Using Surface Demand Trends to Evaluate Multiple Airport Surface Initiatives

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One of the major difficulties in performing post-implementation analysis for an initiative is the lack of control over the environment. Many times, multiple initiatives are being attempted simultaneously and it is difficult to attribute operational impacts to specific programs. In this paper, we examine the taxi time and departure rate impacts of two recent enhancements at Orlando International Airport (MCO): a new runway and enhanced Air Traffic Control surface surveillance through the Airport Surface Detection Equipment – Model X (ASDE-X). Both enhancements have had positive effects on surface efficiency; however, each initiative exhibits unique impact characteristics when examined in relation to the surface demand. More specifically, plots of taxi-out time and departure rate vs. surface demand show quite different behaviors. We interpret the results and believe similar analysis should be useful for refining the estimated benefits of other ASDE-X sites and predicting the impact of future surface initiatives. The suggested methodology of examining the different trend characteristics of a metric in relation to demand should provide a valuable method for future post-implementation analysis.

I. Introduction

THE Federal Aviation Administration (FAA) and the Office of Management and Budget (OMB) require a positive business case to justify all investments. The business case goes through a rigorous review process that attempts to discern the economic cost and benefit of each segment of a proposed program at the site-by-site level. After a decision is made to fund a particular program, there has not been as much care given to reporting the actual effectiveness of the investment compared to the claims in the business case. To remedy this situation, the FAA recently initiated a Post-Implementation Review (PIR) process to assess the effectiveness of initiatives after execution with the same rigor as used during the initial investment process.

One reason for the lack of post-implementation review is the complexity of airport operations. While the proposed impacts of aviation initiatives are simple to state (i.e. enhanced safety, increased efficiency or capacity) they can be difficult to measure in the busy and ever-changing operational environment of the airport surface. One of the major difficulties in performing post-implementation analysis for an initiative is the lack of control over the environment. Many times, multiple initiatives are being attempted simultaneously and it is difficult to attribute operational impacts to specific programs. More accurate data and better measurement methods will be necessary to perform the types of review desired by the agency.

In this paper, we examine the taxi time and departure rate impacts of two recent enhancements at Orlando International Airport (MCO): a new runway and enhanced Air Traffic Control surface surveillance through the Airport Surface Detection Equipment – Model X (ASDE-X). Both enhancements have had positive effects on surface efficiency; however, each initiative exhibits unique impact characteristics when examined in relation to the surface demand. More specifically, plots of taxi-out time and departure rate vs. surface demand show quite different behaviors. We interpret the results and believe similar analysis should be useful for refining the estimated benefits of other ASDE-X sites and predicting the impact of future surface initiatives.

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II. Airport Description

MCO is the busiest airport in Florida (by the number of passengers). The airport serves as a mini-hub for Delta Connection carriers Chautauqua Airlines and Freedom Airlines and a focus city for AirTran Airways, Delta Air Lines and Southwest Airlines. In 2005 it was visited by 34.1 million passengers, making it the 12th busiest airport in the United States and the 21st-busiest in the World.

A new 9,000 ft. fourth parallel runway (17L/35R) that allows simultaneous triple instrument approaches opened for operations in December 2003. Figure 1 presents a diagram of the airport showing runway and terminal locations. The new runway (far right in Figure 1) is located 4,300 feet east of existing Runway 17R/35L. Other recent construction at Orlando consisted of two north cross field taxiways and a forth airside passenger terminal completed in 2000 and one of the tallest Air Traffic Control towers in the nation commissioned in 2002.

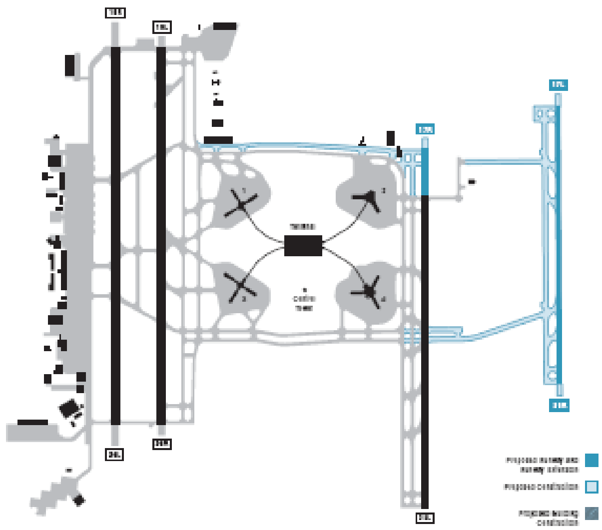

Figure 1. Diagram of MCO with new runway (far right).

