	267
ORD	DFW	75%	57	132	75%	88	271
ORD	DTW	75%	58	139	75%	92	310
ORD	EWR	58%	76	198	58%	106	396
ORD	IAD	75%	67	163	74%	106	385
ORD	IAH	78%	57	129	79%	107	350
ORD	JFK	74%	60	142	74%	181	620
ORD	LAX	73%	56	135	73%	71	217
ORD	LGA	64%	70	172	64%	114	442
ORD	MIA	68%	56	143	67%	101	409
ORD	MSP	74%	58	134	74%	90	281
ORD	PDX	70%	55	140	70%	68	209
ORD	PHL	69%	68	166	69%	116	443
ORD	SFO	70%	55	140	70%	73	251

Table 1: Sample statistics for Flight Delays and Passenger Trip Delays Statistics)

4 STATISTICAL COMPARISON FLIGHT DELAYS AND PASSENGERT TRIP DELAYS

The distributions across all 1030 routes between OEP-35 airports for On-Time Percentage, Average Delay greater than 15, and minutes and Average Delay greater than 95th percentile are shown in Figure 2, 3, and 4.

On-Time Percentage

Figure 1 show the histograms of Flight On-time Percentage and Passenger On-Time Percentage. The 15-OTP and 15-POTP distributions exhibit similarities. Among the 1030 routes, routes with the worst on-time percentages are EWR-PHL(47%), JFK-CLT(48%), JFK-ORD(50%), PHL-EWR(53%) and JFK-DFW(55%). Overall, the NAS has 77% of on-time flights with standard deviation equals to 7%.
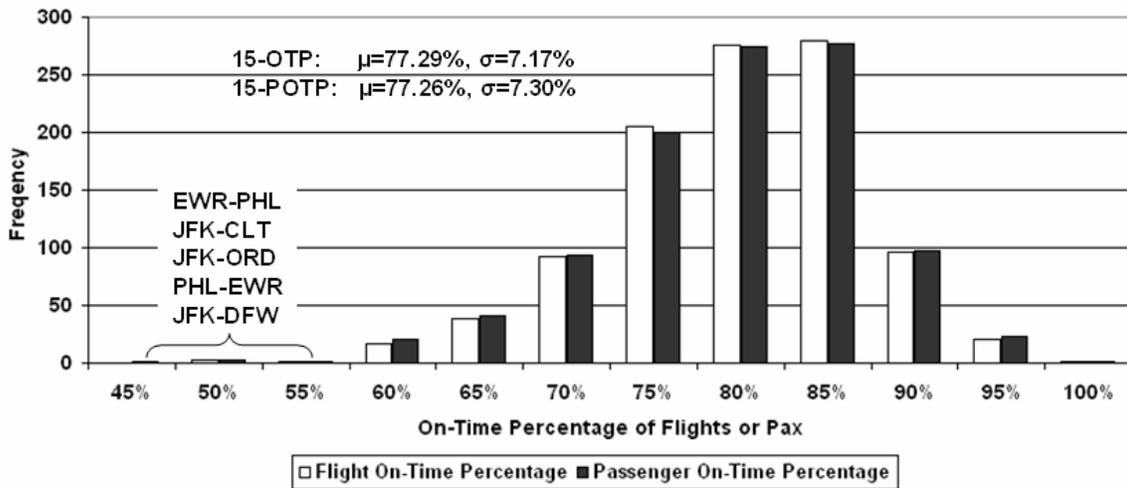
Figure 1: Histograms of Flight Percentage of On-Time and Passenger Percentage of On-Time (15-OTP v.s. 15-POTP)

