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Modeling Passenger Trip Reliability: Why NextGen may not Improve Passenger Delays

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The airlines provide a critical service to the nation's economy, providing rapid, safe, and affordable transportation over large geographic distances. The reliability of this transportation service, defined as the difference between the ticketed arrival time and the actual passenger arrival time, translates into economic productivity. For example, in 2007, the total delays experienced by airline passengers were estimated at 30,000 years. The estimated cost of these delays to the U.S. economy was $16.1B in lost economic productivity (NEXTOR, 2010). Further, one out of five passengers experienced a disrupted trip, and the average trip disruption was 110 minutes (Sherry, 2010; Barnhart et, al. 2010).

The U.S. government and industry are collaborating on two approaches to improve the infrastructure required to operate the airline transportation system (ATS). First the Airport Improvement Plan (FAA, 2010) is working to relieve the bottlenecks at U.S. airports by increasing the flight capacity by adding runways, taxiways, gates, terminal buildings and service facilities at key nodes of the air-transportation system. Second, the proposed $37B air traffic control modernization program, known as NextGen (JPDO, 2010), will improve productivity and the utilization of existing airspace.

Whereas these programs have the potential to improve flight on-time performance, will they result in improved passenger trip reliability and the associated improvement in lost economic productivity ?

This paper describes a probabilistic model of the airline transportation system that can be used to better understand the impact of improved on-time flight performance generated by the Airport Improvement Plan and by NextGen on passenger trip reliability.

The mains results of the analysis using this model are as follows:

- Flight delays account for approximately 41% of the total passenger trip delays. The remaining passenger trip delays are a result trip delays experienced by passengers due to cancelled flights and missed connections.
- The way airlines design their networks has a significant impact on total passenger trip delay. The *ratio between direct and connecting itineraries*, the *time between banks at the hubs*, the *frequency of service*, and the *selection of aircraft size* and *target load factor* play a significant role in determining passenger trip reliability.

These results have broad implications on the potential benefits of NextGen and AIP, the way benefits analyses for NextGen concepts-of-operations are conducted, and the degree of authority regulators have in managing the airline system for passenger consumer protection. For example, under certain circumstances a 10% increase in load factor can nullify the benefits of a 5% improvement in flight on-time performance.

This paper is organized as follows: Section 2 describes the underlying components of the model (i.e. flights, itineraries and disruptions). Section 3 describes passenger trip reliability metrics, Section 4 describes the model. Section

5 provides an analysis using the model for a 50 spoke hub-and-spoke airport. Section 6 provides a discussion of the implications of these results.

FLIGHTS, PASSENGER ITINERARIES AND DISRUPTIONS

Airlines provide the transportation service by scheduling and selling tickets for carrying passengers between origin and destination (O/D) pairs. To maximize utilization of assets (e.g. aircraft, crews, gate agents, etc.), airlines operate a time-space network of flights that is synchronized with the ticketed schedule and the availability of aircraft and labor.

The building block of airline transportation is a *fligh*t between an origin and destination airport. A flight is defined by a flight number, an origin/destination, a scheduled departure time, a scheduled arrival time, an actual departure time, and an actual arrival a time. A flight is also defined uniquely by the available seats, load factor, and once a flight is operated, by a flight status: on-time, delayed, cancelled, diverted.

Feasible sequences of flights to ferry passengers from an origin to a destination are known as *passenger itineraries*. A passenger itinerary is defined uniquely by a single flight (e.g. AAL 123) or by a sequence of flights (e.g. UAL 345 & UAL 456), along with the number of passengers on the itinerary. A passenger itinerary supported by a single flight is classified as *direct itinerary*. A passenger itinerary supported by more than one flight is classified as a *connecting itinerary*. Each passenger itinerary is also uniquely classified by an itinerary status: on-time, delayed, rebooked due to missed connection, rebooked due to cancellation, and diverted.

Networks and Itineraries

Airlines schedule flights to operate in a time-space network of flights such that aircraft and crews can be positioned to operate the flights in contiguous manner throughout the day. A well designed network of itineraries will maximize revenue by meeting passengers travel demands, and minimize costs by using the most cost-effective aircraft, keeping the aircraft utilized as much as possible, and minimizing the impact of disruptions.

