Trend Analysis of Airline Passenger Trip Delays

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ABSTRACT
The purpose of the Air Transportation System (ATS) is to provide safe and efficient transportation of passengers and cargo. The on-time performance of the ATS is measured by flight-based metrics such as flight delays and flight cancellations. Researchers have shown that flight-based metrics do not accurately reflect the passenger trip experience, and especially underestimate the impacts of cancelled flights and missed connections on passenger trip time.

This paper describes a segment-based trend analysis in passenger trip time for the years 2004 and 2005. This paper uses the "estimated passenger trip delay (EPTD)" caused by delayed and cancelled single-segment flights to measure the passenger on-time performance. The EPTD passenger-based metric captures the passenger delays (40M hours) caused by small amount of cancelled flights (<2%). The trend analysis indicates that a small increase in operations (+0.5%) in conjunction with an increase in cancellations (+1.5%) and higher load factors (+5.4%), resulted in 17.4% increase in Estimated Total Passenger Trip Delays in 2005 over 2004. This result reveals the complex nonlinear relationship between the number of operations, the number of cancellations, load factor and passenger trip delays.

INTRODUCTION
On-Time Performance of passenger trips is a critical measurement of the quality of service provided by the Air Transportation System (ATS). It is a significant factor in the service-profit chain that drives airline profitability, productivity and customer loyalty and satisfaction [1]. For a given flight, passenger trip time is determined by flight times, as well as the time accrued by passengers following missed connections and cancellations.

The behavior of the ATS as a transportation system can be modeled by a two tiered flow model: the vehicle tier and the passenger tier, as shown in Figure 1. The flight schedule is the input of the vehicle tier. Affected by a combination of different factors such as traffic volume and weather condition, disruptions (flight delays and flight cancellations) occur, and impose time penalties on passenger trip time.

Researchers have shown that flight-based performance measurements do not accurately reflect the passenger trip experience [3].

- Flight-based performance measurements use "flight" as the measuring unit instead of "passenger". A delayed flight with 30 passengers and a delayed flight with 200 passengers are both one count of "delayed flight" in flight-based performance measurements
- Flight-based performance measurements do not consider passenger factors such as load factor, aircraft size, and number of passenger loaded. Cancelling a flight with high load factor and large size has much stronger impact on passenger trip time than cancelling a flight with low load factor and smaller size. But these two flight cancellations have no difference in flight-based performance measurements.

The difference between the flight-based and passenger-based approach is shown by the following example. Day 1 and day 2 both have 200 scheduled flights and 10 of them are cancelled. The on-time performance of these two days will have no difference when flight-based metrics are used (both 5% cancellation rate). However, the passenger trip performance of these two days could have a big difference: if the ten flights in day 1 are operated by a single airline and cancelled late in the afternoon, the responsible airline won't be able to re-booking all the disrupted passengers in the same day due to shortage of empty seats, and available flights. Parts of the passengers have to wait until the next day. These ten cancelled flights in day 1 will generate significant amount of passenger trip delays. If the ten cancelled flights in day 2 are evenly distributed throughout the day and are from different airlines with lower load factors, the responsible airlines will have enough time and resources to re-booked passengers. The passenger delays generated in day 2 is much less than those generated in Day 1. Flight cancellation has more complicated effect on passenger on-time performance, since it many factors, such as flight frequency, flight delay, cancelled time, load factor and aircraft size, are involved in the re-booking process [2].

This paper uses "Estimate Passenger Trip Delay (EPTD)" as a metric to evaluate the NAS on-time performance from passenger's perspective. The new metric calculates passenger trip delays caused by delayed fights and cancelled flights. Compared with the flight-based metrics, EPTD captures the impacts of flight cancellations on passenger trip delay, and more accurately reflect the travel experience of passengers. The passenger-based metric and measurement could be useful for:

- Traffic flow management
- Airline operation centers
- FAA strategy planning
- Flight reservations and ticket purchases by customers

This paper describes an analysis of the trends in passenger-based metrics between the years 2004 and 2005. The results indicate that a small increase in operations (+0.5%) in conjunction with an increase in cancellations (+1.5%) and higher load factors (+5.4%), resulted in 17.4% increase in total Estimated Passenger Trip Delays (EPTD). This illustrates the non-linear relationship between number of operations, number of cancellations, load factors and passenger trip delays.