III. ASDE-X Description and History

The ASDE-X is a modular surface surveillance system that processes multiple radar sources, multilateration, and Automatic Dependent Surveillance-Broadcast (ADS-B) sensor data to provide seamless movement area coverage and aircraft identification to air traffic controllers.

The goals of the system are to increase controller situational awareness, reduce the risk of critical Category A & B runway incursions, and improve surface operational efficiencies. For the current study we are most interested in gauging the efficiency impacts of ASDE-X.

During the investment process, both safety and efficiency benefits were quantified[1]. The efficiency benefits were based on controller inputs as to the increased capability provided by ASDE-X. The controllers identified four new capabilities that might allow for increased operational efficiency:

- Improved identification of aircraft within a queue (taxi into position and hold, taxi across a runway)
- Improved ability to perform conformance monitoring of taxi route and beacon codes
- Improved surface surveillance during heavy precipitation
- Improved ATC confidence in surface surveillance data.

Below we provide brief descriptions of the capabilities; for more detailed explanations see Ref. 1.

A. Improved Identification

In today's environment, controllers rely on paper flight strips to determine the order of aircraft within a queue. At times, these logs can become out of order either through the rearrangement of the paper records or, more frequently, through the dynamics of traffic movements. When air traffic controllers issue instructions to aircraft that are erroneously thought to be at the front of the queue, confusion arises and additional time is needed to communicate with aircraft to sort out the correct order of the traffic. This communication time can be generally brief but, nonetheless, disrupts the flow of traffic on the airport surface.

Through the incorporation of multilateration, ASDE-X provides data tags for all transponder equipped targets. As a result, controllers are able to view the ASDE-X display to determine the correct order of aircraft within a queue. Although flight strips will continue to be maintained, controllers can now glance at the ASDE-X display to ensure accuracy or to rapidly resolve confusion when it arises.

B. Conformance Monitoring

To ensure both safety and efficiency, controllers are responsible for monitoring whether aircraft follow their prescribed taxi routes. Additionally, once aircraft become airborne, controllers must validate that the proper beacon identification code is associated with the radar target for each aircraft. When aircraft deviate from their taxi routes or provide incorrect or missing identification information, controllers may slow down traffic as they address the situation.

ASDE-X data tags enhance situational awareness and, therefore, the ability of controllers to perform conformance monitoring. By becoming aware of issues sooner, controllers are better equipped to respond in an efficient manner.

C. Improved Visibility

During poor visibility conditions, either nighttime or weather related, controllers must wait for pilot reports indicating their location to monitor aircraft movements and to determine when to issue the appropriate clearances. These clearances include issuing taxi into position and hold instructions, take-off clearances, and clearance to taxi across an active runway.

Communication delays during reduced visibility can have a major impact on the efficiency of operations. Controllers are unable to issue taxi into position and hold clearances to departures operating on runways servicing both arrivals and departures. Therefore, increased miles-in-trail is required between arrivals in order to have the necessary time for departures to access the runway. The increased aircraft spacing will reduce the capacity by up to 50 percent for runways supporting both arrivals and departures. Additionally, controllers must wait an additional 25 to 30 seconds prior to issuing a departure clearance when controlling traffic on intersecting runways. Finally, it is estimated that approximately an additional 10 seconds may be needed prior to clearing an aircraft to taxi across an active runway. All of these delays combine to significantly slow down air traffic at a given airport.

Reduced visibility caused by heavy precipitation may also affect efficiency at airports that have previous radar-only based surface surveillance systems, such as the Airport Surface Detection Equipment - Model 3 (ASDE-3). The radar reflectivity generated by storms can result in a “white-out” or “wash-out” of the targets. Therefore, controllers are unable to distinguish the aircraft on the ASDE-3 display and cannot use the system to effectively monitor traffic.