Efficient transportation can be achieved using a hub-and-spoke network (Morrison & Winston, 1986). With a network structure, flights from the spokes of the network haul passengers to a central hub, where the passengers disembark and connect to flight to other spokes. A typical hub-and-spoke network will operate multiple banks each day. A *bank* includes a group of inbound flights that bring passengers to the hub such that they can connect with the outbound flights.

By definition, each flight in the network will have passengers with direct and connecting itineraries on board. For example, a Delta flight from Washington, D.C. (DCA) to Atlanta (ATL), will have passengers flying on a direct itineraries from DCA to ATL, as well as passengers flying on connecting itineraries from DCA to DEN, MEM, LAX, …, all connecting at ATL. The number of passengers on each flight is the sum of all the passengers on each of the passenger itineraries that form that flight.

The percentage of passengers flying on direct itineraries is a critical factor in determining the economic feasibility of the hub. Hub-and-spoke networks typically operate with between 50% and 65% of the passengers on connecting itineraries (Baik et al, 2010). The other critical factor is the choice of aircraft size, or the manipulation of airfares to drive travel demand. Both of these factors determine the load factor that has implications for the “reserve” seat capacity used to accommodate passengers on cancelled or missed connected itineraries.

Relationship between Flight Disruptions and Itinerary Disruptions

A flight can be disrupted as follows: delayed, cancelled, or diverted. For each of the class of flight disruptions there exists both a probability of disruption and a magnitude of the average flight delay. During the last decade flight on-time performance has hovered around 70% (i.e. probability of disrupted flights is 0.3), with average delay for a delayed flight of 50 minutes (BTS, 2010). The likelihood of a cancelled flight is around 2%.

When flights are disrupted, passenger itineraries are disrupted. The relationship between a flight disruption and a passenger itinerary disruption is summarized in Table 1. The likelihood of a disruption of direct itineraries is a function of the likelihood of the disruptions of flights only. The magnitude of the disruption for passengers on direct itineraries is a function of the flight delay for delayed itineraries, and a function of the availability of seats and time to next flight for passengers rebooked for cancelled itineraries.

The likelihood of a disruption of connecting itineraries is a function of the likelihood of the disruptions of flights as well as the structure of the connections. Connecting itineraries that are delayed reflect the likelihood and magnitude for a delayed flight between the hub and the destination. Connecting itineraries that are cancelled are a function of the cancellation rates for the flights inbound to the hub and outbound from the hub. The magnitude of the disruption for passengers is a function of availability of seats and time to next flight for passengers rebooked on cancelled itineraries. The probability of a missed connection on a connecting itinerary is a function of the likelihood for the delay of flights that are inbound to the hub, with a magnitude of delays that extends beyond the connecting window and the airline policy for coordinating inbound and outbound banks by holding flights. Analysis of historic data indicates a probability of a missed connection at 0.02.

PASSENGER TRIP DELAY METRICS

Reliability in passenger transportation is measured by the difference between ticketed scheduled arrival time and the actual arrival time. This measure takes into account delays accrued by passengers due to delayed flights, as

Itinerary Type	Type of Itinerary Disruption	Type of Flight Disruption	Probability of Itinerary Disruption	Magnitude of Itinerary Disruption (Average)
Direct	Delayed	Arrival of flight O-D is delayed (more than 15 minutes)	Based on Probability of Delayed Flight (typical = 0.3)	Based on Average delay for delayed flights
	Cancelled	Flight O-D is cancelled (	Based on Probability of Cancelled Flight (typical 0.02)	Based on Availability of Seats on subsequent flights and Time to next flight
Connecting	Delayed	Arrival of flight H-D is delayed (more than 15 minutes)	Based on Probability of Delayed Flight (typical 0.3)	Based on Average delay for delayed flights
	Cancelled	Flight O-H is cancelled *or* flight H-D is cancelled	Twice probability of Cancelled Flight (typical 2 * 0.02)	Based on Availability of Seats on subsequent flights and Time to next flight
	Missed Connection	Flight O-H is delayed such that passengers miss connection to H-D	A function of connecting times and airline policies regarding holding flights (typical 0.02)	Based on Availability of Seats on subsequent flights and Time to next flight

The relationship between flight disruptions and passenger itinerary disruptions. Also describes the characteristics of the passenger trip delays.
Table 1

well as rebooking due to cancelled flights and missed connections.

