

Trend Analysis of Airline Passenger Trip Delays

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ABSTRACT

The major goals of the Air Transportation System (ATS) are to ensure the safe, efficient, and orderly movement of passengers and cargo. In general, the on-time performance of the ATS has been measured primarily with flight-based metrics. Researchers have shown that flight-based metrics do not accurately reflect the passenger trip experience by underestimating the impact of cancelled flights and missed connections on passenger trip time.

This paper describes an analysis of the trends in passenger trip time for 2004 and 2005. The 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. Flight cancellations have a greater impact on passenger trip time than flight delays. In 2005, on average, passengers scheduled on cancelled flights experienced 549 minutes delay (+5.8%), while passengers on delayed flights experience 55 minutes delay (+3.8%).

INTRODUCTION

On-Time Performance of passenger trips should be one of the critical performance measures of the quality of service provided by the Air Transportation System (ATS). It has been proven to be 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.

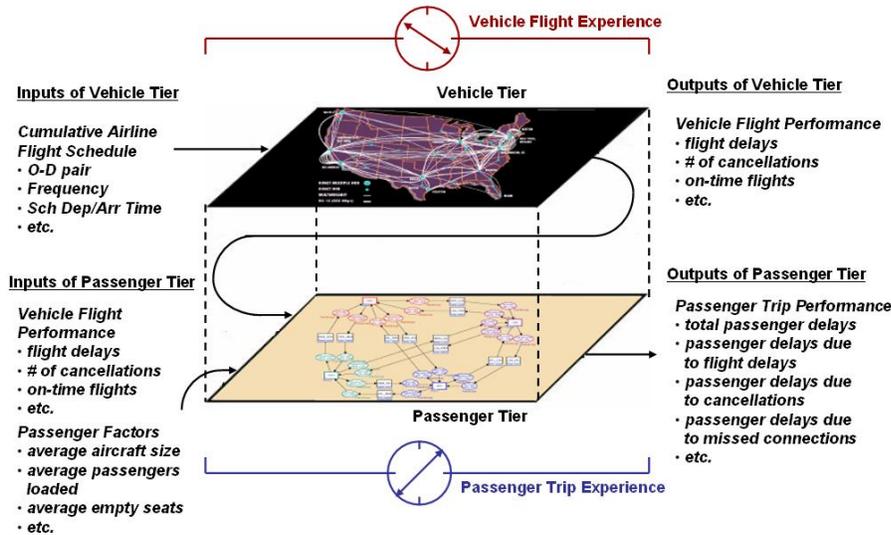


FIGURE 1 Vehicle Tier and Passenger Tier of Air Transportation System

Researchers have shown that flight-based performance metrics do not accurately reflect the passenger trip experience [3]. First they use “flight” instead of “passenger” as the measurement unit. Second, they do not consider passenger factors, which have big impacts on passenger trip delay. As shown in Figure 1, passenger factors includes passenger and seat related information, such as load factor, aircraft size, and number of passenger loaded.

To better understand the divergence between the vehicle tier performance and passenger tier performance, consider 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. However, the performance of these two days could have big difference when it is measured from a passenger’s perspective: if the ten cancellations in day 1 happened in the late afternoon, within a short time period, and from one single airline, the responsible airline will have difficulty re-booking all the disrupted passengers due to shortage of empty seats, and available flights.. Some of the passengers might have to wait until the next day for available seats since their flights are cancelled in the late afternoon. These ten cancelled flights will generate significant amount of passenger delays. The ten cancellations in day 2 are 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 in day 2 will be much lower than those experienced in Day 1. In passenger trip experience, flight cancellation is a much more complicated disruption. Both flight factors (flight frequency, distribution of cancellation, flight delay) and passenger factors (load factor, aircraft size, number of loaded passengers) have impacts on passenger trip time [2].

This paper describes an analysis of the trends in passenger-based metrics between 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 Estimated Total Passenger Trip Delays (ETPTD). 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

The operational (flight) view of the ATS performance has been well developed, while the user (passenger) view of the ATS performance has not received as much attention. Researchers have identified the divergence between the vehicle tier and the passenger tier of the ATS. But there has been less research conducted on

passenger's view of the ATS performance. One of the major reasons is the lack of passenger trip data, which is proprietary airline data.