Average Delay in Excess of 15 Minutes

Figure 2 shows the histograms of Average Magnitude of Flight Delays and the Average Magnitude of Passenger Trip Delays. In 2005, the average delay across all flights was 8 minutes. The average delay for those flights with delays in excess of 15 minutes on the OEP-35 routes ranged from 29 minutes (Salt Lake City – Washington National) to 122 minutes (Honolulu – Minneapolis) with an average of 55 minutes. The worst 5% delays ranged from 28 minutes (Portland to Chicago Midway) to 301 minutes (Honolulu – Minneapolis) with an average delay of 118 minutes.
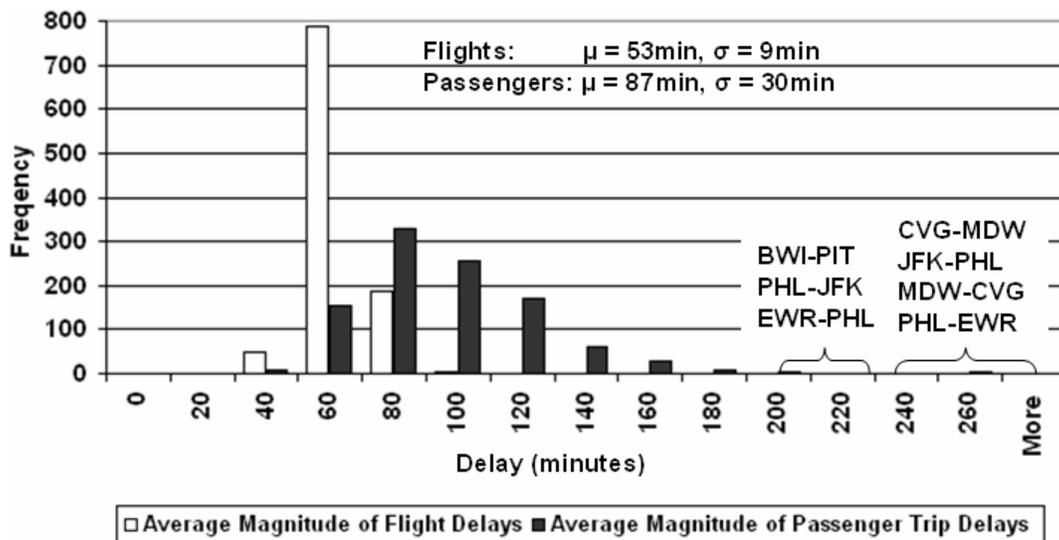

Figure 2: Histograms of Average Magnitude of Flight Delays and Average Magnitude of Passenger Trip Delays

The Average Magnitude for passenger trip delays exhibits a heavier right tail and larger mean than the Average Magnitude for flight delays ($\Delta\sigma$ = 34 min and $\Delta\mu$ = 21 min). This divergence is caused by cancelled flights. The top 7 routes (in Figure 2) with largest Average Magnitude of Passenger Trip Delay are BWI-PIT (203min), CVG-MDW (258min), EWR-PHL (238min), JFK-PHL (253min), MDW-CVG (256min), PHL-EWR (298min), PHL-JFK (209min). Many of these routes are short-haul routes serving shuttle flights with high frequency, small aircraft size, and high cancellation rate. The high cancellation rate results in large passenger trip delays.

Average Delays in Excess of 95th Percentile Delays (Worst-case)

Figure 3 illustrates the distributions of the Average Worst-case Magnitude of Flight Delays and the Average Worst-case Magnitude of Passenger Trip DelaysThe worst 5% of the delays are generally very large flight delays and delays caused by cancelled flights.
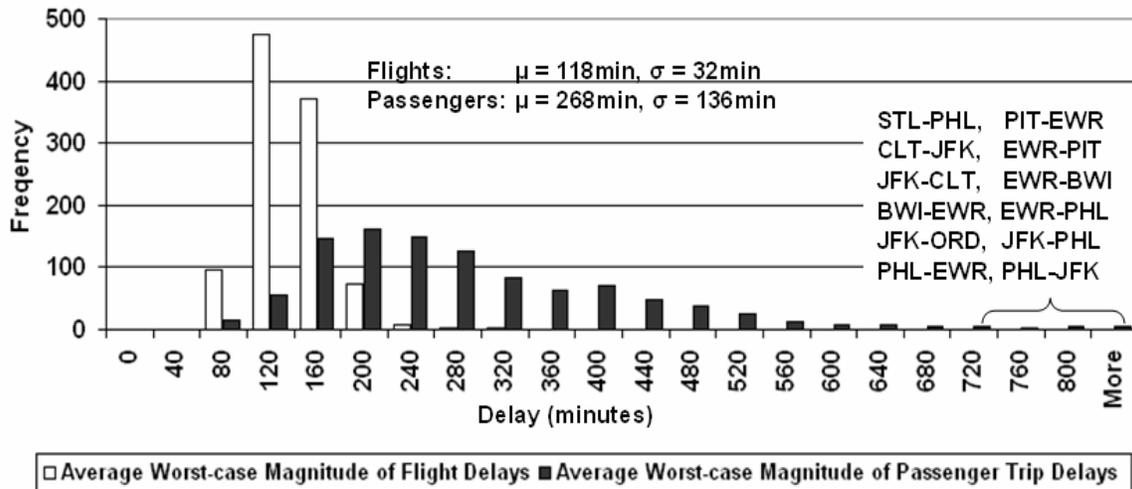

Figure 3: Histograms of Average Worst-Case Magnitude of Flight Delays and Average Worst-Case Magnitude of Passenger Trip Delays

The worst 5% of the flight delays have an average delay of 118 minutes with standard deviation equal to 32 minutes. When the impact of cancelled flights is counted, both mean and standard deviation of the passenger trip delays grows to 268 minutes and 136 minutes. Short haul routes exhibited the worst passenger trip delays.

