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Analysis of Additional Delays Experienced by Flights Subject to Ground Holding

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Flights subject to Ground Delay Programs and Airspace Flow Programs are held on the ground, taking specified delays at their departure airports, to address capacity constraints at their arrival airports and regions of en route airspace, respectively. These ground holds, ranging from tens of minutes to a few hours, affect a large number of flights and can disrupt air traffic operations on a national scale. It is therefore of interest to minimize additional delays for such flights. This paper analyzes the magnitude and nature of additional delays experienced by flights subject to ground holding, utilizing historical flight operations data for five airports whose arrivals experienced the most pre-departure ground holding in 2015. At four of these airports, arrivals subject to ground holding incurred additional gate-arrival delays substantially larger (about two to three times on average) than for arrivals that were not subject to ground holding. These inequities in additional gate-arrival delays were caused primarily by taxi-out delays at the departure airports. Airborne delays were a secondary cause of these delay inequities, and there was a minor contribution from taxi-in delays. There were mixed trends in the role of gate-departure delays not caused by ground holding. Overall, these results motivate a recommendation to expedite surface movements at departure airports for those flights already delayed by ground holding.

Introduction

The objective of traffic flow management is to balance the demand for flight resources, i.e., airspace and airports, with the available supply across the National Airspace System (NAS). If the forecasted demand exceeds the available supply, Traffic Management Initiatives (TMIs) are implemented to maintain safety by regulating the demand. Depending on the nature and scope of the supply/demand imbalance, possible TMIs include: Ground Stop, Ground Delay Program, Re-routing (Playbook, Coded Departure Routes, *ad hoc* local re-routing), Airspace Flow Program, Miles-in-Trail, Departure Sequencing, En route Sequencing, Arrival Sequencing/Metering, Capping, and Tunneling [1].

An airport runs a Ground Delay Program (GDP) when the forecasted arrival rate exceeds the planned airport acceptance rate over a substantial interval of time. This may occur, for example, during periods when there is very high arrival demand while the airport is operating at its nominal landing capacity, or during periods when arrival demand is moderate but the airport acceptance rate has been reduced by local weather conditions such as low ceilings/visibility. During a GDP, departures bound for the affected airport are held on the ground (delayed) at their airports of origin such that a flight's actual wheels-off time matches its assigned Expect Departure Clearance Time (EDCT). A similar ground hold is experienced by flights subject to an Airspace Flow Program (AFP), which is implemented to address a congested airspace constraint typically resulting from convective weather. The airspace supply/demand imbalance is mitigated by regulating the flow of traffic through the congested airspace by issuing EDCTs to flights whose planned routes intersect the airspace constraint. The EDCTs for a GDP or AFP are computed using a ration-by-schedule algorithm [2] to deliver the desired flow rate at the constraint (airport or airspace).

The individual ground delays experienced by flights subject to EDCTs are substantial, typically ranging from tens of minutes to a few hours. In addition to this substantial EDCT delay, such flights often experience additional delays from various other causes including other TMIs. Reference [3] presents aggregate statistics on the implementation of various TMIs (including GDPs and AFPs), while [4] presents aggregate statistics on various types of delays as well as other NAS data of interest. Some other aspects of flight delays are analyzed in [5] and [6]. An analysis of double delays, specifically the interaction between GDPs and arrival metering, affecting short-haul

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flights bound for Newark airport is presented in [7]. The objective of this paper is to compare the magnitude and nature of additional delays for EDCT-affected flights against similar flights that were not affected by EDCTs. The resulting insights may help generate recommendations to address any inequitable penalties imposed on EDCT flights by other delay-causing factors.

