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Taxi Event Extraction from ASDE-X Surveillance for Surface Performance Evaluation

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Unimpeded taxi times can be used to quantify a flight's taxiing delay when compared with its actual taxi time. Currently, flight unimpeded taxi times are calculated by the Federal Aviation Administration using a regression method where flights in the Aviation System Performance Metrics (ASPM) data are clustered on the season of operation, airline, airport, and calendar year. It utilizes the airline-reported gate-Out, wheels-Off, wheels-On, gate-In (OOOI) times reported in ASPM, rounded to the nearest minute. For non-reporting airlines, these times are estimated from similar flights. The purpose of this paper is to evaluate the unimpeded time using a surveillance-based approach by identifying the time a flight spent waiting in the system (i.e. traveling slower than 3 m/s) and comparing it to the total taxi time. This study specifically focuses on analyzing both arrivals and departures for 6 top U.S. airports (ATL, CLT, DEN, IAH, JFK, ORD) during the month of July 2015. Airport Surface Detection Equipment-Model X (ASDE-X) surveillance data was matched with ASPM data in order to have a complete coverage of the taxiing phase of airplanes between the gate and runway for taxi out and in procedures. Results show the benefits of a spatial analysis, which allows for a quick identification of which locations on the taxiways were the most susceptible to cause. This study also evaluates changes in the unimpeded metric when compared to the current method and other proposed methods, such as the 5th-to-15th clustering, that is present in literature.

I. Introduction

UNIMPEDED taxi time, also known as nominal taxi time, is a vital metric for evaluating the efficiency of airport taxiing ground movements. It is defined as the time it takes a flight, arriving or departing, to navigate between the gate and wheels-off/on if the flight does not experience any disruptions. The benefit of defining such a parameter is in evaluating the ground movement performance at busy airports and is considerably useful for airport planning and management. Currently, the Federal Aviation Administration publishes unimpeded taxi-in and taxi-out times in the Aviation System Performance Metric (ASPM) database. These estimates are based on a regression method where flights in ASPM are clustered on the season of operation, airline, airport, and calendar year. This current statistical procedure identifies representative unimpeded flights for comparison within each cluster, where all flights in a single cluster share an unimpeded time. It utilizes the airline-reported gate-Out, wheels-Off, wheels-On, gate-In (OOOI) times reported in ASPM, rounded to the nearest minute. For non-reporting airlines, these times are estimated from similar flights [1].

Today there are 37 airports equipped with Airport Surface Detection Equipment, Model X (ASDE-X) surveillance. Using ASDE-X surveillance information on airport ground movements, alternate unimpeded time algorithms are possible. ASDE-X surveillance information gives a second-by-second timestamp along with the flight's corresponding latitude and longitude during both the taxi-out and taxi-in phases. Several studies in the literature have attempted to incorporate travelled taxi paths and surveillance into the analysis of taxi times, but with notable limitations. For example, Zhang and Wang [2] used estimated instead of actual taxiing information from surveillance at LGA airport. Taxiing routes and taxiing distances were estimated by drawing lines over the airport map and

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estimating the possible taxi distances at the airport. When analyzing surveillance data, Srivastava [3] calculated the taxi distance by simply drawing a straight line from the runway exit used to the gates, which is not the actual travelled distance.

The purpose of this study is to use ASDE-X[5] surveillance information to incorporate new dimensions to the unimpeded time metric; namely, the taxi path, taxi speed, and total time spent waiting as well as identify the locations where the plane experienced delay along its taxiing path. There are several expected benefits of analyzing unimpeded taxi times by this "waiting time" method, where the real behavior of each flight can be studied and be given its own individual unimpeded time. First, the taxi path and distance are incorporated into the metric. Therefore, flights with significantly longer taxi paths are not automatically recorded as impeded. Second, this method can be beneficial when clustering methods yield small sample sizes. If very few flights have shared attributes (e.g. airline, season, runway, etc.), this cluster of flights can have a statistically insignificant sample size and therefore have an unrealistic unimpeded time estimate. Third, this study's method can allow for unimpeded time estimation if all flights in a group experience delay. For example, if a runway is only open for time periods when the airport is congested, then most flights with that runway will be delayed, therefore making it difficult to identify a representative unimpeded time for the cluster. Fourth, a spatial analysis of where flights were traveling at less than a certain speed threshold allows for a quick identification of which locations on the taxiways were the most susceptible to cause delay by time of the day and can be mitigated. That is, the spatial analysis can differentiate between flights that experienced delay while waiting in the departure queue, on the departure runway, to cross an active runway, for a gate to become available, as well as other reasons.

