Board 2: Exploring Average Taxi Times at U.S. Hub Airports with ASDE-X

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INTRODUCTION

Airport taxi times affect operation efficiency and congestion [1][2][3], fuel consumption [4][5], and aircraft emissions [6][7]. Aircraft taxi time refer to the time it takes for an aircraft to move from the gate to takeoff, or to move from landing to the gate [8]. Efforts to better understand and reduce airport taxi times may potentially improve airport capacity and reduce fuel usage, costs, and emissions. Airport Surface Detection Equipment, Model X (ASDE-X) is a surveillance system that provides location and movement information of aircraft and vehicles on the airport to air traffic controllers [9]. ASDE-X was developed to reduce the Category A and B runway incursions at airports by providing continuous information of aircraft and vehicle location on airport movement areas. This equipment was implemented at 35 major U.S. airports [9].

The FAA defines U.S. airports as Large, Medium, Small, and Non hub airports. In National Plan of Integrated Airport System (NPIAS), the Appendix A: List of NPIAS Airports provides a list of U.S. airports and their hub classifications (Small, Medium, and Large hub) [10]. The Aviation System Performance Metrics (ASPM) dataset from the FAA publishes airport and airline operation data of 77 airports in the U.S. [11]. In the dataset, the quarter-hour taxi-in time and quarter-hour taxi-out time of the 77 airports are given [11].

In this study, the researchers explore the possible effect of ASDE-X implementation on airport taxi-times at 71 U.S. airports in the ASPM dataset. ASDE-X is installed at 35 airports and not installed in the other 36 airports in the ASPM dataset. In this paper, taxi times for the ASPM airports with ASDE-X are compared to the airports without ASDE-X.

Identifying potential factors affecting airport taxi times may help researchers build better taxi time prediction model and may help airport managers to make better decisions to improve airport efficiency and capacity. Educators may use this research to teach large-sample data collection, data cleaning and consolidation, design of experiment, and statistical and graphical methods to answer research questions in undergraduate engineering courses. Undergraduate aerospace or aviation students may improve their comprehension of taxi times, ASDE-X, and airport operations from this research.

BACKGROUND

ASDE-X is a surveillance system that provides air traffic controllers aircraft and vehicle surface movement and location information by using radar and satellite technology [9]. ASDE-X was designed to mitigate critical Category A and B runway incursions [9]. The system aims at improving the situational awareness of air traffic controllers by synchronized aircraft and vehicle positions information on the airport map [9].

Aircraft taxi times affect airport capacity and sustainability. Reducing taxi times contributes to reducing aircraft emissions, fuel burn, congestions and improve airport capacity. Previous studies have considered different factors that may affect airport taxi times such as weather conditions [12] [14], number of flights [14] [15], hub classifications [16], and runway configurations [14] [15] [17]. Gupta et al. [16] used the ASPM dataset and collected taxi time data from 33 U.S. hub

airports and analyzed the effect of hub classification and number of airport hot spots on airport taxi times. Wang et al. [18] used the ASPM dataset, collected taxi time data from 33 U.S. hub airports, removed quarter-hours with taxi-in or taxi-out time reported as zero, and analyzed the effect of hub classification and hot spots on the difference between taxi-out and taxi-in times.

Previous research [12] used ASDE-X surveillance data from New York's John F. Kennedy (JFK) airport during the summer of 2010 to build taxi-out prediction model by correlates taxi-out time and taxi-out delays as a set of explanatory variables. The results of the paper showed significant improvement in taxi-out time predictions compared to the FAA's Enhanced Traffic Management System (ETMS). A study [13] used ASDE-X data at Chicago O'Hare International Airport (ORD) to extract the deicing times based on aircraft location information in the deicing facility and developed a simulation model to test for operation improvements. The results suggested that 25.1% of the time aircraft spent in the deicing system could be saved if all deicing pads were open to all aircraft [13].

While there has been research on airport efficiency using ASDE-X data, presence of ASDE-X on airports has not been studied as a factor to analyze its effect on taxi-times at Small, Medium, and Large hub airport. In this paper, the researchers use taxi time data collected from ASPM 77 (71 airports that are classified as Small, Medium, and Large hubs) to compare taxi times at airports that have implemented ASDE-X versus that have not. Therefore, this research compares taxi-out and taxi-in times across three hub classifications (S/M/L) and ASDE-X implementation (Yes/No). This study aims to answer the following research question: *What are the effects of implementing ASDE-X at – Small, Medium, and Large hub airports on the taxi-in and taxi-out times at these airports?*

Accordingly, the following hypotheses are tested in this paper:

> H_o: Taxi-out (or taxi-in) times are the *same* at Small hub (or Medium hub or Large hub) airports *with ASDE-X* as those *without ASDE-X*.
>
> H_a: Taxi-out (or taxi-in) times are *different* at Small hub (or Medium hub or Large hub) airports *with ASDE-X* as those *without ASDE-X*.