Delay Classification

Figure 1 illustrates some key flight-related events and associated time intervals, along a timeline. Gate Out is pushback from the departure gate, Wheels Off is liftoff from a runway of the departure airport, Wheels On is touchdown on a runway of the arrival airport, and Gate In is parking brake engaged at the arrival gate. Each of these events is associated with a scheduled time and an actual time that is often different from the scheduled time. In Fig. 1, the blue rectangles correspond to nominal time intervals, while the red rectangles correspond to time delay intervals. Block time is defined as the interval between Gate Out and Gate In. A "block buffer" is used by airlines to incorporate average historical delays into their schedule; this buffer value is different for each flight according to its past delay experience. This is why a flight could experience modest delays along its air/ground trajectory and still park "early" at its arrival gate. From Fig. 1 it is observed that:

$$\text{Gate-Arrival Delay} = (\text{Gate-Departure Delay} + \text{Taxi-Out Delay} + \text{Airborne Delay} + \text{Taxi-In Delay}) - \text{Block Buffer} \quad (1)$$

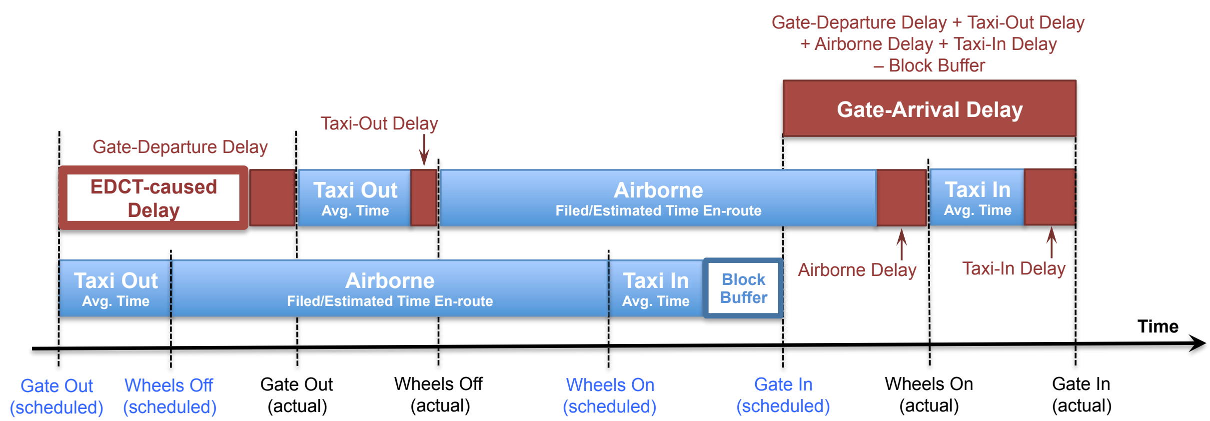

Fig. 1. Definitions of key time intervals and delays

The delay types examined in this study are listed below. Except for EDCT-caused gate-departure delays, any/all of these delays may be negative due to early events.

(1) Gate-departure delay
  a) caused by EDCT
  b) not caused by EDCT
(2) Taxi-out delay
(3) Airborne delay
(4) Taxi-in delay
(5) Gate-arrival delay: equal to the sum of the above delay components, minus the block buffer.

EDCT delay is the difference between the GDP/AFP-assigned wheels-off time and the originally scheduled wheels-off time. In practice, this EDCT-caused delay is generally taken at the departure gate. Gate-departure delays not caused by EDCTs may arise from maintenance/availability issues with the aircraft, delays associated with crew/passenger/baggage connections, or surface movement constraints at the departure airport. Taxi-out/in delays are variances from historical average taxi times at the departure/arrival airports; these variances are caused by prevailing operational factors such as traffic congestion, visibility, rain, or snow.

Airborne delays can arise because flight conditions (e.g., winds, temperature) actually experienced were different from those used for flight planning purposes, and/or because the flight experienced one or more TMIs that affected its trajectory between wheels-off and wheels-on. Examples of such TMIs include speed control to meet miles-in-trail restrictions, speed control or path stretching for arrival spacing/metering, route deviations around convective weather and/or congested airspace, and airborne holding to tactically absorb large delays. Hence any substantial airborne delays experienced by EDCT-affected flights are indicative of additional TMIs experienced by such flights. This is of interest because current operational practice is to design TMIs independently of each other, and hence some flights are affected by multiple TMIs.

Analysis of Historical Delay Data

The Aviation System Performance Metrics (ASPM) database [8] is maintained by the Federal Aviation Administration. It provides various types of historical information, including delay data, for flights operated by all carriers to/from the 77 ASPM domestic airports and all flights operated by the 22 ASPM carriers.