To support this study, a computer tool was created to extract taxiing time, distance, and taxiing trajectories for both departing and arriving flights that operated in July 2015 at ATL, CLT, DEN, IAH, JFK, and ORD. Also, this tool extracted times and locations of key events (e.g. enter runway, wheels-off) using spatial elements in airport geometry and flight information such as flight speed, acceleration/deceleration, and altitude profiles. For study validation, the tool was used to visualize the flight tracks.

II. Extracting Events from ASDE-X

To quantify flight delay and waiting, a computer tool was created to parse the times and locations of key events in the taxiing process, for both arrival and departure procedures. The events for an arrival are shown in Fig. 1 and include 1) enter runway, 2) wheels on, 3) exit runway, and 4) nearest gate. Similar events were extracted for departures. Also, information regarding distance, speed, and acceleration/deceleration were estimated. It is important to note that a "nearest gate" point is extracted and not "gate-in/out" as ASDE-X does not record all the way to the gate itself as this area is masked for airline coverage only. While the extraction of most events is intuitive, the process of extracting complicated events is explained further below. A more detailed explanation of the development of the event parsing tool and all algorithms used can be found in [4].

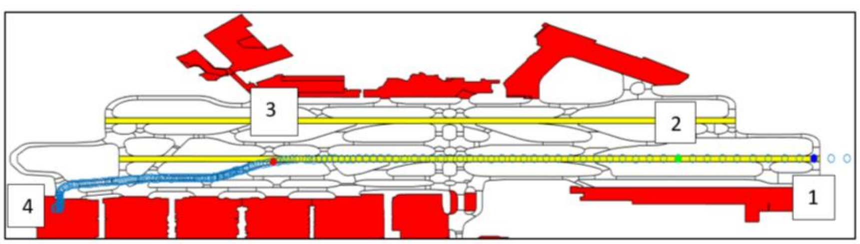

Fig. 1 Sample arrival ATL flight and labeled events

A. Speed and Waiting Time

One of the benefits of using surveillance data is that instantaneous speed can be estimated for each taxiing aircraft, as derived from the locations and times of sequential surveillance points. An example speed profile for a single arriving flight is shown in Fig. 2. Since the calculated speed profiles for each flight showed noisy behavior, the speed profiles were smoothed by moving averages to yield reasonable speed profiles for each individual flight as shown in Fig. 2. Delay and taxi speeds can be estimated and located spatially if the airfield layout and the position of each aircraft are known. Aircraft delays typically occur in the departing queue near the runway or when waiting for a gate

[5] Performance Data Analysis and Reporting System (PDARS) processed and quality controlled ASDE-X

to become available in the terminal area. Such information can help airport managers or planners, where they can recognize the bottlenecks and the reasoning behind severe delays at different airports.

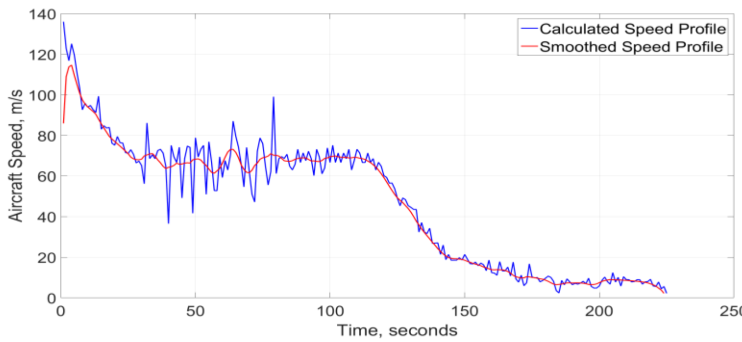

Fig. 2 Calculated and smoothed speed profiles for a single flight in m/s

Figure 3 shows the average flight taxiing speed by airport, with higher taxiing speeds found for DEN and IAH compared to the other four studied airports. Considering an average unimpeded taxiing speed of 7 m/s to 9 m/s during busy periods at airports in the data, for the purposes of this study a flight was considered to experience a period of delay during the times it traveled at a speed of 3 m/s or lower. The selection of 3 m/s is a reasonable compromise because our analysis shows that even in departure queues airplanes do not remain at 0 m/s speed for long. Instead, they have greatly reduced values for taxiing speed.