There are three main metrics used to capture the passenger trip reliability (Sherry & Wang, 2007; Bratu & Barnhart, 2005):

1. Annual Total Passenger Trip Delays
2. Percentage of Passengers Disrupted
3. Average Trip Delay for Disrupted Passengers

Annual Total Passenger Trip Delays represents the cumulative delays experienced by passengers. These delays include disruptions due to delayed flights, cancelled flights, diverted flights and missed connections. This is a holistic metric of the magnitude of the trip delay phenomenon and is used to estimate lost economic productivity.

The Percentage of Passengers Disrupted represents the likelihood of a disruption due to delayed flights, cancelled flights, diverted flights or missed connections. The Average Trip Delay for Disrupted Passengers provides a measure of the magnitude of the delays experienced by disrupted passengers. These two metrics are used to assess the reliability of the airline in providing the transportation service from a passenger standpoint.

When the Percentage of Passengers Disrupted is multiplied to the Average Trip Delays for Disrupted Passengers, the result is an expectation, or a measure of the expected trip delay experienced by a passenger selected at random from the pool of all passengers.

AGGREGATE PROBABILISTIC MODEL

An aggregate, probabilistic model for the operation of a hub-and-spoke network is outlined in the Figure 1. There are four components: (1) Itinerary Structure, (2) Passenger Allocation to Itineraries, (3) Itinerary Disruption, and Passenger Trip Delays. Each of these components is described in the sections below. A detailed description of the model is available in Sherry (2011).

Itinerary Structure

The itinerary structure determines the number of flights and the number of direct and connecting itineraries. A canonical hub-and-spoke network with "N" spokes will yield (2N) direct itineraries, and N(N-1) connecting itineraries. There will always be one Direct Itinerary per Flight, and a maximum of (N-1) Connecting Itineraries on a flight.

A typical hub-and-spoke network will operate multiple banks each day. A bank includes a group of inbound flights that bring passengers to the hub such that they can connect with the outbound flights. The number of banks operated each day, or the time between banks, has a significant effect on the magnitude of delay experienced by passengers that must be rebooked due to a cancelled or miss connected itinerary.

Passenger Allocation

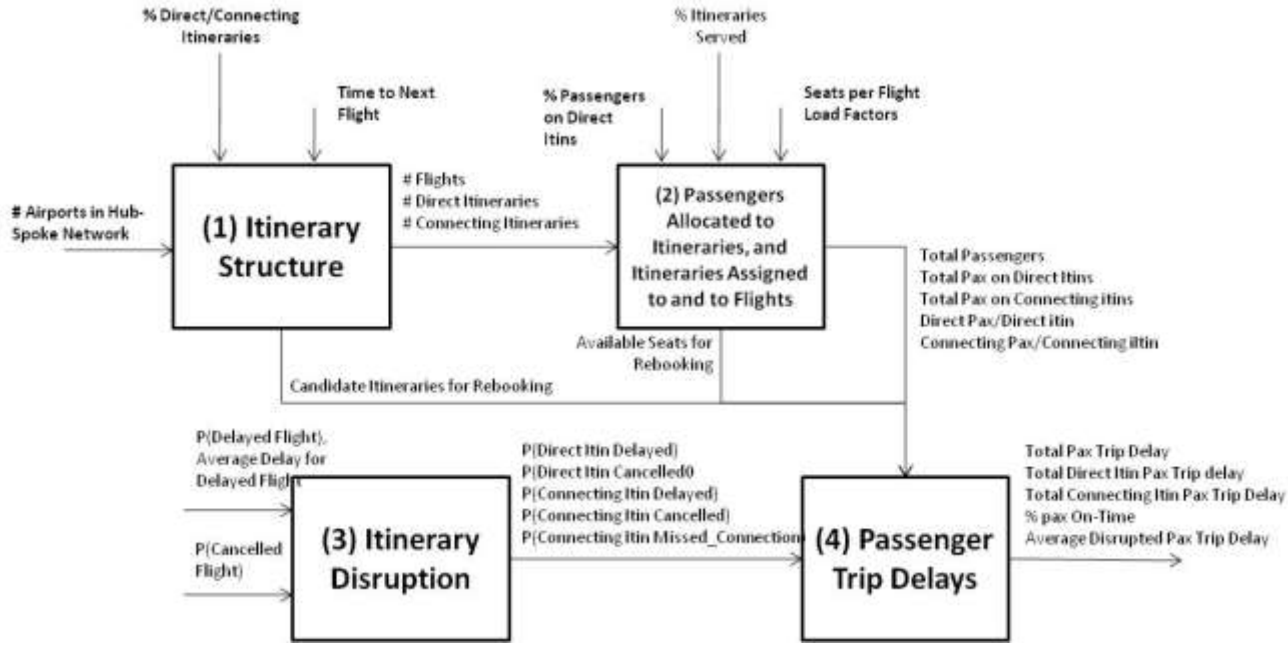
The Passenger Allocation component determines the number of passengers on each type of itinerary. Since connecting itineraries exhibit higher probability of disruptions than direct itineraries, the number of passengers on each type of itinerary is impacts passenger trip reliability. Also, the number of seats per flight and the load factor, determine the availability of seats for rebooked passengers, and impacts the magnitude of delay experienced by these passengers.