METHODOLOGY

To answer the research question, airport taxi-time data was collected from ASPM 77 [11] dataset, hub classifications from FAA NPIAS [10], and ASDE-X information from FAA [9].

Data Collection and Consolidation: In the FAA NPIAS report [10], the U.S. airports are classified as Large, Medium, Small, or Non hub airports. The 77 airports in ASPM dataset were cross-matched with the NPIAS report to find hub classification of each airport. Among the 77 airports in ASPM, there are 30 large hub airports, 30 medium hub airports, 44 small hub airports, 2 non hub airports, and 4 airports with no classification information. This paper uses data from the airports that are classified as Small, Medium, or Large hub airports (a total of 71 out of 77 airports in ASPM). A list of 35 airports that have implemented ASDE-X was collected from FAA Technology ASDE-X webpage [9]. Hub classifications for these 35 airports were found from NPIAS report. Table 1 lists the number of Small, Medium, and Large hub airports with or without ASDE-X implementation.

Table 1. Hub Classification [10] and ASDE-X implementation [9] at 71 Airports

	With ASDE-X [9]		Without ASDE-X		
Hub Classifications [10]	Number of Airports	Number of Quarter-Hours with at least one operation (*n*)	Number of Airports	Number of Quarter-Hours with at least one operation (*n*)	**Total Number of Airports**
Small (S)	2	1298	9	3701	**11**
Medium (M)	7	6659	23	22084	**30**
Large (L)	26	32172	4	4892	**30**
Total	**35**		**36**		**71**

Note: ASPM 77 dataset contains information for 77 airports; only 71 of them are classified as Small, Medium, or Large in FAA NPIAS report. This paper uses taxi-time data from these 71 airports.

The researchers collected average quarter-hour taxi-in and taxi-out time at each of the 71 U.S. hub airports from the ASPM dataset [11] from May 1, 2023, to September 30, 2023. The researchers selected such timeframe to capture the summer busy time at airport meanwhile reducing the effect of extreme weather on taxi times such as snow or ice. The researchers collected average quarter-hour taxi times for the top 20 busiest days (6 AM to 10 PM local time) by total number of operations at each of the 71 airports from May 1, 2023, to September 30, 2023. Figure 1 shows a snapshot of a sample of the consolidated data. Zeros in the taxi time data suggested that there were no operations during the respective quarter-hour period. These zeros have been removed from the data sample. Table 1 shows the number of quarter hours with at least one operation corresponding to each of the hub classification and ASDE-X implementation.

Figure 1. Snapshot of a sample of the consolidated data

ASPM Dataset [11]								NPIAS 2023-2027 [10]	ASDE-X Implementation Information [9]
Facility	**Date**	**Quarter**	**Hour**	**Departures for Metric Computation**	**Average Quarter-Hour Taxi-out Time**	**Arrivals for Metric Computation**	**Average Quarter-Hour Taxi-in Time**	**Hub Classification**	**ASDE-X**
ABQ	5/24/2023	1	10	2	10	4	6	M	0
ABQ	5/24/2023	1	13	2	16	1	3	M	0
ATL	6/8/2023	1	8	21	15.29	28	8.61	L	1
ATL	6/8/2023	1	9	23	17.96	27	11.3	L	1
BHM	5/8/2023	1	11	2	11.5	2	3	S	0
BHM	5/8/2023	1	14	1	13	4	3.75	S	0

Note. The data in this figure has the same headings as Gupta et al. [16] and Wang et al. [18]. These studies include number of hot spots data from NPIAS, whereas, this paper includes ASDE-X data.

Data analysis: In this paper, Minitab was used to conduct the statistical analysis. To answer the research question, the average quarter-hour taxi time data was segregated by hub classification and ASDE-X implementation. The researchers used Student's *t* parametric test to calculate and compare the 95% confidence intervals for the mean taxi times. Due to large number of outliers in the data, the researchers also used Mann-Whitney non-parametric test to calculate the 95% confidence intervals for the median taxi times. These tests were conducted individually for both taxi-out and taxi-in times.

RESULTS

In this paper, average quarter-hour taxi-in and taxi out time, airport hub classification data, and ASDE-X implementation information were collected for 71 U.S. hub airports. Based on the data, the researcher rejected the null hypothesis of the Anderson-Darling test and concluded that the data violated the assumption of normality ($p < 0.005$) for each combination of hub classification and ASDE-X implementation.