This paper is organized as follows. The next section describes previous research on passenger metrics. The third section describes the algorithms used to estimate passenger trip delay. The fourth section describes the results of the analysis of annual trends in passenger metrics. The last section provides conclusions and future work.

PREVIOUS WORK

Bratu and Barnhart's research [3] on flight schedule reliability analyzed the impacts of disrupted activities on passenger trip time used proprietary airline data to investigate the impact of delayed flights, cancelled flights and missed connections, on passenger trip time. They estimated passengers scheduled on the cancelled flights, or missed their connections have experienced an average delay of 303 minutes in August 2000. Their investigation validated and measured the discrepancy between passenger delays and flight delays with real data. They identified that flight-based metrics alone are a poor proxy for passenger delays for hub-and-spoke airlines.

The limitation of Bratu and Barnhart's research is that all the results are constrained by one-month (August 2000) passenger booking data provided by a single legacy airline. So their research emphasized more on "analysis of a single airline performance" instead of "predictability of the system performance", and it can not be expended to a system-level analysis.

Ball, Lovell, Mukherjee and Subramanian [6] developed a passenger delay analytical model, which works as part of the NAS Strategy Simulator. The analytical model is based on a decision tree which determines the probability of delayed, missed connection, cancelled and on-time flight legs. The advantage of Ball's research is that they are trying to use it in a predictable system-level model. But Ball's research heavily depends on Bratu and Barnhart's results. They assume a fixed passenger delay (7 hours) for all the passengers encountering missed connection or flight cancellations. This assumption ignores the specific properties of different airport and routes, and assumes a homogenous transportation network.

Table 1 lists major difference between Bratu and Barnhart (2005), Ball, Lovell, Mukherjee and Subramanian (2006), and this paper in estimating passenger trip delay.

TABLE 1 Difference in Estimating Passenger Trip Delay

Aspects	Bratu & Barnhart (2005)	Ball (2006)	Wang (2006)
Source of Data	One-month passenger booking data from an single legacy airline, combined with ASPM flight operation data	ASPM and Bratu & Barnhart's Statistics	Publicly accessible databases from BTS (Bureau of Transportation Statistics): AOTP*, T-100*.
Goals	Analyze airline flight schedule reliability	Estimate passenger delays in the ATS	Measure the ATS on-time performance from a passenger's perspective
Perspective	Airline's perspective	Passenger's perspective	Passenger's perspective
Level of Detail	Detailed analysis on performance of a single airline in one month	Very high level analysis on system-level performance	Detailed analysis on system-level performance

METHODOLOGY

Passenger trip data is proprietary airline data that can only be provided by airlines. Special algorithms are developed [3] to estimate passenger trip delays using publicly accessible single-segment flight data.

Passenger trip delay is caused by two activities: delayed flight and cancelled flight:

1. The "Passenger Trip Delay 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 then 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 equation for this process is listed below:

$$\text{PassengerDelay(i)} = Pax(i) * (ActArrTime(i) - SchArrTime(i)) \quad (1)$$

   where
   i = flight with arrival delay > 15 minutes
   Pax(i) = number of passengers on delayed flight i
   ActArrTime(i) = actual arrival time for flight i
   SchArrTime(i) = scheduled arrival time for flight i

2. The "Passenger Trip Delay due to cancelled flights" is computed as the time difference between the scheduled arrive time of the cancelled flight, and the actual arrive time of the re-booked flight. Passengers on cancelled flight are assumed to be re-booked to the nearest available flight which flies the same origin-destination pair and operated by the same carrier. 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. In general, passengers from a cancelled flight will be relocated to 2 or 3 different flights due to the large number of passengers need to be re-booked on the same route, and the limited empty seats on each available flight on the route. A 15 hours upper-bound is derived from (Bratu and Barnhart 2005) and reflects an estimate of the upper-bound of passenger trip delays due to cancelled flights. We assume the disrupted passengers with an unacceptably long delay exceeding 15 hours will be re-routed or re-accommodated on another airline, and their passenger trip delays are set to be 15 hours. The equation for this process is listed below:

$$\text{PassengerDelay(i)} = \sum_{j1=1}^{n} Pax(j1) * (ActArrTime(j1) - SchArrTime(i)) + \sum_{j2=1}^{N-n} Pax(j2) * 15hrs \quad (2)$$

   where
   i = cancelled flight
   j1 = available flight with passenger delay <= 15 hours (within 15 hrs upper-bound)
   j2 = available flight with passenger delay > 15 hours (exceeding 15 hrs upper-bound)

N = total number of available flights needed to finish relocating passengers on cancelled flight i
n = subset of N, number of available flights that re-booked passengers on these flights have passenger delay > 15 hours
Pax(j1) = number of passengers re-booked on flight j1 from cancelled flight i
ActArrTime(j1) = actual arrival time for available flight j1
SchArrTime(i) = scheduled arrival time for cancelled flight i

Table 2 gives an example of passenger trip delay caused by a cancelled flight. Assume a flight with 100 passengers to DCA is cancelled. Its scheduled arrival time is 12:00 pm. The first available fight has 30 empty seats and it arrives at DCA at 2:00 pm. The second available flight has 45 empty seats and it arrives at DCA at 3:00 pm. The third available flight has 40 empty seats and it arrives at DCA at 4:00 pm. The passengers re-booked on the first available flight will experience a delay of 2 hours each. The passengers re-booked on the second and third available flight will experience a delay of 3 hours and 4 hours respectively. The Total Passenger Delay Time due to this flight cancellation is 2(hr)*30 + 3(hr)*45 + 4(hr)*25 = 295 hours.

TABLE 2 Example: Estimate Passenger Trip Delay Caused By Cancelled Flight

Available Flights	Empty Seats	Re-booked Pax from cancelled flight	Empty Seats Left	Delays expd by each pax relocated to this flight	Total delays exp by pax relocated to this flight
Available Flights1	30	30	0	2 hrs	30×2=60 hrs
Available Flights 2	45	45	0	3 hrs	45×3=135 hrs
Available Flights3	40	25	15	4 hrs	25×4=100 hrs
		Total = **100** re-booked passengers			Total = **295** hrs

* expd = experienced; pax = passenger(s)

Figure 2 shows the logical structure of the Passenger Trip Delay estimating process

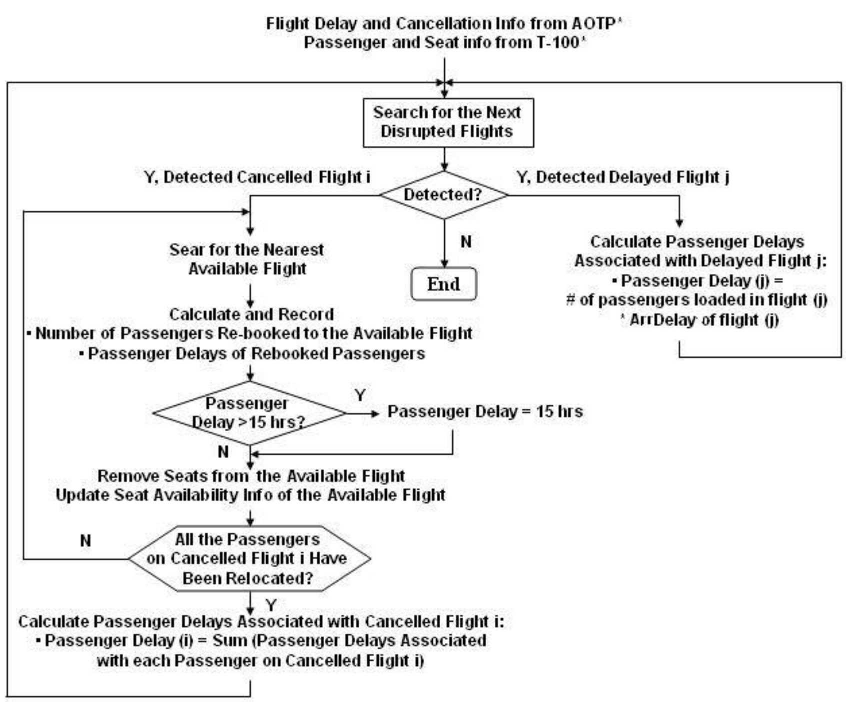

FIGURE 2 Estimating Passenger Trip Delay Algorithm

Flight operational data and carrier data used in the algorithm are from two segment-based flight databases provided by Bureau of Transportation and Statistic (BTS):