Itinerary Disruption

The Itinerary Disruption components takes as inputs the probability of a delayed flight, and generates the probability and the average magnitude of disruption for each type of itinerary according to the rules in Table 1.

Passenger Trip Reliability

The Passenger Trip Reliability component takes as inputs the number of each type of itinerary, the number of passengers on each itinerary, and the likelihood and magnitude of



Components of the probabilistic model of passenger trip reliability for the airline transportation system

Figure 1.

itinerary disruptions. The outputs of the module are the passenger trip delay statistics: total delay, average delay for disrupted passengers and percent passengers disrupted. Passengers on direct itineraries are less likely to be disrupted than passengers on connecting itineraries. Passengers that are rebooked due to a cancelled itinerary or a missed connection will

FACTORS THAT IMPACT PASSENGER TRIP RELIABILITY

The model of itinerary disruptions described above, identified four factors that affect the passenger trip reliability metrics. Whereas it is commonly understood that flight delays are the a source of passenger trip delays, this model shows the significant roles played by percentage of passengers on direct/connecting itineraries, load factor/aircraft size, and time-to-next flight. Table 2 summarizes the impact of each of the four factors has on passenger trip reliability. The percentage of passengers on direct/connecting itineraries determines the

Factor	Number of Disrupted Passengers	Probability of Disrupted Itinerary	Magnitude of Delay on Disrupted Itinerary
(1) Itinerary network/percentage of passengers on direct and connecting itineraries	Number of passengers on direct and connecting itineraries	N/A	N/A
(2) Flight on-time performance	N/A	Probability of delayed, cancelled and cancelled flights on direct itineraries and delayed, cancelled, and missed connection on connecting itineraries	Delays for delayed flights on direct itineraries and connecting itineraries
(3) Load Factors/Aircraft Size	Number of passengers on disrupted flights	N/A	Rebooking delays due to cancelled flights and missed connections
(4) Time-to-Next Flight/Service Frequency	N/A	N/A	Rebooking delays due to cancelled flights and missed connections

Summary of the impact each of the four factors has on passenger trip reliability.

Table 2.

number of passengers on each type of itinerary. Since connecting itineraries are more likely to be disrupted than direct itineraries, as the number of passengers on connecting itineraries grows so the passenger trip reliability metrics will degrade.

Flight on-time performance impacts the probability of a disrupted itinerary as well as the magnitude of itinerary delays. As the flight on-time performance degrades, the probability of a delayed flight, the probability of a cancelled flight, and the probability of a missed connection increase. As the flight on-time performance degrades, the magnitude of delays for itineraries disrupted by delayed flights increases.

Load factor and aircraft size determine the number of passengers in the transportation system. Load factor and time-to-next flight affect the magnitude of delays for passengers that must be rebooked due to cancelled flights or missed connections.

CASE STUDY OF A HUB-AND-SPOKE NETWORK

Table 3 summarizes the results of a case study analysis of a 51 airport hub-and-spoke network (i.e. 50 spoke airports and one hub airport) with baseline configuration for the airline transportation system representing statistics from 2007: Passengers itineraries are split 50-50 between direct and connecting, load factor is 80%, average time between banks is 120 minutes, and flight performance is 70% on-time with 2% cancelled flights. Passengers on direct itineraries experience lower delays than passengers on connecting itineraries. Passengers disrupted by delayed flights account for 41% of the Total Passenger Trip Delay.