Taxi-out Time: Table 2 shows the consolidated descriptive statistics and 95% confidence intervals for mean (using Student's *t*) and median (using Mann-Whitney) taxi-out times across the three hub classifications and two ASDE-X implementation categories.

For Small hub airports in the study (11 airports – 2 with ASDE-X; 9 without ASDE-X)

- Using the Student's *t* test and 95% Confidence Intervals, the mean quarter-hour taxi-out time with ASDE-X implementation (14.80 – 15.69 minutes) was found to be statistically longer than the mean quarter-hour taxi-out time without ASDE-X implementation (14.07 – 14.45 minutes).
- Using the Mann-Whitney non-parametric test and 95% Confidence Intervals, the median quarter-hour taxi-out time with ASDE-X implementation (13.25 – 14.00 minutes) was found to be statistically longer than the median quarter-hour taxi-out time without ASDE-X implementation (13.00 – 13.00 minutes).

For Medium hub airports in the study (30 airports – 7 with ASDE-X; 23 without ASDE-X)

- Using the Student's *t* test and 95% Confidence Intervals, there was *no statistically significant difference* found between the mean quarter-hour taxi-out time with ASDE-X implementation (13.69 – 13.91 minutes) and the mean quarter-hour taxi-out time without ASDE-X implementation (13.79 – 13.93 minutes).
- Using the Mann-Whitney non-parametric test and 95% Confidence Intervals, there was *no statistically significant difference* found between the median quarter-hour taxi-out time with ASDE-X implementation (13.00 – 13.00 minutes) was found to be statistically longer than the median quarter-hour taxi-out time without ASDE-X implementation (13.00 – 13.00 minutes).

For Large hub airports in the study (30 airports – 26 with ASDE-X; 4 without ASDE-X)

- Using the Student's *t* test and 95% Confidence Intervals, the mean quarter-hour taxi-out time with ASDE-X implementation (19.22 – 19.36 minutes) was found to be statistically longer than the mean quarter-hour taxi-out time without ASDE-X implementation (16.34 – 16.65 minutes).
- Using the Mann-Whitney non-parametric test and 95% Confidence Intervals, the median quarter-hour taxi-out time with ASDE-X implementation (17.62 – 17.80 minutes) was found to be statistically longer than the median quarter-hour taxi-out time without ASDE-X implementation (15.25– 15.50 minutes).

Table 2. Taxi-out time – Descriptive Statistics and 95% CI for Mean and Median.

Airport Hub Classification	Taxi-out Time (minutes)													
	With ASDE-X							Without ASDE-X						
	n	Mean time	Median time	StDev	Anderson-Darling Normality Test	95% CI for μ *(Student's t)*	95% CI for η *(Mann Whitney)*	*n*	Mean time	Median time	StDev	Anderson-Darling Normality Test	95% CI for μ *(Student's t)*	95% CI for η *(Mann Whitney)*
Small Hub	1298	15.25	13.00	8.19	$p < 0.005$	(14.80, 15.69)	(13.25, 14.00)	3701	14.26	13.00	5.82	$p < 0.005$	(14.07, 14.45)	(13.00, 13.00)
Medium Hub	6659	13.80	13.00	4.61	$p < 0.005$	(13.69, 13.91)	(13.00, 13.00)	22084	13.86	13.00	5.14	$p < 0.005$	(13.79, 13.93)	(13.00, 13.00)
Large Hub	32172	19.29	17.75	6.69	$p < 0.005$	(19.22, 19.36)	(17.67, 17.80)	4892	16.50	15.35	5.49	$p < 0.005$	(16.34, 16.65)	(15.25, 15.50)

Note: n is the number of quarter-hour time periods that have at least one flight operation corresponding to the hub classification and ASDE-X implementation. All taxi times are in minutes.

Table 3. Taxi-in time – Descriptive Statistics and 95% CI for Mean and Median.

Airport Hub Classification	Taxi-in Time (minutes)													
	With ASDE-X							Without ASDE-X						
	n	Mean time	Median time	StDev	Anderson-Darling Normality Test	95% CI for μ *(Student's t)*	95% CI for η *(Mann Whitney)*	*n*	Mean time	Median time	StDev	Anderson-Darling Normality Test	95% CI for μ *(Student's t)*	95% CI for η *(Mann Whitney)*
Small Hub	1298	7.16	5.50	8.76	$p < 0.005$	(6.68, 7.64)	(5.40, 5.67)	3701	5.28	4.50	3.81	$p < 0.005$	(5.16, 5.41)	(4.33, 4.50)
Medium Hub	6659	6.84	6.00	3.39	$p < 0.005$	(6.76, 6.92)	(6.00, 6.13)	22084	5.79	5.00	3.41	$p < 0.005$	(5.74, 5.83)	(5.00, 5.00)
Large Hub	32172	9.27	8.48	4.27	$p < 0.005$	(9.23, 9.32)	(8.41, 8.50)	4892	7.88	6.78	5.10	$p < 0.005$	(7.34, 8.02)	(6.71, 6.89)

Note: n is the number of quarter-hour time periods that have at least one flight operation corresponding to the hub classification and ASDE-X implementation. All taxi times are in minutes.