Selection of Analysis Airports

Using the "Airport Analysis: EDCT Report" function of ASPM, the airports with the most EDCT-affected arrivals in 2015 were identified by examining the percentage of arrivals subject to EDCTs – see Fig. 2. According to this criterion, the top five EDCT-affected airports in 2015 were: New York – LaGuardia (LGA), San Francisco (SFO), Newark (EWR), New York – Kennedy (JFK), and Philadelphia (PHL). Collectively, arrivals at these five airports accounted for 16% of arrivals at the 35 Operational Evolution Partnership (OEP 35) airports, but the EDCT-affected arrivals at these five airports accounted for 52% of EDCT-affected arrivals at the OEP 35 airports. These five airports were selected for further analysis in this paper.

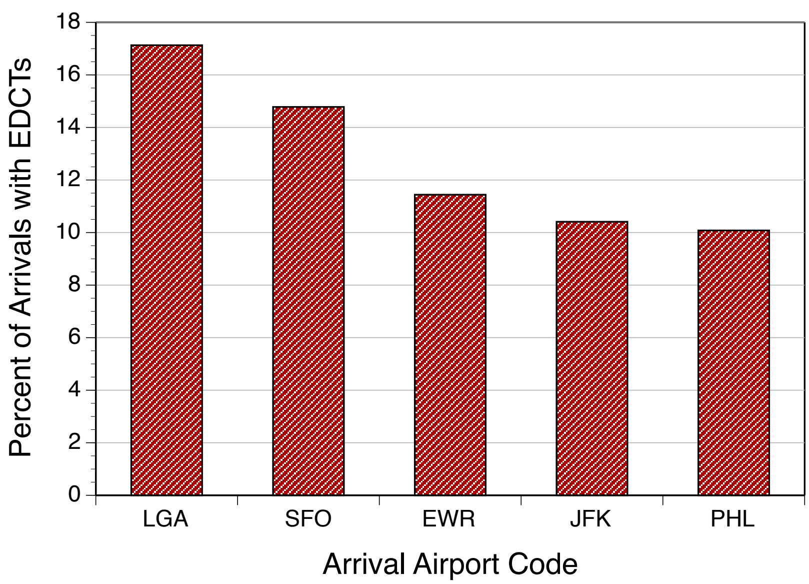

Fig. 2. Top-five EDCT airports in 2015

At each of the above airports, more than 10% of all arrivals were subject to an EDCT. The percentages shown in Fig. 2 correspond to arrivals during all of 2015, but flights were subject to EDCTs only during: 140 days for LGA, 159 days for SFO, 130 days for EWR, 155 days for JFK, and 121 days for PHL. Hence on an EDCT day, a much higher percentage (as high as ~80%) of arrivals at an airport may be subject to EDCTs.

The median and mean values of EDCT delays for the selected airports are presented in Fig. 3. The median is ~30 min and the mean is ~45 minutes, indicating a long tail in the distribution with the 90^{th} percentile (not shown in Fig. 3) of ~100 min. Hence on an EDCT day a large number of flights are subjected to very substantial delays. It is therefore desirable to minimize additional delays experienced by such flights.