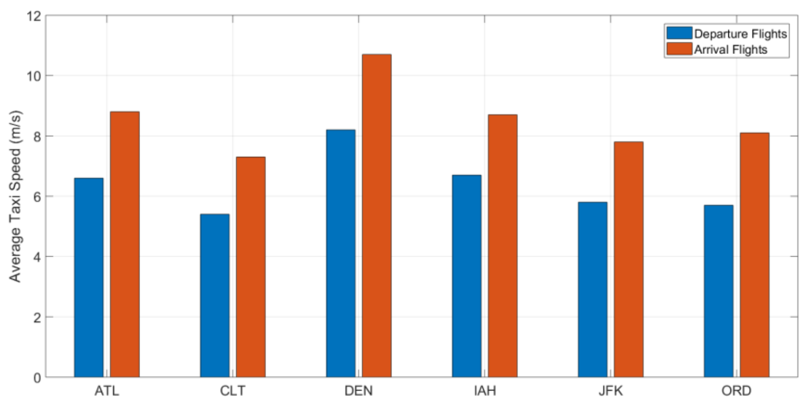

Fig. 3 Average Taxi Speed for Arrivals and Departures

B. Departure Runway

At some airports, it is common for flights to cross an active runway, while in route to a final departure runway. Therefore, defining the final departure runway simply as the first runway to have a significant number of points could set an early “enter runway” event, impacting both the estimated taxi time and runway occupancy time. Therefore, the final departure runway was defined as the runway polygon with at least 17 points, where the maximum acceleration occurs, and a 200-foot altitude change aftewr entering the runway polygon.

C. Wheels-On and Off

Although ASDE-X records altitude, its measurements do not have the precision required to determine exactly where on the runway a wheels-on or wheels-off event occurred, as shown in Figure 2. Therefore, findings from a landing/take-off study at ORD was incorporated into the computer tool. Specifically, videos of landings/take-offs were analyzed in [5] to see how the wheels-off and wheels-on events could be estimated with respect to other events that do not depend on altitude measurements. Using the video coverage, it was found that on average, the wheels-on event occurs ten seconds before full deceleration. Similarly, wheels-off is approximately five seconds after the point of highest acceleration.

D. Coverage of Extracted Events with ASPM Database

Table 1 outlines the coverage of the flights in which sufficient surveillance information was provided to extract all key events in the taxi-in/out processes. For example, there were 38,973 arrival flights analyzed from the July 2015 PDARS ASDE-X data for ATL. Of these flights, 98.4% had complete enough surveillance information to study all events and its associated arrival runway. Similarly, coverage of departure flights is also shown in Table 1. It is important to note that DEN and JFK had lower coverage compared to other airports, specifically where the "near gate" point was the main limiting event for reporting.

Table 1 Summary of ASDE-X Number of Operations

Airport Name	# Parsed Arrival Flights	% Arrivals with All Events	# Parsed Departure Flights	% Departures with All Events
ATL	38,973	98.4%	37,185	98.3%
CLT	22,786	98.3%	21,666	96.9%
DEN	24,015	87.0%	22,188	85.0%
IAH	22,414	93.0%	22,048	92.4%
JFK	18,465	85.0%	17,011	81.0%
ORD	39,053	97.6%	37,899	94.1%

Using the waiting time method, the unimpeded taxiing time can be estimated by subtracting the time spent traveling less than 3 m/s from the entire taxiing time from gate to the wheels-off (departure flights) or from the wheels-on to the gate (arrival flights). As stated before, the flight tracks recorded in the ASDE-X data do not cover the movement of airplanes in the gate area and only a "near gate" point can be recorded. To incorporate true gate-out/in times into the surveillance-based approach, airline-reported gate-out and gate-in times were provided from ASPM to create a full taxiing profile for each individual flight. This merged dataset allows for an unimpeded time estimation with a surveillance-based approach.