- Airline on-time performance (AOTP) database - It contains "departure delays and arrival delays for non-stop domestic flights by major air carriers, and provides such additional items as origin and destination airports, flight numbers, cancelled or diverted flights [8]" (Bureau of Transportation Statistics)

- Air carrier statistics database (T-100) - It contains "domestic non-stop segment data by aircraft type and service class for passengers, freight and mail transported, available capacity, scheduled departures, departures performed and aircraft hours [9]" .(Bureau of Transportation Statistics)

The AOTP database provides scheduled and actual departure/arrival time of all the non-stop single-segment flights in the NAS, while T-100 database provides monthly aggregated passenger and seat information for non-cancelled flights operated by different carriers. By combining AOTP and T-100, we obtain both the operational information, such as arrival delay, and passenger information such as seats, load factor and number of passenger loaded on the aircraft for each flight in the database. Having the passenger and seat information for each flight, the algorithm knows how many passengers to rebook for a cancelled flight and how many empty seats are available for non-cancelled available flights during the re-booking process.

RESULTS

Estimated Passenger Trip Delay (EPTD) for the 1044 routes in 2004 and 1050 routes in 2005 between the 35 OEP airports were computed. The OEP35 airports account for 73% of total enplanements and 69% of total operations in the air transportation system [10].

The analysis results for the OEP 35 airports are listed in Table 3. This table compares the flight-based on-time performance and the passenger-based on-time performance in 2004 with those in 2005.

TABLE 3 Comparison of ATS Performance between 2004 and 2005

Categories	Factors	2004		2005		% Change
Vehicle Performance	# Scheduled Flights	2,928,999		2,942,222		0.5%
	# On-Time Flights	2,278,776		2,249,287		(1.3%)
	# Delayed Flights (>15min)	597,959		639,909		7.0%
	# Cancelled Flights	52,264		53,026		1.5%
	# Disrupted Flights (both delayed and cancelled)	650,223		692,935		6.6%
	Avg. # Operated Flights on each route (annual flight frequency)*	2,819		2,810		(0.3%)
Passenger /Seat Factors	Avg. Aircraft Size	134		134		-
	Avg. # Passengers loaded on each flight	99		104		5.1%
	Avg. Empty Seats on each flight	35		30		(14.3%)
	Avg. Load Factor	74%		78%		5.4%
Passenger Performance	Passenger Trip Delay caused by delayed flights	Total	52 M hrs	Total	61 M hrs	17.3%
		Avg.	53 min	Avg.	55 min	3.8%
	Passenger Trip Delay caused by cancelled flights	Total	34 M hrs	Total	40 M hrs	17.6%
		Avg.	519 min	Avg.	549 min	5.8%
	Passenger Trip Delay for disrupted passengers (both delayed and cancelled flights)	Total	86 M hrs	Total	101 M hrs	17.4%
		Avg.	82 min	Avg.	86 min	4.9%
	Avg. Passenger Trip Delay for all passengers	18 min		20 min		11.1%

* This count is for regularly scheduled routes which had flights at least once another day

The total number of scheduled flights between the OEP35 airports only increased by 0.5% from 2004 to 2005. But the number of disrupted flights (delayed and cancelled flights) increased by 6.6%. This indicates there is a high proportion of disruptions within the 0.5% more schedule flights. It has been hypothesized that as the system approaches its capacity limits, disruptions will increase nonlinearly with a small increase in scheduled flights [11].

The flight on-time performance dropped from 2,278,776 on-time arrivals in 2004 to 2,249,287 on-time arrivals in 2005. Except for the slight increase (1.5%) of cancelled flights, flight delay becomes a more common phenomenon in 2005 with 7% growth.