Bratu and Barnhart's research [3] on flight schedule reliability has made a breakthrough in estimating passenger trip delay. They 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 passenger delays due to missed connections and flight cancellations, and established relationships between passenger delays and other statistical factors. 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 expanded 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 all the disrupted passengers in the system experience 7 hours delay. This assumption discards the specific properties of different airport and routes, and assumes a homogenous transportation network. So we remain skeptical of the result reliability.

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

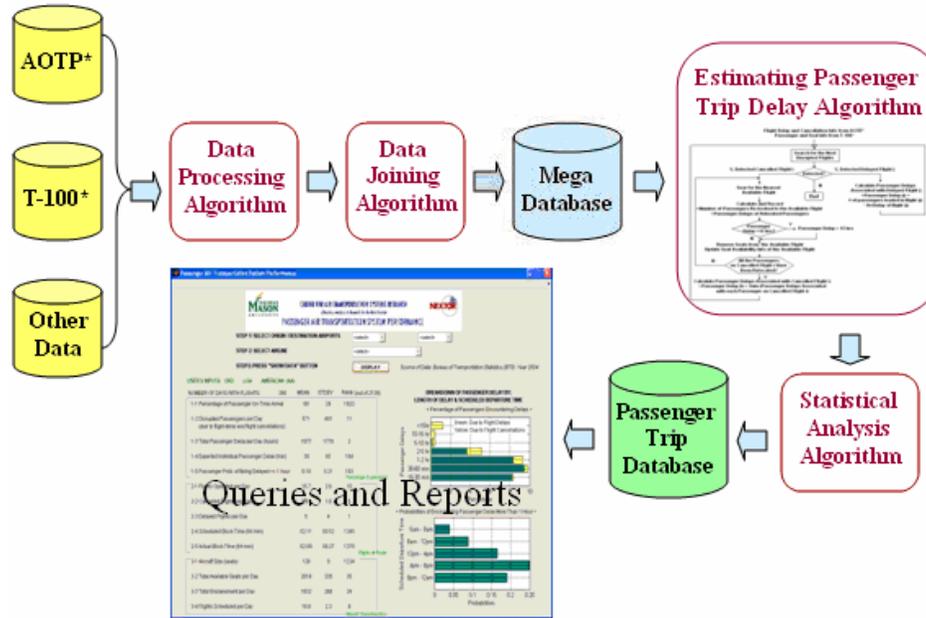
Aspects	Bratu & Barnhart (2005)	Ball (2006)	This Paper
Data	One-month passenger booking data from an single legacy airline, combined with ASPM flight operation data	ASPM and Bratu & Barnhart's Statistics	Publicly accessible databases from BTS (Bureau of Transportation Statistics): AOTP*, T-100*.
Goals	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
Model	Test different airline strategies for disrupted relocating passengers	Estimate average passenger delay in system level	Understand and predict impacts on passenger trip delay given anticipated changes in the future
Level	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

The passenger trip time should be one of the top-level performance metrics of the air transportation system. This metric determines passenger's choice of transportation mode, and has been positively correlated with airline revenue growth and consumer satisfaction.

Passenger trip data is proprietary airline data that airlines are not willing to share due to competitions. Limited by the data source, passenger trip delay is hard to be estimated and validated. Algorithms were developed by Wang [3] to use publicly accessible flight-based databases to convert flight data to passenger trip data.

As shown in Figure 2, different algorithms are designed to manipulate the data in different phases. First, the flight data is collected from several publicly accessible databases emphasizing on different aspects of the ATS. Then the data is processed in the “Data Processing Algorithm” to filter out errors and formalize the data format. The “Data Joining Algorithm” joins different databases together with shared common keys to form a “Mega-database” upon all these flight-based databases. The Mega-database contains both flight data and aggregated passenger and seat data. “Estimating Passenger Trip Delay Algorithm” is then applied on the mega-database to estimate passenger trip delays caused by delayed and cancelled flights. Passenger-based performance metric: Estimated Total Passenger Trip Delay (ETPTD) is calculated in this algorithm. After estimating passenger trip delay for all the disrupted flights in the Mega-database, a “Passenger Trip Database” is generated, and it works as the backstage database to support a graphic user interface (GUI) tool named Air Transportation Network Analysis Tool (ATNAT). Details for the ATNAT can be found in [7].