Given that both ASPM and ASDE-X datasets are needed for the surveillance method, coverage of flights are measured and compared to the coverage of the current statistical method which is only dependent on ASPM information. Fig. 5 compares the number of flights identified by each of the three methods. For example, ASPM data contains 41,308 arrivals for ATL in the study period. A total of 38,973 arrival flights and corresponding surface events were extracted from the ASDE-X dataset for ATL. Merging the two datasets resulted in 31,700 flights having both ASPM and ASDE-X coverage. The analyzed ASPM flights are the ones with flight records which had OOOI information.

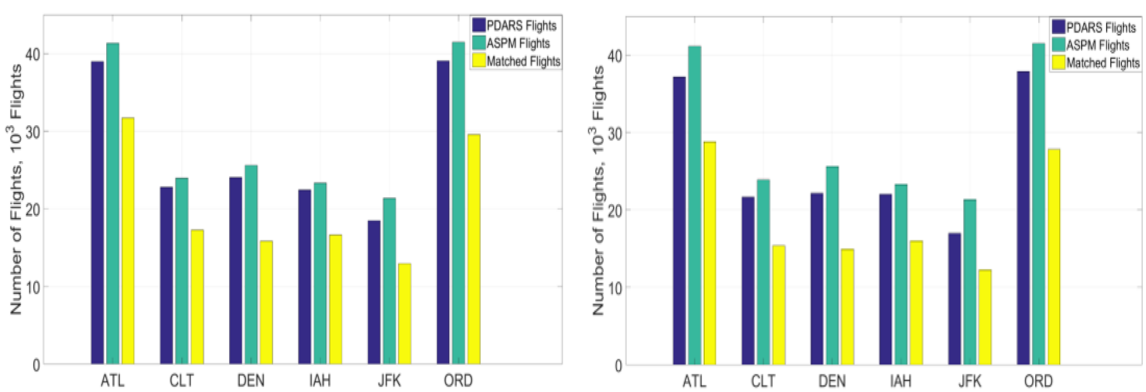

Fig. 5 Coverage of Arrival Flights in the Left Plot, Coverage of Departure Flights in the Right Plot

III. Methodology

Table 2 outlines the unimpeded taxi time estimation for each method. Methods NomTo and 5^{th}-15^{th} were used to compare the waiting method results. For the purposes of this study, matched flights between ASPM and PDARS datasets were used to keep the flight population consistent for comparison purposes across all three methods.

Table 2 Methodology Summary

Method	Unimpeded Time Calculation
FAA Regression (NomTo)	This method is currently used by FAA to measure the unimpeded taxi time and delay for each operation. Flights are grouped based on operation type, operation season, flight carrier, and actual gate-off or gate-in times. A regression method is used to estimate the unimpeded taxi times [5]. This is based off of OOOI-reported times in ASPM.
5^{th}-to-15^{th}	Flights sharing the same runway and gate cluster were grouped together and based on the reported taxi times, the average of the taxi times between 5^{th} percentile and 15^{th} percentile taxi times was considered as the unimpeded taxi time for each runway-gate group cluster. This is based off of OOOI-reported times in ASPM.
Waiting	Moments during taxiing phase that the flight was taxiing below 3 m/s were captured and this cumulative waiting time was considered as delay. Since surveillance data does not cover the masked gate areas, the gate out/in times were used from the matching record in ASPM dataset. Unimpeded taxi time is the difference between the overall taxi time and the waiting moments. Gate in/out times come from ASPM and wheels-on/off are from the parsed PDARS ASDE-X events.

IV. Results

This section outlines the comparison of three unimpeded taxiing time methods. The results presented in this section are based on the matched flights between the ASPM and PDARS datasets, where arrivals and departures are analyzed separately. In this section we also present a data visualization and spatial analysis tool developed to view the benefits of using surveillance in surface performance analysis.