Trip Reliability Metric	**Direct**	**Connecting**	**Total**
Total Pax Trip Delay	4K hours	7.6K hours	11.6K hours
% Pax Disrupted	32.5%	38.1%	
Average Pax Trip Delay for Disrupted Pax	93 mins	150 mins	69 mins

Trip Reliability Metrics for 51 airport hub-and-spoke using 2007 airlines transportation statistics

Table 3

Table 4 shows the impact of changing each one of the four factors that impact passenger trip reliability. The first row in Table 4 provides the statistics for the baseline configuration.

The next four rows in Table 4 describe the impact on Total Passenger Trip Delay, Percentage Passengers Disrupted, and Average Trip Delay for Disrupted Passengers of four scenarios that have taken place between 2007 and 2010:

1. Airlines consolidate operations resulting in 10% more passengers on connecting itineraries
2. Airlines adjust fleet mix to smaller aircraft and improve revenue management resulting in increase in load factor by 10%
3. Airlines respond to cost pressures by reducing frequency of service and/or implementing rolling banks resulting in an increase in the average time to next flight of from 120 minutes to 180 minutes.
4. Increase in airport/airspace capacity and/or reduced schedule congestion resulting in improved flight on-time performance of 5%

The results in the three right-hand columns show that passenger shifting itineraries can have an effect of passenger trip reliability. These effects, however, are relatively small in

Factor	% Passengers on Direct	% Load Factor (Seats Adjusted)	% Delayed & Cancelled Flights	Time between Banks	Change in Total Pax Trip Delay	Change in % Pax Disrupted	Change in Average Disrupted Pax Delay
Baseline	**50%**	80%	30% / 2%	120 mins	-	-	-
1. Consolidating flights to hubs resulting in shift to connecting itineraries	**45%**	80%	30% / 2%	120 mins	Increase 6%	Decrease 1.7%	Increase 4.5%
2. Downguaging and/or Improved Revenue Management resulting in increased load factor	50%	**88%**	30% / 2%	120 mins	Increase 32%	No Change	Increase 43%
3. Reduced Frequency and/or Rolling Banks resulting in longer Time to Next Flight	50%	80%	30% / 2%	**180 mins**	Increase 37%	No Change	Increase 36%
4. ATC/Airport Capacity decrease or Peaking congested Schedules resulting in improved Flight On-time Performance	50%	80%	**25% / 1.8%**	120 mins	Decrease 16%	Decrease 18%	Decrease 12%
5. All of the above scenarios combined	**45%**	**88%**	**25% / 1.8%**	**180 mins**	Increase 55%	Decrease -19%	Increase 92%

Impact of changes from individual factors on passenger trip reliability. Non-flight performance factors of load factor and time-ton-next-flight are significant and can overcome benefits gained by improved on-time flight performance.

Table 4

comparison to the effects of increased load factor and increase in time-to-next-flight.

Changes in load factor and time-to-next-flight increase the two Passenger Delay metrics by more than 30% each. These independent effects are in excess of the benefits of increased capacity and de-peaked schedules from improved flight on-time performance that offer only approximately 15% improvements.

The last row in Table 4 shows the impact on passenger trip reliability metrics when all four scenarios are implemented simultaneously. The combined effect of these actions resulted in an increase in Total Passenger Trip Delay and Average Trip Delay for Disrupted Passengers, and a decrease in Percentage of Passengers on Disrupted Flights. The benefits of shifting itineraries and improved flight on-time performance result in improvements in Percentage of Passengers on Disrupted Flights. The benefits of improved flight on-time performance on Total Passenger Trip Delay and Average Trip Delay, however, were swamped by the increases due to load factor and time-to-next-flight. Further the cumulative effects are not additive, indicating a non-linear interaction between the parameters.

CONCLUSIONS

This paper has shown that passenger trip reliability is determined by flight performance factors (i.e. flight on-time performance) *as well as* factors that have nothing to do with flight performance (i.e. load factors, frequency of service, and itinerary design). As a consequence, passenger trip reliability is a complex phenomenon that crosses traditional jurisdictional boundaries.