D. Improved Confidence

The ability of ASDE-X to process inputs from multiple sensors, such as both radar and multilateration ground stations, greatly increases the situational awareness of controllers with no previous surface surveillance and improves the overall quality of the surface surveillance information for those with previous versions of the ASDE system. ASDE-X performance will include better track continuity, fewer false targets, and an increased probability of detection as compared to the ASDE-3. These improvements in conjunction with target data tags will increase common situational awareness leading to improvements in surface traffic management.

The controllers also identified scenarios where each capability (outlined above) could be used to reduce taxi time. The frequency and effectiveness of ASDE-X for each scenario were estimated using archived operational data and controller focus group inputs. The majority of the benefits involved savings in taxi-out time. In the following analyses we will also focus on taxi-out time.

After commissioning of the first operational ASDE-X site (General Mitchell Milwaukee International Airport – MKE), the program performed a post-implementation analysis to support further development of the program.

The initial examination of surface efficiency using the FAA’s Aviation System Performance Metrics database[§] before and after ASDE-X implementation found no significant trends. Examining the total traffic counts recorded by the FAA tower at MKE, it was found that ASPM data only accounted for 7 to 10 percent of the departures in the

[§] The ASPM database is archived by the FAA Office of Policy and Plans (APO) and is available at http://www.apo.data.faa.gov/

baseline period. Also during the time of interest, the number of ASPM flights increased, while the number of total tower-recorded flights did not increase. This suggests that the makeup of the ASPM data before and after ASDE-X implementation at MKE was somewhat different. Because of these reasons, we believe that the overall trends (or lack thereof) seen in the ASPM data may not properly reflect changes in the surface efficiency due to ASDE-X.

To better isolate the effects of ASDE-X on taxi times, the ASDE-X program office in cooperation with the FAA Air Traffic Organization (ATO) Operations Research group performed a second analysis of MKE surface efficiency. They used comments from the tower controllers to further filter the ASPM data to assure common data sets for comparison. The analysis also focused on a specific departure push when ASDE-X was most likely used for comparison.

The results suggested a one-minute decrease in taxi-out time after ASDE-X implementation and over a 30 second decrease in total departure delay (delay at gate plus taxi delay). These results generally supported the claims of the business case.

Prior to ASDE-X, MCO tower had no surface surveillance system. The ASDE-X system began testing for initial operational use (IOC) in September 2004 and was commissioned by the operational readiness date (ORD) in October 2004. Initial use of ASDE-X at MCO occurred nine months after the new runway opened. The relatively short time between these two events limits the amount of data we can use to examine the impact of each event separately. In the following analyses, we first examine the combined impact of both the new runway and ASDE-X, and then attempt to isolate the separate impacts of each.

IV. Methodology

The most obvious way to examine surface efficiency is through taxi times. As mentioned before, the FAA's ASPM database is a convenient and up-to-date archive of available taxi data. The database records taxi-out times from pushback (Out) to takeoff (Off) and taxi-in times from landing (On) to gate-arrival (In) for flights at the top 75 airports. For selected commercial flights the Out-Off-On-In (OOOI) data is directly recorded from sensors on the aircraft[**]. For the remaining flights, ASPM estimates Off and On times using radar tracks from the Enhanced Traffic Management System (ETMS) and estimates Out and In times using flight plan information and average historical taxi times. Unfortunately, the estimated taxi times in ASPM can be incorrect by several minutes at airports with few OOOI flights[2]. Because of this, we will use only the OOOI data when examining mean taxi times. Approximately 72 percent of flights at MCO automatically record OOOI times.

While we hope to measure changes in taxi times because of surface changes (runway and ASDE-X), we are certain that the taxi times are also heavily influenced by demand and weather.[2,3,4] The first step in any taxi time analysis will be to isolate taxi time data with like traffic and weather conditions for periods before and after the change.

The factor that most affects taxi time is demand. Changes in demand are especially relevant for MCO because the number of operations grew by 20 percent during the period of interest (between 2003 and 2005).

There are a few different options for quantifying surface demand; however, the most relevant would be runway queue length. A recent study[5] found the main factor determining taxi-out time was queue length. We do not have enough information to determine specific runway queue lengths over the time spans involved. However, if we define a more general "surface demand" for an aircraft to be the number of takeoffs between an aircraft's pushback and takeoff, we can have a general measure that should relate to runway queues.