A. Taxi-Out Time

Table 3 shows the average unimpeded taxi out time for all three methods and Table 4 shows the corresponding delays in minutes. The waiting method on average reported lower unimpeded taxi out times at ATL and ORD when compared with the other two methods; however, at CLT and IAH, the waiting method yielded higher values when compared with the other two methods. JFK consistently had the highest unimpeded taxi out time for departure operations. Considering an average taxi out distance of 3.3 km for JFK (the highest among all 6 studied airports) and an average taxi out speed of 5.81 m/s, there is a noticeable delay issue for departure flights at this airport. The majority of departures at JFK operate on runway 31L, requiring long departure queues to form in the adjacent taxiway prior to take-off roll. This delay in the terminal area yields both high taxi out and unimpeded taxi out times for JFK. Therefore, the taxi-out delay at JFK is due to both reduced speed and increased taxi-path length. Overall, the waiting method yields lower values of delay at most of the facilities compared to the current statistically-based method.

Table 3 Average Unimpeded Taxi Out (Minutes)

Airport	FAA Regression (NomTo)	5^{th}- 15^{th} Percentile	Waiting Method
ATL	13.0	11.7	11.6
CLT	12.2	12.1	12.7
DEN	11.3	10.0	11.7
IAH	11.4	11.7	12.1
JFK	17.8	17.3	17.3
ORD	11.7	12.3	11.5

Table 4 Average Reported Delay for Departure Flights (Minutes)

Airport	FAA Regression (NomTo)	5^{th}- 15^{th} Percentile	Waiting Method
ATL	6.0	7.3	6.7
CLT	8.3	8.5	7.7
DEN	3.7	4.9	2.7
IAH	5.4	5.1	3.9
JFK	12.0	12.5	15.3
ORD	9.2	8.6	8.9

There are many factors that can play a role in the different delay and unimpeded time reporting across the methods, including assigned runway, departure gate, and aircraft type. To analyze this further, departure gates were clustered into groups, where the gate groups for ATL airport are shown in Figure 6. These groupings were defined based on similar entry points to the taxiways for each airport. As a case study, we considered ATL flights from gate group B and gate group M to runway 27R were analyzed further, as shown in Figure 7. These two cases differ greatly in terms of distance between the gate and runway as well as the fleet mix. Specifically, gate group B is mainly used for domestic flights, while gate group M is mostly used by international flights. Therefore, most of the aircraft operating from gate group M belong to RECAT groups B and C. Aircraft operating from gate group B belong to RECAT groups D and E.

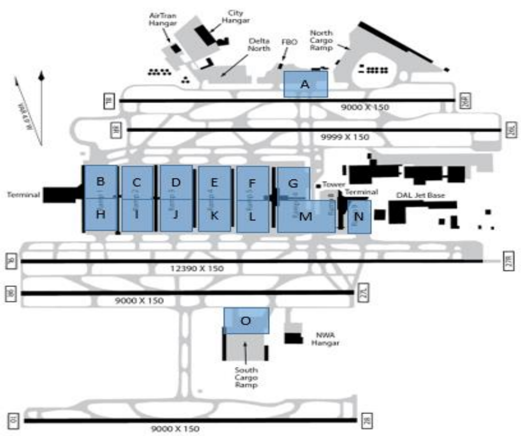

Fig. 6 ATL Gate Groupings

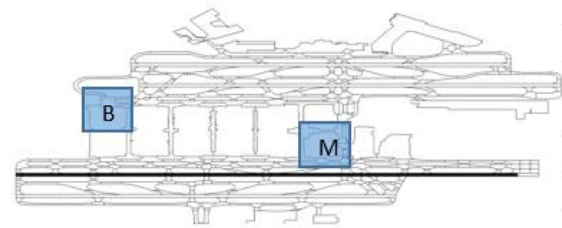

Fig. 7 Runway 27R with Gate Groups B and M

Fig 8 shows a comparison between delays reported by the FAA regression method and waiting method for gate group B using runway 27R. As can be seen, the FAA regression method regularly reports greater delays compared to the waiting method for this gate group-runway cluster when 3 m/s is used as the delay benchmark speed. Neither departure hour nor the aircraft RECAT grouping seemed to have direct effect on the reported delays for gate group B. Figure 9 compares the reported delays for gate group M for departing runway 27R. A different behavior is noticed compared to the trends shown in Fig 8. The waiting method estimates greater delays than the FAA regression method for all RECAT groups. Therefore, in this case study the waiting time method tended to add more delays to aircraft covering shorter taxiing distances compared with the FAA regression. Time of day did not have any distinguishable differences between the two methods.