The average load factor increased from 74% in 2004 to 78% in 2005. The increase in average number of passenger loaded (+5.1%) coupled with fewer empty seats (-14.3%) reduced the flexibility of passenger re-booking process. The direct consequence of the high load factor is having more disrupted passengers for re-booking when a flight is cancelled, and having less empty seats to absorb the disrupted passengers. Same amount of cancelled flights will generate much more passenger trip delays under high load factor circumstance than low load factor circumstance.

Overall, there were more disruptions, less empty seats and lower flight frequency in 2005 than in 2004, which resulted in degraded passenger trip experience, though the scheduled flight operations only increased by 0.5%. Figure 4 shows the percentage changes in flight performance and their corresponding percentage changes in passenger performance. In summary, small increase in disrupted flights (+6.6%) incurred 17.4% growth in passenger trip delay. Passenger performance in 2004 and 2005 has the following characteristics:

1. Cancelled flights generate disproportional EPTD: Cancelled flights, which only counts for 1.8% of the schedule flights in both years, have generated 34 and 40 million hours EPTD in 2004 and 2005. On average, passengers scheduled on cancelled flights experience 519 minutes delay in 2004 and 549 minutes delay in 2005. Compared with EPTD due to delayed flights, EPTD due to cancelled flights has much stronger impacts on the passenger trip time.

2. Non-linear relationship between cancelled flights and the corresponding EPTD: Though the number of cancelled flights only increased by 1.5%, the corresponding passenger trip delay has grew by 17.6%, and the average passenger trip delay increased by 5.8%. This reveals the nonlinear relationship between the number of cancelled flights and the EPTD caused by cancelled flights when the system is close to its capacity limit. If the number of scheduled flights keeps increasing without any improvement in capacity, a small growth of operations might result in huge negative impacts on passenger trip time.

3. Delayed flights account for 60% of the total passenger trip delays in both years. The total EPTD caused by flight delays has increased from 52 million hours in 2004 to 61 million hours. This increase is a result of more delayed flights and higher average flight delay. The 7% growth of delayed flights accounts for most of the 9 million hours increase in EPTD in 2005, since there is only a slight increase (3.8%) of average passenger delay for passengers scheduled on delayed flights.

4. In general, passengers received worse on-time performance in 2005 than in 2004. Values for passenger trip time related metrics grew from 2004 to 2005. The impact of flight cancellations on passenger trip time is the strongest one, which brought more than 9 hours time penalty on passenger trip time on average.

Factors	2004	2005	% Change
# Scheduled Flights	2,928,999	2,942,222	0.5%
# Delayed Flights (>15min)	597,959	639,909	7.0%
# Cancelled Flights	52,264	53,026	1.5%
# Disrupted Flights (both delayed and cancelled)	650,223	692,935	6.6%

7% flights → 17.3% ETPTD

1.5% flights → 17.6% ETPTD

6.6% flights → 17.4% ETPTD

Factors	2004		2005		% Change
Passenger Trip Delay caused by delayed flights	Total	52 M hrs	Total	61 M hrs	17.3%
	Avg.	53 min	Avg.	55 min	3.8%
Passenger Trip Delay caused by cancelled flights	Total	34 M hrs	Total	40 M hrs	17.6%
	Avg.	519 min	Avg.	549 min	5.8%
Passenger Trip Delay for disrupted passengers	Total	86 M hrs	Total	101 M hrs	17.4%
	Avg.	82 min	Avg.	86 min	4.9%