Comparing taxi-out time to surface demand should allow us to examine surface performance in more detail. The surface demand accounts for changes in traffic level better than the mean data. We continued to divide the data into different sets by approach conditions to account for difference in weather. To estimate the number of takeoffs between an aircraft's pushback and takeoff (surface demand), we use all the taxi times available in ASPM (not just directly recorded OOOI data). While we use all aircraft to assign a surface demand for a flight, we only present taxi-out time results for flights with known OOOI data because of possible large errors in non-recorded OOOI taxi-out times.

Our definition of surface demand also allows examination of airport departure rates. The demand was defined as a number of departures. If we divide by the taxi-out time, we create an instantaneous measure of departure rate measured for each aircraft. For high enough surface demand (presumably long runway queues), one would expect

[**] Out – gate out time recorded when brake released, Off – takeoff time as recorded by reduction of weight on wheels during liftoff, On – landing time as determined by weight on wheels, In – gate in time recorded when aircraft door opened.

the departure rate to reach a maximum. This maximum can be interpreted as the departure capacity of the airport. In the following analyses we will also examine departure rate maxima to explore departure capacity changes.

The other factor we consider is the weather. ASPM records airport surface visibility and ceiling. Using these variables, an algorithm divides the weather into Instrument Approach conditions (IA) or Visual Approach conditions (VA) based on facility input. To qualify for VA conditions at MCO, the visibility must be greater than three miles and the ceiling must be greater than 2500 feet. While this is a gross simplification of weather effects, this division should help isolate periods of relatively good and bad weather. We could separate the data by defining more levels of weather conditions; however, this reduces the amount of data per condition, and subsequently does not allow statistically significant conclusions. We expect that average taxi times would increase during bad weather. Of the MCO flights recorded in ASPM, 93 percent operated in VA conditions and 7 percent operated in IA conditions. While the amount of reduced weather at MCO is small, the impacts can be severe. For example, Hurricane Charley caused the airport to shut down for 6 days in 2004.

V. Combined Analysis

The purpose of the combined analysis is to measure the aggregate effect of the new runway and ASDE-X. Runway 17L/35R began operation in December 2003 and ASDE-X became operational in September 2004. Consequently, we chose a baseline period from January 2003 through November 2003, and a post-implementation period is January 2005 through November 2005.

The results of the combined analysis for VA conditions are presented in Figure 2. We chose to focus on VA conditions because these conditions contained enough data to make statistical conclusions for each surface demand. Figure 2A displays mean taxi-out time in relation to surface demand, while Figure 2B displays the average departure rate vs. surface demand.

For the graph in Figure 2A, all of the points on the after period curve lie beneath those in the before period curve. For example, the mean taxi-out time after ASDE-X is 2.1 minutes less than in the period before the new runway for a surface demand of 10 aircraft. This analysis implies that MCO departures were considerably more efficient after both initiatives.

The shapes of the curves in Figure 2A imply that taxi-out time is not linear with surface demand. As the surface demand grows the taxi time rises at a higher rate.

As mentioned in the last section, our definition of surface demand also allows examination of airport departure rates. Using the data for surface demand of 10 aircraft in Figure 2A, we can say that during the before period it took 18.7 minutes to depart 10 aircraft, while after both initiatives it took 16.6 minutes to depart the same number of aircraft. This corresponds to an increase in the hourly departure rate from 32 aircraft/hour before the runway to 36 aircraft/hour after ASDE-X.