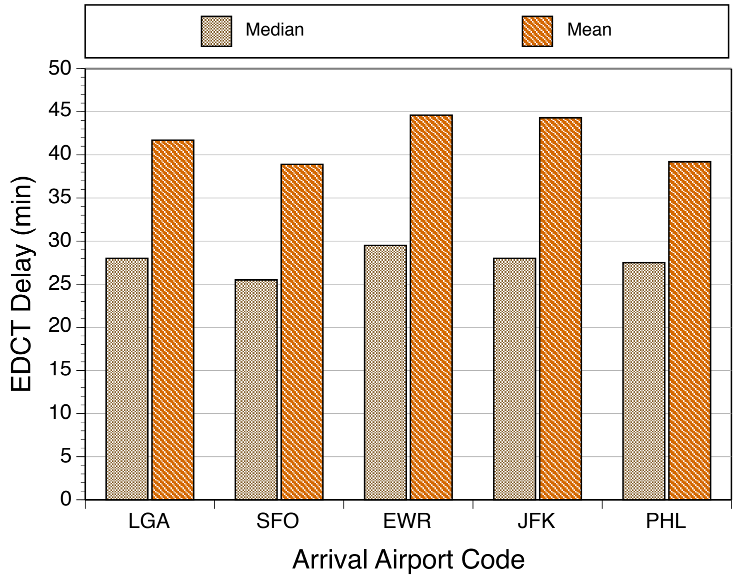

Fig. 3. Median and mean EDCT delays

Example Delay Data for Individual Flights

To provide some insight about delays at the data granularity of individual flights, delay results are now presented for LGA arrivals during the month of June 2015. Using the "City Pair Analysis: All Flights" function of ASPM, schedule-based delay data were obtained for all flights departing from all (over 300) domestic airports for which ASPM data is available. In order to break ASPM data output down to the resolution of a single flight (or at most a few flights) per record, the "Grouping" options used were: Date, Departure Airport, Local Departure Hour, Local Arrival Hour.

The resulting ASPM data set contained records for 13,950 flights that arrived at LGA in June 2015. Of these, 3,128 flights (22%) were subject to EDCTs, i.e., experienced ground holds at their departure airports due to a GDP or AFP. Due to the achieved resolution of ASPM data output, it was not possible to properly correlate delay component data for some (~6%) of the EDCT-affected flights. There were 2,938 EDCT-affected flights for which delay component data could be properly correlated; Fig. 4 shows the EDCT delay for these flights as a function of LGA local arrival hour. The average EDCT delay was 46 minutes, the median was ~30 minutes, and the 90th percentile was ~110 minutes. Some of the outliers had more than four hours of EDCT delay.

Figure 5 plots gate-arrival delay against EDCT delay for affected flights; note that the EDCT delay is a very significant component of gate-arrival delay for these flights. The red line in Fig. 5 represents the locus of points where the gate-arrival delay is equal to the EDCT delay. Any data point that lies above this line corresponds to a situation where the flight experienced a net delay in addition to the departure delay imposed by the EDCT. This could arise from a composite of gate-out delay (not caused by EDCT), taxi-out delay, airborne delay, taxi-in delay, and block buffer. About half of the data points are below the red line; they correspond to situations where some (or all) of the EDCT delay was offset by negative (early) values of the delays just mentioned, and/or due to the block buffer built into the airlines' flight schedules. Some of these flights had negative gate-arrival delays, meaning that they arrived earlier than their scheduled arrival time even though they were subjected to (small) EDCT delays.

Figure 6 plots airborne delay against EDCT delay for affected flights; the mean airborne delay was 8.6 minutes, and the 90th percentile mark was ~25 minutes. It is noted that airborne delay is completely separate from EDCT delay, and that large values of airborne delay are indicative of TMIs such as speed control, re-routing, and holding. The 10% tail of the distribution contains airborne delays ranging from 25 to 60 minutes (with a few outliers beyond); this is significant considering that the average flight time for U.S. domestic operations is on the order of 90 minutes.