Taxi-in Time: Table 3 shows the consolidated descriptive statistics and 95% confidence intervals for mean (using Student's *t*) and median (using Mann-Whitney) taxi-in times across the three hub classifications and two ASDE-X implementation categories.

For Small hub airports in the study (11 airports – 2 with ASDE-X; 9 without ASDE-X)

- Using the Student's *t* test and 95% Confidence Intervals, the mean quarter-hour taxi-in time with ASDE-X implementation (6.68 – 7.64 minutes) was found to be statistically longer than the mean quarter-hour taxi-in time without ASDE-X implementation (5.16 – 5.41 minutes).
- Using the Mann-Whitney non-parametric test and 95% Confidence Intervals, the median quarter-hour taxi-in time with ASDE-X implementation (5.40 – 5.67 minutes) was found to be statistically longer than the median quarter-hour taxi-in time without ASDE-X implementation (4.33 – 4.50 minutes).

For Medium hub airports in the study (30 airports – 7 with ASDE-X; 23 without ASDE-X)

- Using the Student's *t* test and 95% Confidence Intervals, the mean quarter-hour taxi-in time with ASDE-X implementation (6.76 – 6.92 minutes) was found to be statistically longer than the mean quarter-hour taxi-in time without ASDE-X implementation (5.74 – 5.83 minutes).
- Using the Mann-Whitney non-parametric test and 95% Confidence Intervals, the median quarter-hour taxi-in time with ASDE-X implementation (6.00 – 6.13 minutes) was found to be statistically longer than the median quarter-hour taxi-in time without ASDE-X implementation (5.00 – 5.00 minutes).

For Large hub airports in the study (30 airports – 26 with ASDE-X; 4 without ASDE-X)

- Using the Student's *t* test and 95% Confidence Intervals, the mean quarter-hour taxi-in time with ASDE-X implementation (9.23 – 9.32 minutes) was found to be statistically longer than the mean quarter-hour taxi-in time without ASDE-X implementation (7.34 – 8.02 minutes).
- Using the Mann-Whitney non-parametric test and 95% Confidence Intervals, the median quarter-hour taxi-in time with ASDE-X implementation (8.41 – 8.50 minutes) was found to be statistically longer than the median quarter-hour taxi-in time without ASDE-X implementation (6.71 – 6.89 minutes).

DISCUSSION

This paper collected data from ASPM dataset and analyzed average quarter-hour taxi time of 71 U.S. hub airports. It is assumed that the taxi time data from the ASPM dataset is accurately recorded, and the measure methods are consistent across different airports. In this paper, the researchers used Student's *t* parametric tests to find the differences between mean taxi times. However, the Anderson-Darling tests suggest that the data collected violated the assumption of normality. Therefore, the researchers also used Wilcoxon Signed non-parametric test to find the differences between median taxi times.

This paper may be used to teach introductory level classes focusing on statistical and data analysis. The methodologies in this research can be used as an example to teach undergraduate and graduate engineering students to learn data collection, data cleaning, and data consolidation when there is large amount of data presents. Students may also learn how and when to use parametric and non-parametric statistical tests when facing large sample.

CONCLUSION

In this paper, the researchers collected taxi times data from 71 U.S. hub airports and compared taxi times at airports with ASDE-X and airports without ASDE-X. The researchers used Student's *t* parametric tests to compare the mean taxi-times and the Mann-Whitney non-parametric tests to compare the median taxi-times across Small, Medium, and Large hub airports. The statistical tests were conducted individually for taxi-out time and taxi-in time.

The researchers concluded that mean and median taxi-out times at Small and Large hub airports with ASDE-X were statistically longer than mean and median taxi-out times at Small and Large hub airports without ASDE-X. The researchers found no significant difference found between the mean (and median) taxi-out times at Medium hub airports with ASDE-X and without ASDE-X. This result was not aligned with the researchers' intuition. The researchers found that the mean and median taxi-in times at Small, Medium, and Large hub airports with ASDE-X were statistically longer than the mean and median taxi-in times at airports without ASDE-X.

Future research may focus on including other factors that may affect taxi times such as weather conditions and runway configurations. Other research methodologies such as Bayesian statistics or simulation analysis may be considered.

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