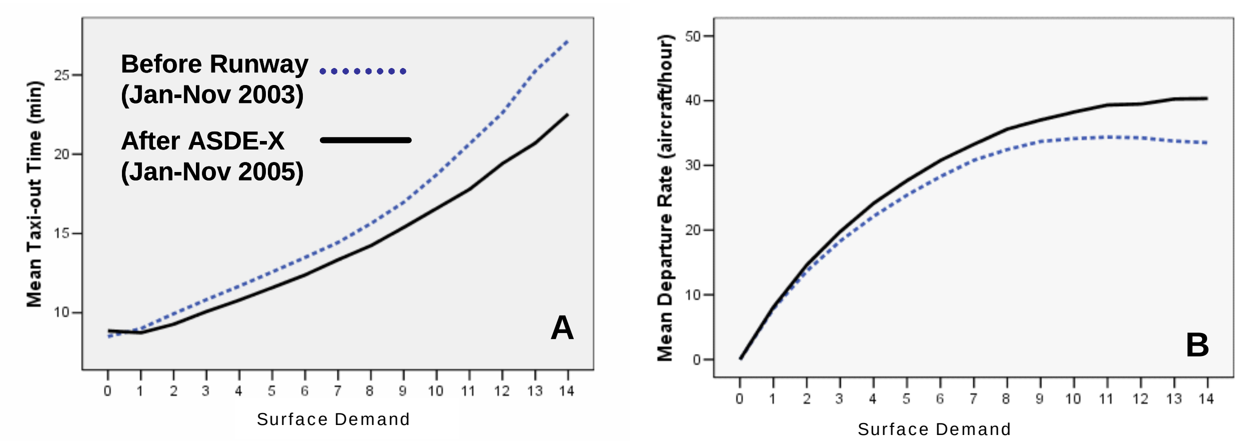

Figure 2. Mean Taxi-out Time (A) and Mean Departure Rate (B) vs. Surface Demand before and after both initiatives in VA conditions.

Using the taxi time and surface demand values for each flight, we plot the average departure rates for the different data sets. Figure 2B displays the mean hourly departure rate versus surface demand during the before and after periods for VA conditions.

For Figure 2B, the average departure rate in the after period is higher for each value of surface demand. The difference appears to grow with surface demand and is especially noticeable above a surface demand of 10 aircraft.

At high demands (above 10 aircraft), both the curves flatten considerably. The departure rate plateau for the after period is greater than that for the before period by several aircraft per hour. If the higher departure rate were due solely to increased demand, we would expect the values to continue to rise in a linear fashion. However, the flattening of the curves indicates that some departure rate limit has been reached. This limit is the departure capacity. We will revisit the departure capacity curves in Figure 2B again and estimate the value of the departure capacity after examining the separate trends for the new runway and ASDE-X.

VI. Runway Analysis

For the runway only analysis, we chose a before period from January through August 2003 and an after period from January through August 2004. The after period is constrained by the initial use of ASDE-X that started in September 2004. We repeated the analysis done in the previous section for these periods.

The results of the runway analysis for VA conditions are presented in Figure 3. Figure 3A displays mean taxi-out in relation to surface demand, while Figure 3B displays the average departure rate vs. surface demand.

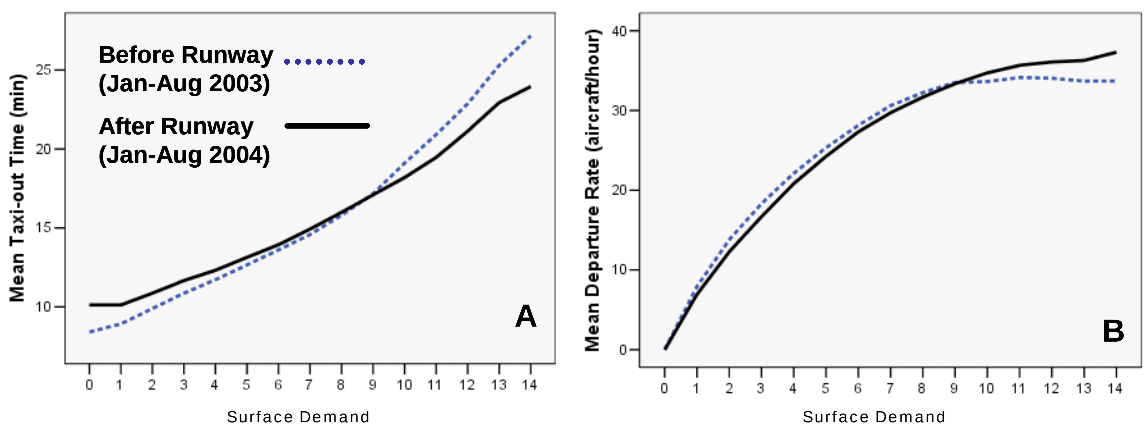

Figure 3. Mean Taxi-out Time (A) and Mean Departure Rate (B) vs. Surface Demand before and after the new runway in VA conditions

The graph in Figure 3A is somewhat different than the results seen in Figure 2A because the two curves cross. For low demand (less than 8 aircraft) the mean taxi-out time is longer after the addition of the new runway. For demands greater than 9 aircraft the mean taxi-out time is less after the addition of the new runway.