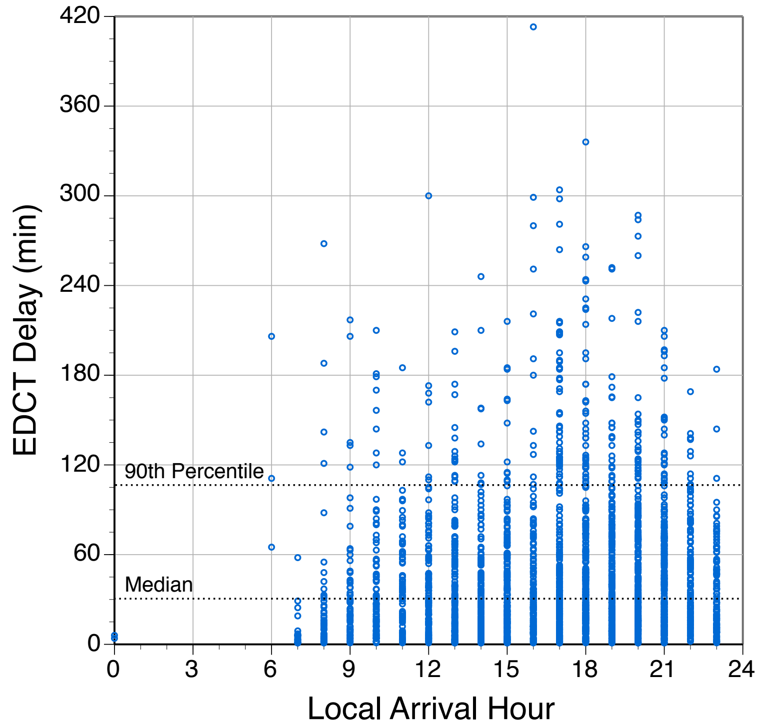

Fig. 4. EDCT Delay vs. Local Arrival Hour

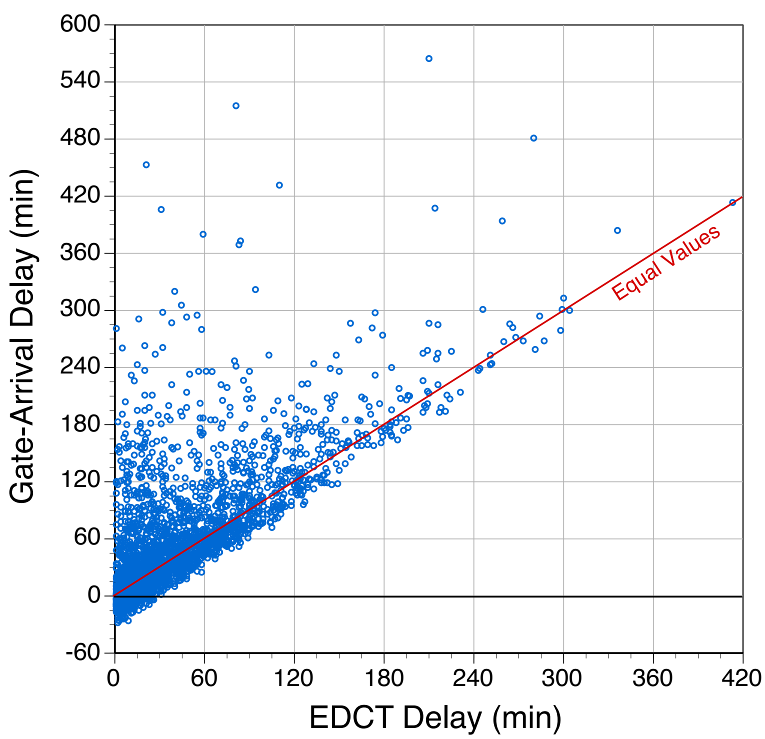

Fig. 5. Gate-Arrival Delay vs. EDCT Delay

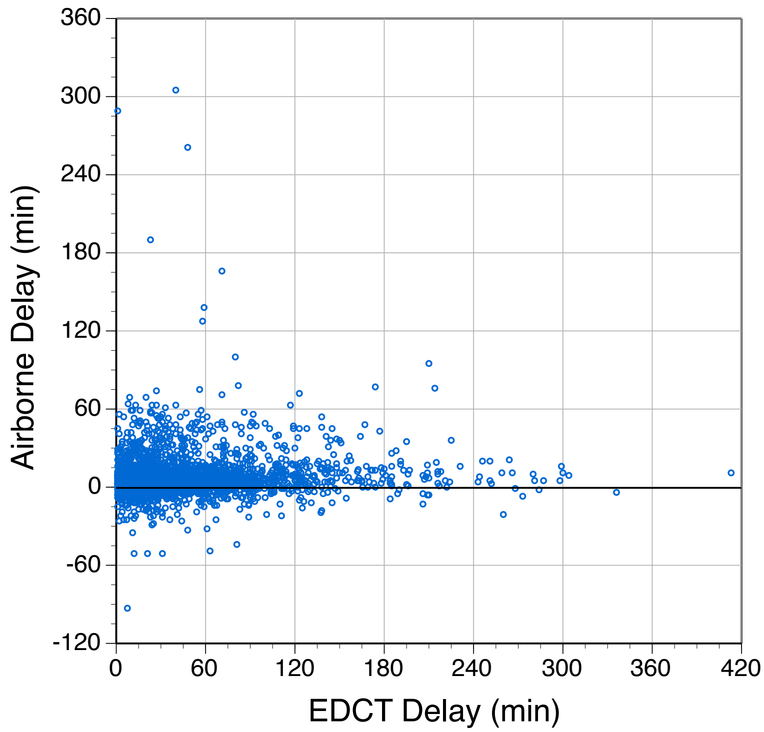

Fig. 6. Airborne Delay vs. EDCT Delay

Comparison of Average Delays: EDCT vs. Non-EDCT Flights

The various types of delays experienced by EDCT-affected flights are now compared with the complementary set of non-EDCT flights for the five selected airports over the year 2015. In order to make a proper comparison, the analysis used data only for those days when the respective airports had any arrivals that experienced EDCTs (140 days for LGA, 159 days for SFO, 130 days for EWR, 155 days for JFK, and 121 days for PHL). It is recognized that on such a day, EDCT and non-EDCT flights bound for the same airport would likely operate during different hours of that day. The raw delay data were obtained from the ASPM database as described in the previous sub-section. Delays of individual flights were aggregated for presentation as average values in this sub-section. Results are presented here for data in the year 2015. Results were also computed for 2014 as well as 2013 data and overall they were found to be generally similar to results for 2015, thus providing some evidence that 2015 was not an abnormal/anomalous year for delay experience.

Figure 7 presents average gate-arrival delays, adjusted for EDCT flights by subtracting out the ground-hold (i.e., EDCT-caused) delay. This enables a fair comparison of gate-arrival delays across EDCT and non-EDCT flights. Thus Fig. 7 shows average gate-arrival delays, for both EDCT and non-EDCT flights, arising from all factors other than EDCT delays. It is observed that for EWR, JFK, LGA, and PHL, the average gate-arrival delays are much larger (by a factor