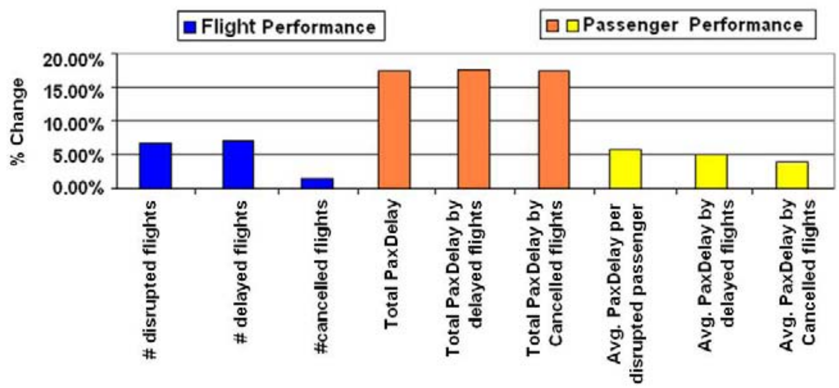

FIGURE 4 Flight and Passenger Performance Percentage Changes in 2004 and 2005

CONCLUSIONS

The goal of the Air Transportation System is to ensure the safe and efficient transportation of passengers and cargo. Historically, the on-time performance of the ATS has been measured by flight-based metrics. While these metrics provide insights into some aspects of the system performance, they do not provide a complete picture [12]. Researchers have proved that flight-based metrics are poor proxy for passenger experience.

This paper use "Estimated Passenger Trip Delay (EPTD)" as the performance metric to measure the on-time performance from a passenger's perspective, and to more accurately reflect passenger's travel experience. The paper describes an analysis on passenger trip delay. Algorithms used in the analysis generate passenger trip information from publicly accessible flight databases. The analysis is based on a closed network formed by the OEP 35 airports in 2004 and 2005.

Managing EPTD Due to Cancelled Flights

The underlying model of this research is that EPTD is a function of both flight factors and passenger factors. The result is closely related to combined impacts of

- flight frequency to the destination of cancelled flight;
- flight delays;
- flight cancelled time;
- number of passengers scheduled on the cancelled flights;
- number of empty seats on available flights;
- load factor of available flights

Flight cancellation is a complicated disruption to passengers since it has a stronger impact on passenger trip delay than flight delay does. On average, passengers scheduled on cancelled flights experienced 519 and 549 minutes of delay while passengers scheduled on the delayed flights experienced 53 and 55 minutes delay in 2004 and 2005 respectively. To mitigate the effects of flight cancellation on passenger trip time, airlines could either provide redundant resources or reduce cancellation. The redundant resources include more empty seats, lower load factor, higher flight frequency, backup aircraft and flight crew. These redundant resources ensure the flexibility of re-booking process when disruptions happen. But on the other hand they increase airline costs and lower airline efficiency.

Passenger's Perspective

Passengers must treat trip time as a stochastic phenomenon that can be assigned a probability of occurrence, but cannot be avoided entirely in any systematic manner. Passenger factors, which can be ignored in the flight performance, need to be carefully considered when evaluating ATS on-time performance from a passenger's perspective. It shall be emphasized that airports and routes in the network are not homogeneous. They have their own specific behavior patterns, and these behavior patterns form the network properties. After understanding the different behavior patterns of routes and airports, simple strategies can be used by passengers to lower their risk of delay by choosing different airports or departure time. For example, for trip from Washington, D.C. to Chicago in 2004, passengers chose flights from Washington Reagan International Airport (DCA) to Midway (MDW) had a 5% probability of encountering delay of more than an hour, whereas passengers that chose to fly to Chicago O'Hare had 12% of probability of encountering delay more than an hour.

LIMITATIONS AND FUTURE WORK

There are several areas with assumptions identified for future work.

1. The algorithm is based on an assumption that flights in non-peak hours have the same load factor as flights in non-peak hours. For the purpose of the analysis of the performance of the air transportation system, this assumption is satisfactory. Future work is planned to investigate actual passenger enplanements and aircraft size for cancelled flights from proprietary airline passenger data to validate this assumption.
2. The data used in this analysis is non-stop single-segment data which exclude the possible problems happened in the connecting process. The algorithm will be extended to include estimates of delays described from missed connections.
3. The algorithm uses a straightforward rule-of-thumb in re-booking passengers to the next available flight operated by the same carrier (including subsidiaries). Whereas this assumption is satisfactory for the analysis of the air transportation system, use of the metric for other purposes should take the re-booking strategy of the airlines into consideration. This too is a topic for future work as well as an analysis of the impact of airline cancellation policies on EPTD such as re-booking on other airlines.

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