The trends seen in the data can be explained by examining the airport diagram in Figure 1. The new runway (far right in Figure 1) is farther from the terminals than any of the other runways. If traffic were not a factor, then it is reasonable to assume that any flight departing on the new runway would have to taxi for a longer distance (and time) than it would for the other runways. So for low surface demand (no runway queues) there is no real taxi-time advantage to using the new runway.

However, as departure demand increases, the mean taxi-out time grows at a faster rate before the addition of the new runway. Presumably, this increase is caused by aircraft needing to wait in a runway queue before departure. The new runway alleviates some of the demand per runway, consequently lessening the taxi-out waiting time for some aircraft.

Figure 3B displays the mean hourly departure rate versus surface demand during the before and after periods for VA conditions. Much like Figure 3A, Figure 3B contains a transition point where the two curves cross.

The average departure rate in the after period is less than the before period for surface demands less than 9 aircraft. If we look closer at this data using statistical difference tests, we find that while there is a visible difference in the departure rate for values of the queue below 9 aircraft, the values at any particular queue are statistically similar. Put another way, there is no statistical evidence that the departure rate is lower for those lower values of the queue.

At high demands (above 10 aircraft), the departure rate plateau for the after period is greater than that for the before data by a few aircraft per hour. The difference here is larger and is statistically significant when examined with an independent samples t-test. The higher departure rate plateau is consistent with the idea that the additional runway provides additional departure capacity.

VII. ASDE-X Analysis

A conclusion sec For the ASDE-X only analysis, we chose a before period from January through August 2004 and an after period from January through August 2005. The before period is constrained so that all the data is after the new runway came into operation (December 2003). We repeated the analysis done in the previous sections for these periods.

The results of the ASDE-X analysis for VA conditions are presented in Figure 4. Figure 4A displays mean taxi-out in relation to surface demand, while Figure 4B displays the average departure rate vs. surface demand.

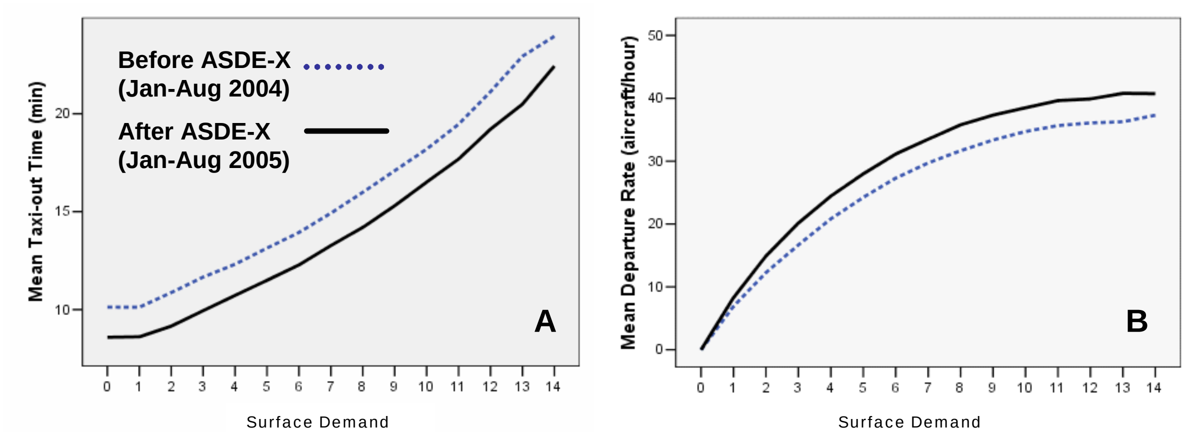

Figure 4. Mean Taxi-out Time (A) and Mean Departure Rate (B) vs. Surface Demand before and after ASDE-X in VA conditions

The graph in Figure 4A is somewhat different than either of the results seen in Figures 2A or 3A. Like Figure 2A (and unlike Figure 3A), all of the points on the after period curve lie beneath those in the before period curve. However, unlike Figure 2A, the difference in taxi-out time does not appear to change with surface demand. For each value of the queue there is a near constant decrease of approximately 1.5 minutes in taxi-out time in the after period.