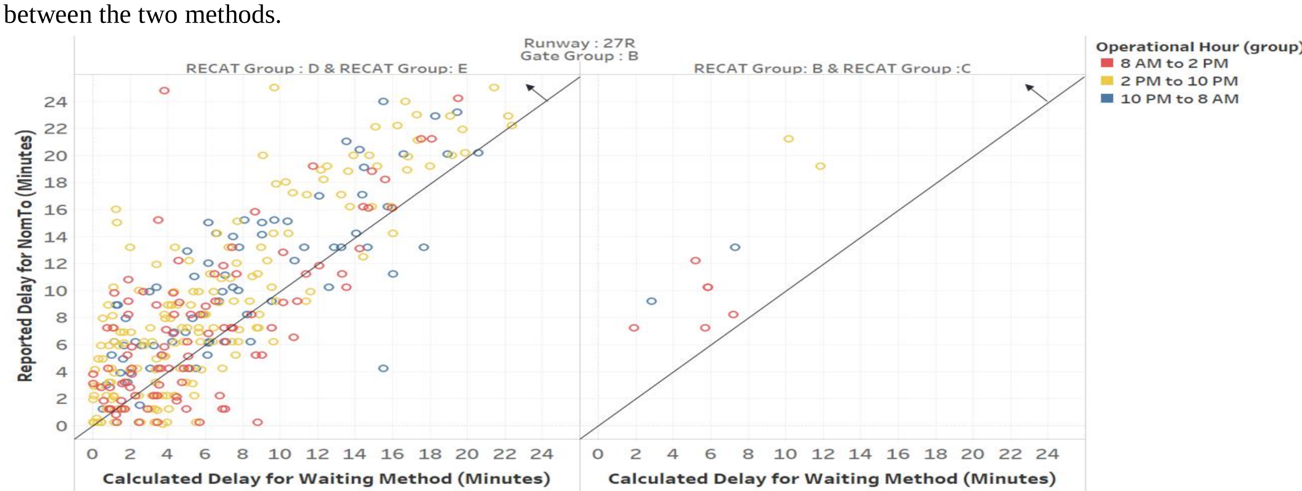

Fig.8 Comparing the Reported Delay for Gate Group B- Runway 27R by Different Methods