Airline Business Decisions Have Significant Impact on Passenger Trip Reliability

As passenger demand for air transportation service fluctuates, airlines are obliged to continuously adjust their operations. To achieve, revenue, cost, profit and market-share targets, airlines respond by adjusting itineraries, banking structures, aircraft size, and load factors. Table 5 provides a summary of the changes in the market for air travel and the industry between 2007 and 2010 and the effects on the factors that affect passenger trip reliability.

In many cases the enterprise actions are not congruent with the goal of maximizing the reliability of passenger trips. For example, recent airline successes in increasing revenue and asset utilization through Revenue Management (Cross, 1997) and Demand-Driven Dispatch (Berge et. al**,** 1993) have resulted in increased load factors and increased time between flights. These actions, however, result in longer delays for passengers rebooked due to cancelled flights or missed connections. In other cases, increased time between banks has improved on-time flight performance and reduced the likelihood of a missed connection, but increased the time-to-next flight.

Changes in Market and Industry	Factors that Affect Passenger Trip Reliability
Changes in passenger travel geographic demand Seasonal changes in airlines networks Consolidation of competing airline networks Expansion/contraction of hub operations Availability of competing modes of transportation	Determines the % Passengers on Direct and Connecting Itineraries
Efforts to reduce airline costs and provide improve passenger quality of service	Determines time between banks (e.g. rolling banks, continuous banks)
Changes in travel demand in existing network	Determines Aircraft Size and Loaf Factor
Airlines adjust airfares and over-booking rates to meet revenue, profit, and market-share	Determines Load Factor
Reduced schedules or increased airport and airspace capacity and productivity (e.g. NextGen)	Determines flight delays (and cancellation rates)

Summary of changes in the air travel market and industry that affect factors that drive passenger trip reliability.

ATC Modernization and NextGen

One of the underlying assumptions associated with ATC modernization initiatives is that when flight on-time performance improves, passenger trip delay statistics will improve too. This was not borne out in the estimated passenger trip delay statistics during the period 2007 – 2009 (see Sherry, 2010; Barnhart et. al, 2010). During this period, reductions in flight schedules lead to reduced congestion, which lead to improved on-time performance. However, passenger trip reliability did not change proportionally to the improvements in on-time flight performance.

This model shows that flight delays are *one* of four factors that affect passenger trip reliability. The structure of the airline space-time network, fleet mix, and airline revenue and competitive strategies all have a significant role. Changes in aircraft size along with revenue management improvements that increase load factor have the biggest impact on passenger trip reliability metrics. Banking structure and frequency of service, along with flight on-time performance have the next greatest impact. Shifting itineraries has a lower impact than all the others.

ATC Modernization Benefits Analysis and NAS-wide Simulations

NAS-wide simulations are one of the methods used to estimate annual system-wide benefits for Air Traffic Control modernization concepts-of-operations and technologies (e.g. NextGen). These tools simulate the operation of up to 60,000 flights per day in various combinations of demand (i.e. flights) and capacity (i.e. airport and airspace capacity). The main input to the simulation is a schedule of flights (not a schedule of passenger itineraries). As a result, estimates of passenger delays generated directly from these simulations assume all passengers are on direct itineraries only. The impact of cancelled flights, missed connection, and airline network effects are not directly generated.

The model described in this paper shows that the reduction in lost economic productivity generated from NAS-wide simulations will be under-reported, as passenger trip delays due to delayed flights only account for approximately 45% of the total passenger trip delays.

Further, the model identifies the significant roles played by factors other than flight performance, such as airline itinerary structure, airline fleet mix (i.e. aircraft size), load factors and airline hub banking structure, on total passenger trip delay. Careful book-keeping must be done capture the underlying factors assumed when validating the return-on-investment for NextGen to account for airline network structure effects. For example, for a 51 airport hub-and-spoke network, a 7-10% increase in load-factor can nullify the reduction in total passenger trip delay gained by a 5% improvement in flight on-time performance achieved by NextGen.