Statistical Comparison

Table 2 summarizes the statistics for 2005 over all 1030 routes formed by OEP-35 airports. By inspection of the table, percentage of on-time flights is similar to the percentage on-time passengers. The mean of the average delay for flights delayed in excess of 15 minutes is 34 minutes lower than the mean of the average delay for passenger trips. The average worst-case flights delays in excess of 95th percentile is 150 minutes lower than average worst-case passenger delays in excess of 95th percentile.

	Percentage On-Time		Mean Average Magnitude of Delay		Mean Average Worst-Case Magnitude of Delays	
	15-OTP	15-POTP	Flights	Passengers	Flights	Passengers
Average	0.7729	0.7726	53	87	118	268
Standard Deviation	0.072	0.073	9.1	30.2	32.0	136.4
The worst 5% (excess 95 percentile)	0.877	0.877	68	138	170	510

Table: Comparison of Statistics for distribution of Flight Delays across all flights and distribution of Passenger Trip Delays across all flights.

Paired t-tests and χ^2 tests are performed on the above three sets of Flight Delay and Passenger Trip Delay metrics.

A paired t-test of percentage on-time across all routes can not reject the null hypothesis that Passenger On-Time Percentage has the same distribution mean as Flight On-Time Percentage (P-value 0.1858, 95% confidence interval -0.000015, 0.0008). The χ^2 test can NOT reject the null hypothesis that the Passenger On-Time Percentage and Flight On-Time Percentage have equal variance (P-value 0.5618). Altogether, there is no significant evidence to claim the hypothesis that the distribution of Flight On-Time Percentage is different to the distribution as Passenger On-Time Percentage.

A paired t-test can not reject the null hypothesis that the distribution mean of the "Average Magnitude of Passenger Trip Delays" is 34 minutes in excess of the distribution mean of the "Average Magnitude of Flight Delays" (P-value 0.9985, 95% confidence interval -1.633, 1.6304).

A paired t-test can not T reject the null hypothesis that the distribution mean of "Average Worst-Case Magnitude of Passenger Trip Delays" is 150 minutes in excess of the distribution mean of "Average Worst-Case Magnitude of Flight Delays" (P-value 0.9704, 95% confidence interval -7.545, 7.2642).

χ^2 tests do reject the hypothesis that both of the above two distributions (Average Magnitude of Delays, and Average Worst-Case Magnitude of Delays) have equal variance. Both p-values are less than 0.001. The distributions of 15-POTP "Magnitude of Delay" metrics are significantly wider than the distributions of 15-OTP "Magnitude of Delay" metrics

The results of the t-tests and χ^2 tests quantify the non-negligible difference in the magnitude of delays experienced by passengers.

5   CONCLUSIONS

The statistical results above conclude that the Flight Delays do not represent a fair description of the performance of Passenger Trip Delays between OEP-35 airports. The passenger trip delays in excess of the flight delays are not negligible. With an average of 34 minutes difference between average delays across all routes and 2.5 hours difference between the average worst-case delays, the passenger trip delays affect passenger connections to other flights as well as other modes of transportation.

These results have significant implications for the way passengers think about air transportation and should choose flights, and the way consumer protection of airline travelers is provided.

Using 15-POTP for Purchasing Airline Tickets

When passengers purchase an airline ticket they have made a commitment to a specific flight. This flight has historically exhibited a degree of randomness in its on-time performance. For example, an origin-destination pair that exhibits a 15-POTP of 98% provides a significantly more robust performance than a flight on an origin-destination pair with a 15-POTP of 47%. Given the disparity of 15-POTP on routes, the passenger selection of a route is akin to "rolling the dice" with the "odds" associated with route 15-POTP. Routes with greater probability of trip delays in excess of 15 minutes should be avoided in favor of routes with lower probability of delays. The 15-POTP provides the basis for this type of decision.

Integrating Probability of Delay with Magnitude of Delay

Passenger choices of flights from and to large metropolitan areas have expanded over the past decade to include choice of departure and arrival airport. For example, Boston, New York, Washington D.C., San Francisco, Los Angeles, and South Florida are all serviced by multiple airports. The choice of airport pairs provides the passenger with an additional degree of freedom in selecting flights. 15-POTP for routes between the Washington, D.C. and Chicago are shown in Table 3.