* AOTP = Airline On-Time Performance data (from BTS)
 * T-100 = Air Carrier Statistics (Form 41 Traffic) domestic data (from BTS)

FIGURE 2 Algorithms to Estimate Passenger Trip Delay

The two databases shown in Figure 2 are flight-based databases which can be obtained on the Bureau of Transportation and Statistic (BTS) website:

- 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 “Estimating Passenger Trip Delay” algorithm described here is designed to compute the Estimated Total Passenger Trip Delay (ETPTD) for single segments flights. The algorithm includes trip delays that are a result of delays caused by rebooking passengers on later flights due to cancelled flights and/or delays incurred by flight delays.

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:

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

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

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:

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

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

An example for the estimation of average passenger delay time caused by a cancelled flight is provided in Table 2. Assume a flight with 100 passengers is cancelled. Its scheduled arrival time is 12:00 pm. The first available flight has 30 empty seats and it arrives at 2:00 pm. The second available flight has 45 empty seats and it arrives at 3:00 pm. The third available flight has 40 empty seats and it arrives 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 available flight will experience a delay of 3 hours each. Those passengers re-booked on the third available flight will experience a delay of 4 hours. The Total Passenger Delay Time due to the cancelled flight 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

* exp = experienced; pax = passenger(s)

The overall algorithm for computation of passenger trip delay is provided in Figure 3.

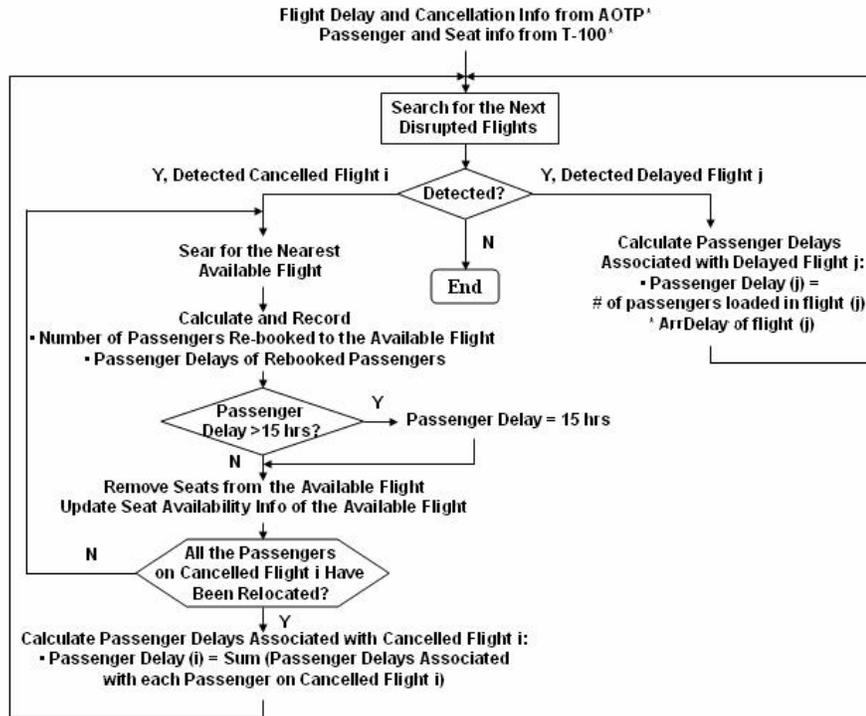


FIGURE 3 Estimating Passenger Trip Delay Algorithm

RESULTS

Estimated Total Passenger Trip Delay (ETPTD) 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 results of the analysis of 2004 and 2005 data for the OEP 35 airports are listed in Table 3. This table compares the vehicle performance, passenger factors and passenger performance in 2004 with those in 2005. The percentage changes (the last column of Table 3) depicted in Figure 4.