of about two to three) for EDCT flights than for non-EDCT flights. SFO shows the reverse relationship, with a smaller average gate-arrival delay for EDCT flights. Across airports, average gate-arrival delays for non-EDCT flights were on the order of 5 min while average gate-arrival delays for EDCT flights (excluding SFO arrivals) were on the order of 15 min. The remainder of this section examines the components of gate-arrival delay.

The components of adjusted gate-arrival delay are: gate-departure delay (adjusted for EDCT flights by subtracting out the ground-hold delay), taxi-out delay, airborne delay, and taxi-in delay. Average values of these four delay components are shown in Figs. 8 to 11, respectively. The y-axis (delay minutes) scales are intentionally kept equal in Figs. 7 to 11 to facilitate the perception of relative magnitudes across the various delay quantities. Recall that the block buffer is a subtractive element in the computation of gate-arrival delay (see Eq. (1)).

Figure 8 presents average gate-departure delays, adjusted for EDCT flights by subtracting out the ground-hold (i.e., EDCT-caused) delay. Note that the individual gate-departure delays were experienced at the numerous departure airports sending flights to EWR, JFK, LGA, PHL, and SFO. Also, gate-departure delays not caused by

EDCTs can arise from airline constraints as well as departure-airport constraints. Only minor differences between EDCT and non-EDCT flights were observed for EWR, LGA, and PHL arrivals. For JFK arrivals, the average gate-departure delay is larger for EDCT flights. SFO arrivals show the reverse trend, with a smaller average gate-departure delay for EDCT flights. These same characteristics for JFK and SFO arrivals were also observed in 2014 as well as 2013 data, indicating a consistent trend.