Does this 1.5 minute decrease result from ASDE-X? That is a question that deserves more analysis. To the authors, an average two-minute decrease per aircraft seems somewhat large; it is certainly much larger than what was claimed in the investment analysis. What we can say about the change is that, whatever the mechanism, it is applied evenly across all demand levels.

Figure 4B displays the mean hourly departure rate versus surface demand during the before and after periods for VA conditions. Like the difference in average taxi-out time, the departure rate difference between the before and after periods is close to constant except for very low demands (less than 4 aircraft)

Like the previous results, at high demands (above 10 aircraft), the departure rate plateau for the after period is greater than that for the before data by a few aircraft per hour. This implies that some change in the after period positively affected the departure capacity.

VIII. Departure Rate Comparison

As a comparison of the three analyses, we present further examination of the departure rate plateau. There are several methods that can be used to estimate a value for the departure rate plateau[6]. We decided to examine the mean value of the departure rate for all flights that have surface demands from 10 aircraft to 14 aircraft. An independent samples t-test was performed to determine if the difference in the means was significant. Table 1 presents the departure rate plateau mean values, the difference in the means, and the p-value results of the t-test. A p-value of .050 or greater is not significant at the 95 percent level. Note that the difference in the means is significant for all the cases.

Focusing on the VA condition results listed in Table 1, we see that the departure capacity rose from 33.9 aircraft per hour, to 35.7 aircraft per hour after the addition of the new runway. Subsequently, the before period for the ASDE-X analysis started with the post-runway rate of 35.7 aircraft per hour. After ASDE-X the departure capacity appears to have grown to 39.5 aircraft per hour. The combined analysis displays similar results with a total increase in the departure capacity of 5.0 aircraft an hour in VA conditions. The results for the combined case are not a simple addition of the separate cases because different (and somewhat longer) time periods were used for the combined analysis.

Table 1. Departure rate plateau means and differences before and after surface projects at MCO

Measurement	Approaches	Before (aircraft/hour)	After (aircraft/hour)	Difference (aircraft/hour)	t-test p-value
Runway Only Jan-Aug ‘03 vs. ‘04	VA	33.9	35.7	1.8	.000
	IA	31.4	35.7	4.3	.000
ASDE-X only Jan-Aug ’04 vs. ‘05	VA	35.7	39.5	3.9	.000
	IA	35.7	37.9	2.1	.000
Runway + ASDE-X Jan-Nov ’03 vs. ‘05	VA	34.1	39.2	5.0	.000
	IA	32.1	37.8	5.7	.000

Table 1 also lists results for instrument approach conditions (IA) for comparison. Before the new runway, the departure rate during IA conditions is less than the departure rate in VA conditions. After the new runway, the departure rate for both IA and VA conditions is the same implying that the new runway had a greater impact during IA conditions.

While ASDE-X appears to increase the departure rate above and beyond the new runway in both IA and VA conditions, it did not have as great an effect during IA conditions. This may seem somewhat surprising given the claim that ASDE-X should be most useful during periods of reduced visibility. After discussing this finding with program office staff, we found that during the measurement period the tower had implemented a procedure to not use ASDE-X during rain storms because of possible apparent false targets. Since that time a separate “rain mode” has been implemented that improves this issue.

The combined analysis shows a total increase in departure case of 5.7 aircraft an hour during IA conditions.

IX. Summary

In summary, MCO has seen a large decrease in average taxi-time and a subsequent increase in the maximum departure rate (5 to 6 aircraft and hour) when measured in relation to surface demand after implementation of a new runway and a surface surveillance system for the air traffic control tower. Two additional analyses were performed to isolate the separate effects of the runway and the surface surveillance by examining smaller periods before and after each implementation. Both analyses indicated that changes between the before and after periods reduced mean taxi-time and increased departure rates, but the two initiatives had somewhat different characteristics.

The difference in the characteristics of the taxi-out times vs. surface demand and the departure rate vs. surface demand trends between the new runway and the implementation of controller surface surveillance can provide a way to examine different types of changes on the airport surface. After a new runway, an airport can expect an increase in the departure capacity. After controllers are given greater situational awareness through a surface surveillance system, the airport may expect a consistent drop in taxi times for all demands. Further analysis must be conducted to confirm the relatively large measured impact of surface surveillance at MCO to determine if other airport infrastructure or procedural changes account for some of the acquired benefit.

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