Most Reliable Routes					
Ranks	Origin	Dest	**15-POTP**	Average Magnitude of PaxDelay	Average Worst-Case Magnitude of PaxDelay
1	**DCA**	**MDW**	92%	120	171
2	BWI	MDW	82%	67	147
2	BWI	ORD	82%	102	295
4	DCA	ORD	80%	123	364
5	IAD	ORD	78%	103	342
6	IAD	MDW	76%	152	565

Routes with Least Passenger Trip Delay					
Ranks	Origin	Dest	15-POTP	Average Magnitude of PaxDelay	Average Worst-Case Magnitude of PaxDelay
1	**BWI**	**MDW**	82%	67	147
2	BWI	ORD	82%	102	295
3	IAD	ORD	78%	103	342
4	DCA	MDW	92%	120	171
5	DCA	ORD	80%	123	364
6	IAD	MDW	76%	152	565

Table 3: Example of Using 15-POTP for Purchasing Airline Tickets

Figure 4 plots the statistics in Table 3 in two charts. The chart area is divided into four blocks. Routes in the upper-left block are the most reliable routes that have high passenger on-time percentage and low average magnitude of passenger trip delays.
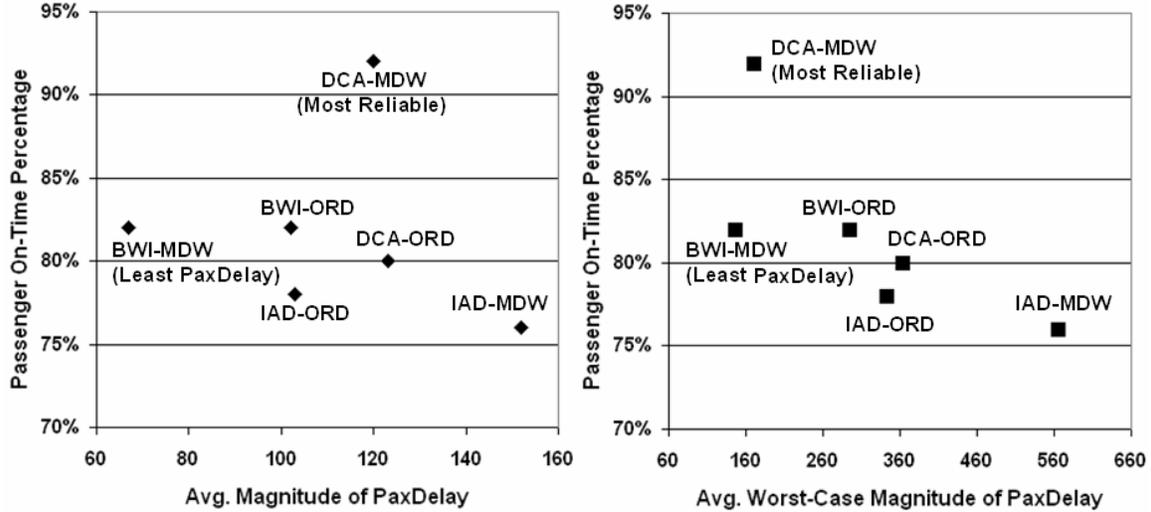

Figure 4: Plots of Reliability of Routes Between Washington D.C. and Chicago

The highest reliability route is DCA to MDW with a 14% differential over routes departing IAD for either ORD or MDW, and 10% differential for flights on the BWI to MDW route. Risk-averse passengers with scheduled connecting time less than 1.5 hours might prefer the second reliable route BWI-MDW, since it has the lowest Magnitude of Passenger Trip Delays.

Consumer Protection

The traditional view of consumer protection – the one adopted by the Department of Transportation – is to provide a comparison of flight-based services provided by the airlines to the passengers. This approach is based on the premise that the difference in service is derived only by the performance of the airlines. This view of consumer protection fails to recognize that the airlines performance is largely similar on the same routes. In fact the largest differences occur between routes (see above).

Further, by reporting only the percentage of on-time flights, which is representative of the percentage of on-time passengers, does not provide the consumer with a complete picture. It is equally important to understand the magnitude of delays experienced by the passenger (not the flight).

Based on the results of this paper, the following recommendations for consumer protection can be made:

1. Passenger on-time performance (not flight on-time performance) as discussed in this paper

2. Passenger Delay for Trips arriving in excess of 15 minutes of scheduled arrival time and Passenger Delay for Trips arriving in excess of the 95th percentile delays
3. Comparison between routes with alternative origin/destination airport pairs
4. Comparison between routes with alternative connecting airports.

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