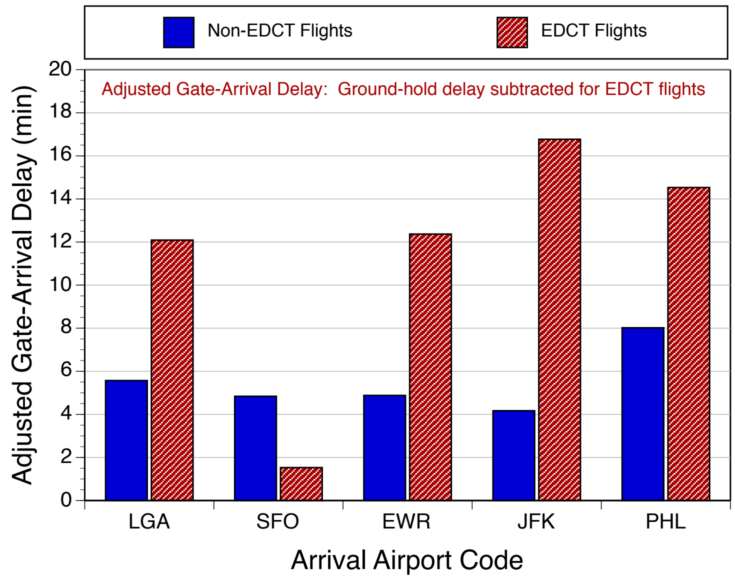

Fig. 7. Adjusted Gate-Arrival Delay

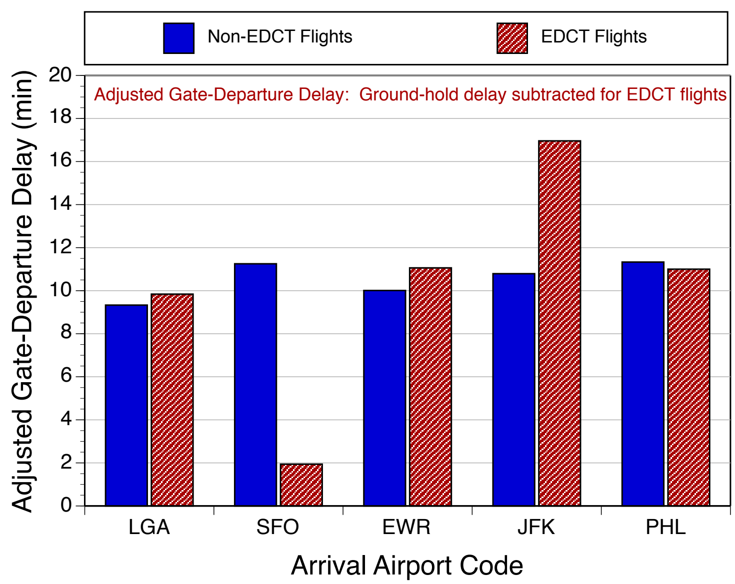

Fig. 8. Adjusted Gate-Departure Delay

Figure 9 shows significantly larger average taxi-out delays for EDCT flights arriving at all five airports; the same relationship was found with remarkable consistency in 2014 as well as 2013 data. Note that the individual taxi-out delays were experienced at the numerous departure airports sending flights to EWR, JFK, LGA, PHL, and SFO.

Figure 10 shows larger average airborne delays for EDCT flights arriving at all five airports, indicating that some of these flights may have been subjected to other TMIs in addition to a ground hold at the departure airport.

Figure 11 shows only minor differences in average taxi in-delays between EDCT and non-EDCT flights for arrivals at all five airports.