Consumer Protection

A Passenger Bill of Rights is government legislation or rule that sets service standards for airline passengers. The European Union (E.U.) has a comprehensive set of rules related to the airlines responsibilities for compensation and assistance of passengers in the event of cancellations, long delays and denied boarding. The E.U. Air Passenger Bill of Rights mandates compensation for passengers in the event of denied boarding based on distance of flight. In the event of long delays passengers must be provided services, meals, hotel accommodation or the option for reimbursement. Financial compensation for a cancelled flight is due unless the airline has informed passengers of the flights' cancellation 14 days prior to the flight, or if the passengers have been rerouted close to their original travel times. Airlines are exempt from compensation should the cancellation be due to extraordinary circumstances.

In contrast the U.S. Passenger Bill of Rights includes only provisions for denied boarding and for extended delays (> 2 hours) on the tarmac. This bill of rights does not include any provisions for passenger compensation for delayed or cancelled itineraries. Based on the passenger itinerary model described in this paper, the absence of cancellations and missed connections in the bill are significant omissions, as these factors are significant contributors to individual total passenger trip delays.

Complex Phenomenon and Jurisdictional Boundaries

The model described in this paper identifies how enterprise decision related to competitive strategies and cost structures can impact passenger trip reliability. In addition to the inherent complexity is the fact that the factors that affect passenger trip reliability crosses traditional boundaries of jurisdiction and prevents any one enterprise (e.g. government or a single airline) from solving the system-wide issues. Airline decisions affecting load factors, aircraft size, itinerary service, and bank structure are at the core of the competitive strategies of the airlines that, in theory, leads to price competition and benefits to consumers. As a consequence, they have historically been outside the jurisdiction of government oversight and regulation. Any government attempt to legislate across these boundaries is likely to impact the competitive structure of the airline business.

References

Baik, H., T Li, N. Chintapudi (2010) Estimation of Flight Delay Costs for U.S. Domestic Air Passengers. Transportation Research Record. Journal of the Transportation Research Board. No. 2177. Page 49.

Barnhart, C., D. Fearing, and V. Vaze (submitted 2010) Modeling Passenger Travel and Delays in the National Air Transportation System. Submitted to Operations Research, August 3, 2010.

Berge, M.E. C. A. Hopperstad (1993) Demand Driven Dispatch: A Method for Dynamic Aircraft Capacity Assignment, Models and Algorithms. OPERATIONS RESEARCH, Vol. 41, No. 1, January-February 1993, pp. 153-168

Bratu, S., Barnhart, C. (2005). An Analysis of Passenger Delays Using Flight Operations and Passenger Booking Data. *Journal of Transportation and Statistics, Number 1, Volume13, 1-27*

Bureau of Transportation and Statistics (2010). Airline On-Time Performance Data, Form 41 Traffic T-100 Domestic Segment Data, DB1_B Coupon Data. Available: *http://www.transtats.bts.gov*. *2010*

Cross, R. (1997) Revenue Management: Hard-Core Tactics for Market Domination. New York, NY: Broadway Books

Federal Aviation Administration (2010) Airport Improvement Program. Website for FAA Airports business unit. http://www.faa.gov/airports/aip/

Morrison, S. and C. Winston (1986) the Economic Effects of Airline De-regulation. The Brookings Institution. Washington, D.C. pages 4-10.

NextGen, 2010 “FAA’s NextGen 2010 Implementation Plan” http://www.faa.gov/nextgen/media/appendix_b.pdf

NEXTOR (2010) Total Delay Impact Study: A Comprehensive Assessment of the Costs and Impacts of Flight Delay in the United States. Report prepared for FAA Air Traffic organization - Strategy and Performance Business Unit Washington D.C.

Sherry, Lance, D. Wang (2007) Air Travel Consumer Protection: Metric for Passenger On-Time Performance. Transportation Research Record, Transportation Research Board of the National Academies, Volume 2007, pages 22-27.

Subramanian, B. 92007) *Aggregate Statistical Models for National Airspace System Performance*. MS thesis, University of Maryland, College Park, 2007.

Tien, S. A., B, Subramanian, and M. Ball (2008). Constructing a Passenger Trip Delay Metric: An Aggregate-level Approach. Proceedings International Conference on Research in Air Transportation (ICRAT-2008), Fairfax, VA, 2008

Zhu, Y. (2007) Evaluating Airline Delays: The Role of Airline Networks, Schedules and Passenger Demands. Masters Thesis, MIT, Cambridge, Massachusetts. Advisor: Cynthia Barnhart.

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