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

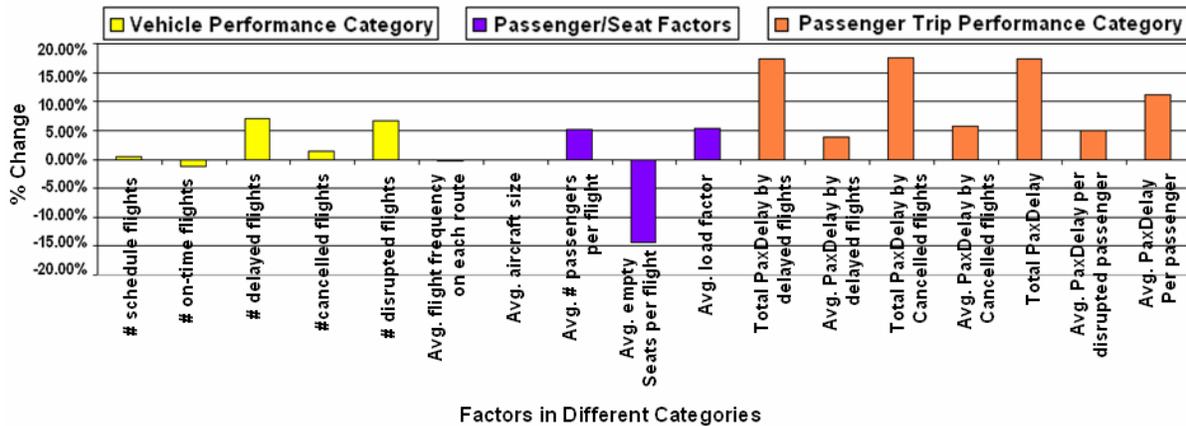


FIGURE 4 Factor Percentage Changes in 2004 and 2005

For the vehicle performance: 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.

For the passenger and seat factors, aircrafts used by airlines do not have major changes, and the average aircraft size remains 134 seats per flight in both years. The average load factor has increased from 74% in 2004 to 78% in 2005. The change in passenger load factor (+5.1%) coupled with fewer empty seats (-14.3%) reduced the flexibility of the re-booking process. When flight disruptions happen, more passenger trip delays will be generated due to limited resources like empty seats, available flights, and flight crew.

Vehicle performance and passenger factors work together as the inputs to the passenger tier, they results in the passenger performance. 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%. Passenger performance in 2004 and 2005 has the following characteristics:

1. Cancelled flights generate disproportional ETPTD: Cancelled flights, which only counts for 1.8% of the schedule flights in both years, have generated 34 and 40 million hours ETPTD 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 ETPTD due to delayed flights, ETPTD due to cancelled flights has much stronger impacts on the passenger trip time.

2. Non-linear relationship between cancelled flights and the corresponding ETPTD: Though the number of cancelled flights only increased by 1.5%, the corresponding passenger trip delay has grown 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 ETPTD caused by cancelled flights when the system is close to its capacity limit. If airlines keep scheduling more flights with no action on capacity improvement, 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 ETPTD 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 ETPTD 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. All the passenger trip time related metrics: average passenger trip delay due to delayed flights, average passenger trip delay due to cancelled flights, average passenger trip delay for disrupted passengers, and average passenger trip delay for all passengers, 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.

CONCLUSIONS

The major goals of the Air Transportation System are to ensure the safe, efficient, and orderly movement of passengers and cargo. Historically, the on-time performance of the ATS has been measured primarily with 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 shown that flight-based metrics only are poor proxy for passenger experience.

This paper describes an analysis of 2004 and 2005 data using algorithms that generate passenger trip information using publicly accessible flight-based databases. It estimates passenger trip delay and evaluates the ATS on-time performance from a passenger's perspective. Analysis is based on a closed network formed by the OEP 35 airports in 2004 and 2005.

Passenger-Based and Flight-Based Metrics

Divergence exists between the performance of the Vehicle Tier and the performance of the Passenger Tier. The results of this paper confirm the findings of researchers Bratu, Barnhart and Sarmadi [3]-[5], Ball, Lovell, Mukherjee and Subramanian [6] that flight-based metrics only are poor proxy for passenger trip experience. Passenger-based metric: ETPTD, is proposed in this paper to accurately reflect passenger trip experience, and to properly evaluate the ATS on-time performance from a passenger's perspective.

Managing ETPTD Due to Cancelled Flights

The underlying model of this research is that ETPTD 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;
- number of passengers scheduled on the cancelled flights;
- number of empty seats on available flights;
- load factor of available flights

Flight cancellation is a much more complicated disruption to passenger trip time, and 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 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. In terms of reducing cancellations, there is no regulation like passenger bill of rights to ensure the quality of service received by U.S. passengers. Airlines benefit from bad behaviors since they are not under any legal obligation to guarantee their schedules [13]. Passengers are more like buying a lottery instead of an airline/passenger contract when they purchase air tickets, since they will not receive any compensation for flight delay or cancellation. In addition, poor information on cancellations performance of airlines is provided.

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 Vehicle Tier 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.

FUTURE WORK

There are several areas identified for future work. One of the big questions that must be answered is the accuracy of the assumption that flights in non-peak hours have the same load factor as flights in non-peak hours. Also, the algorithm will be extended to include estimates of delays described from missed connections.

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