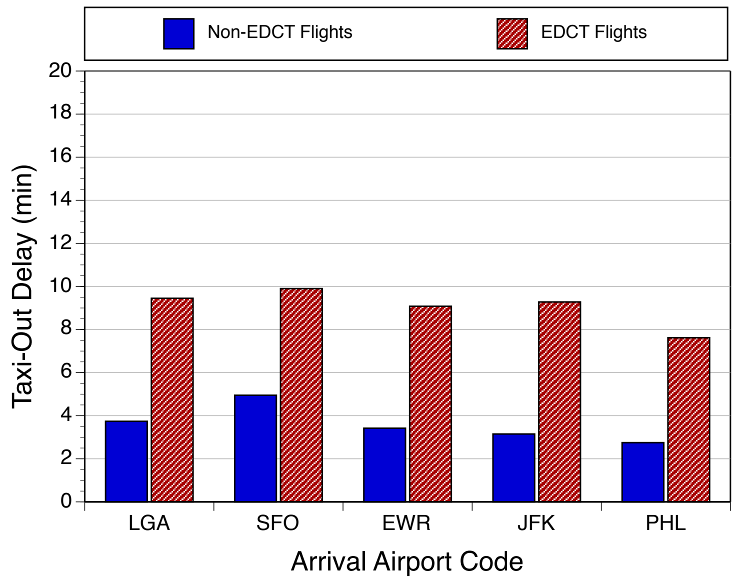

Fig. 9. Taxi-Out Delay

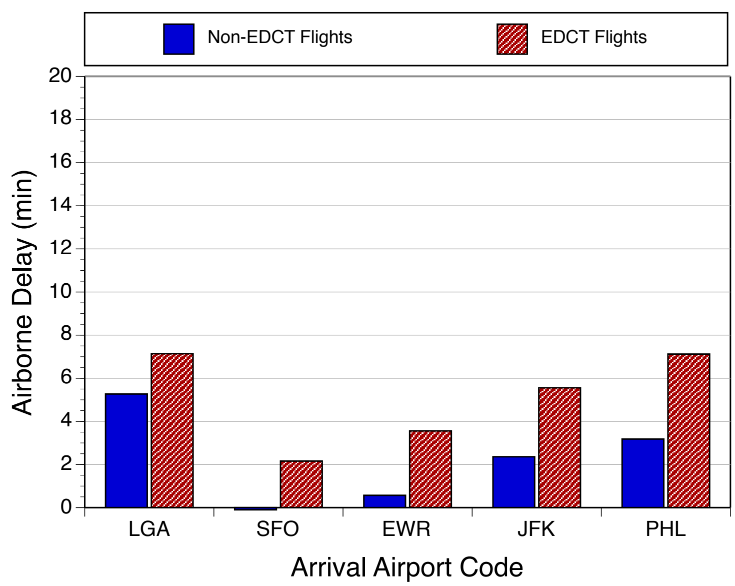

Fig. 10. Airborne Delay

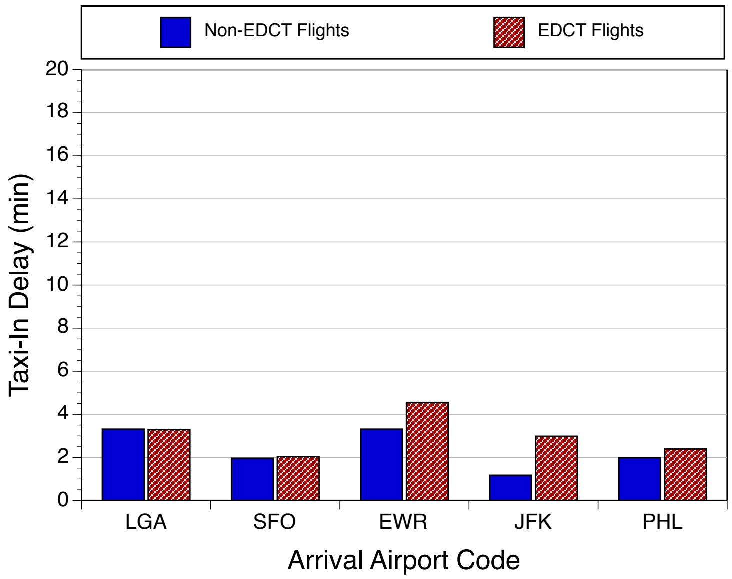

Fig. 11. Taxi-In Delay

Conclusions

An analysis was conducted on the magnitude and nature of additional delays experienced by flights subject to ground holding for GDPs/AFPs, utilizing historical flight operations data for five airports (LGA, SFO, EWR, JFK, PHL) whose arrivals experienced the most pre-departure ground holding in 2015. For all of these airports except SFO, arrivals subject to ground holding incurred additional (in excess of EDCT) gate-arrival delays substantially larger (about two to three times on average) than for arrivals that were not subject to ground holding. These inequities in additional gate-arrival delays were caused primarily by taxi-out delays at the departure airports. Airborne delays were a secondary cause of these delay inequities, and there was a minor contribution from taxi-in delays.

There were mixed trends in the role of gate-departure delays not caused by ground holding. For EWR, LGA, and PHL arrivals the average gate-departure delays were roughly the same for EDCT and non-EDCT flights, while JFK arrivals exhibited larger average gate-departure delays for EDCT flights. SFO arrivals exhibited the reverse trend with smaller average gate-departure delays for EDCT flights.

The main result of this analysis is that EDCT flights experienced substantially larger taxi-out delays than non-EDCT flights, generally resulting in correspondingly larger gate-arrival delays. This motivates a recommendation to expedite surface movements at departure airports for those flights already delayed by ground holding for GDPs and AFPs. This could be done, for example, by assigning higher priority to such flights in decision support tools for surface movement planning.

Acknowledgment

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