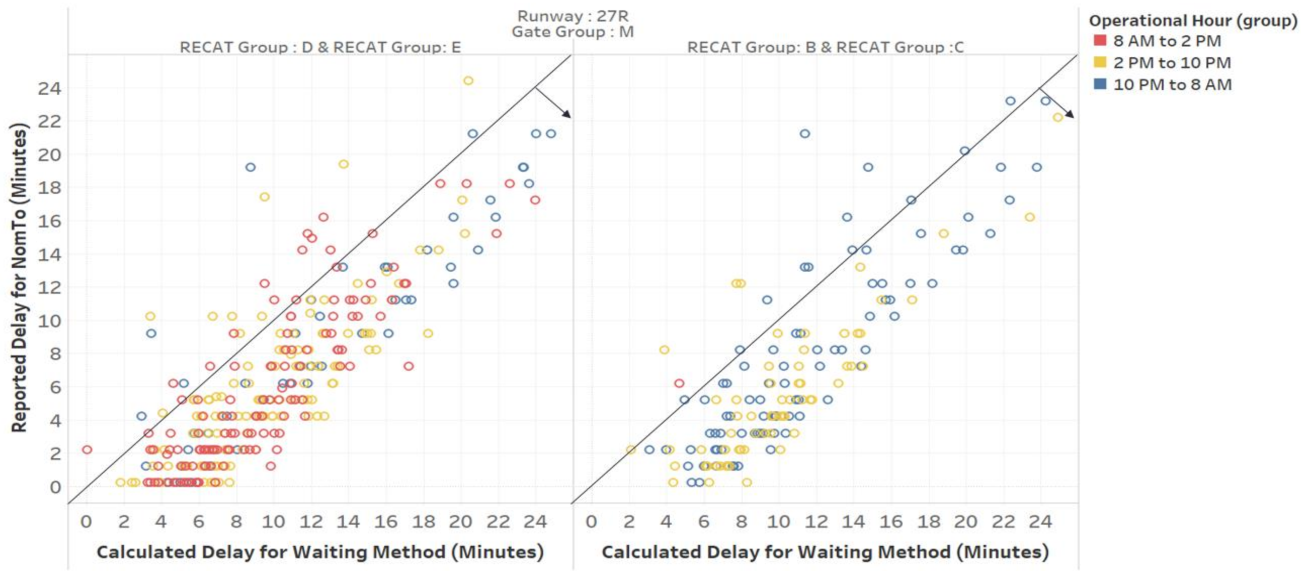

Fig. 9 Comparing the Reported Delay for Gate Group M- Runway 27R by Different Methods

B. Taxi-In Time

Due to interactions with other flights and a lack of available gates for arrival flights at large airports during peak hours, many arrival flights experience delays during the taxi-in process. Therefore, analyzing taxiing parameters for arrival flights is also important for planning purposes. For the arrival flights both ASPM and PDARS ASDE-X datasets were examined with the three methods. Just like departures the reported results belong to the matched flights between both datasets. Table 5 shows the average unimpeded taxi-in times and Table 6 shows the average delay using three different methods.

As seen in Table 5, the waiting method declared higher values of taxi-in times for arrival flights in general. At ORD and CLT the reported values using the waiting method are noticeably higher than the other two methods; however, at ATL and DEN the numbers reported by waiting method are approximately the same as the ones reported by the FAA regression method. The unimpeded times estimated by the 5th to 15th method produced lower taxi in time values for ATL, DEN, and JFK which might underestimate longer delayed flights due to considerable low reported taxi in times. Among the 6 studied airports JFK has the highest unimpeded taxi in time.

Table 6 shows that on average the waiting method reported lower values of delay for arrival flights at all airports. Considering the fact that this method reported higher delays for departure operations, we conclude that the taxiing speed threshold of 3 m/s was not met as many times during taxiing journey for arrival flights as for departures. This makes sense considering that for most of the analyzed airports, the taxiways assigned to the arrival flights led to fewer interactions between flights than the taxiways assigned to departure flights. Also being delayed in long departure queues led to lower average taxiing speeds for departures.

Table 5 Average Unimpeded Taxi In Times (Minutes)

Airport	FAA Regression (NomTo)	5th- 15th Percentile	Waiting Method
ATL	6.8	5.6	6.2
CLT	5.7	6.7	7.6
DEN	6.3	5.6	6.3
IAH	5.1	5.1	6.3
JFK	7.2	5.3	7.5
ORD	5.8	7.7	8.7

Table 6 Average Reported Delay for Arrival Flights (Minutes)

Airport	FAA Regression (NomTo)	5th- 15th Percentile	Waiting Method
ATL	1.6	2.58	1.53
CLT	5.8	4.9	3.8
DEN	1.55	2.2	1.1
IAH	3.6	3.6	1.5
JFK	2.3	4.1	1.4
ORD	6.6	4.7	3

E. Data Visualization and Spatial Analysis

In addition to quantifying delay with the speed threshold (e.g. 3 m/s), using surveillance data allows for other informative performance evaluation capabilities. Specifically, visualizing the locations and times where delays occur during the taxi process, as shown in Figure 7. The figure illustrates the taxi-out behavior for three ATL departure flights, where the movements with speeds lower than 3 m/s are highlighted in red. Using this computer tool, it is found that for most departure flights the delay occurs in the departure queue. However, in Fig. 11, it is shown that a departure flight to Atlanta's runway 28 (the southernmost runway in Figure 11) experienced most of its delay prior to crossing the active runways with only a portion of the delay being attributed to the departure queue. Using such a tool can identify the exact areas that could benefit from delay mitigation strategies.

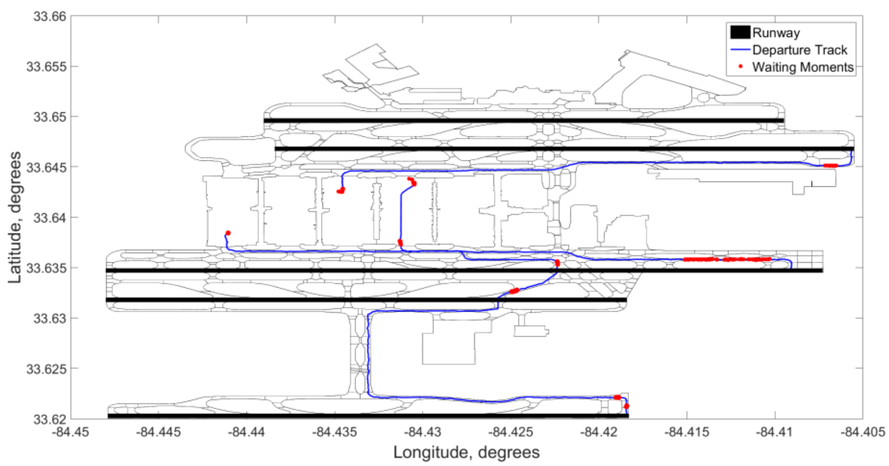

Fig. 11 Sample tracks indicating locations of delay for 3 ATL departure flights

By aggregating the flight-level spatial information, the average taxiing speed can be estimated for different taxiway segments or polygons. This is shown in Figure 12, which illustrates the average taxi speed in each polygon for operation hours between 09 AM and 10 AM during month July 2015 for ATL. Polygons near the departure runways show warmer colors which means that most of flights had lower taxi speeds due to the departure queue or turning maneuver towards to departure runways. Using this type of analysis can help air traffic controllers, airport managers and airport designers by enabling them to identify the bottlenecks at airports and track the exact location of the delays by time of day for arrival and departure flights.

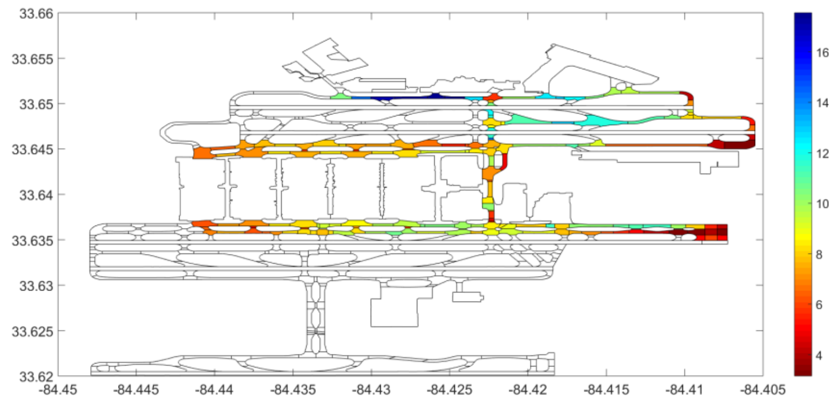

Fig. 12 Average Taxi Speed (m/s) on Taxiway Segments for July 2015 Between 09 AM and 10 AM at ATL

V. Conclusions

Unimpeded taxi time is a complex performance measure that can be difficult to accurately capture when evaluating the taxiing performance at airports. In this paper, three methods were compared for estimating the unimpeded time of each taxiing aircraft. Statistical methods like the FAA regression method, and 5th-15th percentile method are currently used for estimating unimpeded taxi times, but are based on flight clustering to estimate unimpeded times for grouped flights. By analyzing speed through surveillance, individual flight unimpeded times can be estimated that account for taxiing path complexity. In addition to using surveillance to estimate unimpeded taxi times, it enables airport authorities and air traffic controllers to identify system bottlenecks, including both the location and the time of day in which they occur. Due to surveillance coverage, future research could look at the efficiency of the taxi path for individual flights in addition to the taxi time.

VI. Acknowledgments

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