ASSESSING THE IMPACTS OF THE
JFK GROUND MANAGEMENT PROGRAM

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Abstract

The Ground Management Program at John F. Kennedy International Airport (JFK) aims to leverage the availability of comprehensive airport surface surveillance data and airline schedule information to better manage the taxi-out process, reduce taxi times, and improve efficiency. During periods when departure demand exceeds capacity, departing aircraft are held at the gate or another holding location, and released to the runway in time to join a short departure queue before taking off. As a result, aircraft absorb delay with engines off, and decrease their fuel burn, emissions, and engine maintenance costs.

This paper evaluates data from before and after departure metering was initiated at JFK, to assess its impacts. The results show that airport performance has improved, and that the departure metering is responsible for a significant portion of the improvements. The paper also finds that the new, more automated, Ground Management Program that was implemented in April 2012 has continued to yield significant benefits. The average taxi-out time savings at JFK due to departure metering in the summer of 2012 is estimated to be about 1.5-2.7 minutes per flight.

Introduction

The Port Authority of New York and New Jersey (PANYNJ) implemented a departure metering program at John F. Kennedy International Airport (JFK) in response to a major runway reconstruction project in 2010. The program was designed to avoid long departure queues by allowing departures to take delays at the gate or another holding location, rather than on the taxiways. Due to its success, the PANYNJ and other airport stakeholders decided to continue the departure metering after the completion of the construction project. The program continued in its original form throughout 2011, and in April 2012 a new Ground Management Program (GMP) was introduced. The GMP built on the capabilities of the original metering program, adding tools with enhanced automation capabilities, shared data for greater situational awareness, and greater flexibility for carriers.

Prior work has shown that the original metering program yielded significant gains in taxi-out time [1]. This paper is the first study that assesses the new GMP, and compares it to both the periods before any metering, as well as to the original departure metering program. Specifically, this analysis compares three time periods:

- Summer 2009, before the introduction of departure metering at JFK.
- Summer 2011, under the original metering program (but after the completion of the runway reconstruction project).
- Summer 2012, under the Ground Management Program.

The analysis presented in this paper finds that departure metering has significantly reduced departure queues and taxi-out times at JFK, leading to large savings in fuel burn and emissions. The introduction of metering coincided with substantial improvement from 2009 to 2011, while the new GMP in 2012 saw further reductions in taxi times and delays.

Related Work

Departure metering for reducing airport surface congestion was first proposed more than a decade ago, in studies such as the Departure Planner [2]. There has also been prior research on surface congestion control using Collaborative Virtual Queues, in which aircraft that are ready to push back join a virtual queue rather than a physical one [3, 4].

Field demonstrations of congestion management techniques have also been carried out at several locations in the US and Europe. Examples include the field tests of Pushback Rate Control at Boston Logan (BOS) [5, 6], the Tower Flight Data Manager (TFDM) demonstration at Dallas Fort Worth (DFW) airport [7], the Collaborative Departure Queue Management concept at Memphis (MEM) airport [8], simulations of the Spot and Runway Departure Advisor (SARDA) concept at DFW [9], and the trials of the Departure Manager (DMAN) concept in Athens International airport (ATH) [10].

JFK Ground Management Program History

The Port Authority began a departure metering program at JFK Airport due to a runway reconstruction project in 2010. The tools and procedures used for this program were adapted from those previously used to manage the airport during severe winter weather, with PASSUR OpsNet used to communicate metering times to carriers. The goal of this program was to allow delays to be taken at the gate or in the ramp, rather than on the taxiways. The program continued to provide benefits during 2011 as the airport operated without major construction activities.

In 2011, the Port Authority decided to put into place a fully integrated ground management program with several key objectives: To allow delay to be taken at the gate or other holding locations in order to reduce taxi times; to improve the management of the departure queue, and deliver a good sequence and mix of departures; and finally, to provide a common platform, information and collaboration mechanism to all users at the airport, thereby improving the safety, efficiency, and predictability of operations. An overarching goal was to preserve the gains achieved by the original metering program while transitioning to a more automated, collaborative process.

The new Ground Management Program began operating at JFK in April 2012. It followed the same principles as the previous metering program, but with improved data sharing, situational awareness, automation capabilities, carrier flexibility, and collaborative tools. These capabilities were delivered using the Saab Sensis Aerobahn platform. Since the start of the new program, the GMP has continued to evolve. Departure queue sequence improvement was added in late summer 2012, deicing functionality was added in the fall, and numerous adjustments to algorithms and user interfaces have been made based on continuous user feedback.

Ground Management Program Implementation

Departure metering is a key feature of the Ground Management Program at JFK. Algorithms within the Aerobahn system continuously monitor current and projected airport conditions using surface surveillance data, airline schedule information, carrier input of updated flight readiness, and input of current and expected runway configuration and departure throughput. The system determines the available capacity, and determines how many departures should proceed to the runway during each time period, with the goal of maintaining the queue at a certain target length (provided enough demand exists). It then allocates these available departure opportunities among carriers using a ration-by-schedule principle. The system then assigns individual flights to particular departure slots, and assigns for each one a Target Movement Area Time (TMAT), when the flight should exit the ramp and proceed to the runway. Carriers may swap flights according to their priorities, and they manage their own ramp areas consistent with achieving compliance with the TMAT of each flight. Air traffic control manages traffic in the movement area (taxiways and runways) with no change in ATC procedures.

The system monitors compliance with prescribed TMAT times and provides compliance reports for individual flights, individual days, or longer time periods. This enables carriers to ensure that everyone is treated fairly, and it helps facilitate future compliance and efficient operation.

Beyond departure metering, the Ground Management Program provides shared information presented in a common software platform and set of tools. To facilitate collaboration, the program is managed by a staffed, on-site Coordination Center to coordinate among carriers and manage challenging conditions. The Coordination Center is especially valuable during irregular operations and severe

weather. The program also features regular, frequent discussions among airport stakeholders, including the Port Authority, carriers, and air traffic control. These discussions identify what is working well and what can be improved. Procedures and tools have continuously adjusted and improved based on these discussions.

Data Sources

The analyses in this paper use surveillance data from the Airport Surface Detection Equipment (ASDE-X) system, the U.S. Bureau of Transportation Statistics' (BTS) on-time performance dataset, and the Aerobahn system. ASDE-X and BTS data from June-August 2009, 2011 and 2012 are analyzed. The analysis of Aerobahn data is limited to June-August 2012.

The BTS dataset includes only domestic flights by major U.S. carriers, and accounts for about 60% of flights at JFK Airport. For each flight, the dataset provides the scheduled and actual gate departure, take-off, landing, and scheduled and actual gate arrival times. Furthermore, any delay between scheduled and actual gate departure is divided by cause (late aircraft arrival, security delay, etc.). The BTS dataset is used to measure trends in average quantities (such as taxi-out duration), assuming that year-to-year trends in the data are representative of trends for all flights.

ASDE-X surface surveillance data, which covers all flights at JFK, is used to evaluate metrics such as departure queue length and runway throughput. It is also used to measure quantities not captured by other sources, such as, movement area entry and departure queue entry times.

The Saab Sensis Aerobahn system provides metering times for departures in summer 2012, when it was operational. The Aerobahn data are used to assess the impact of the assigned gate-holds in 2012, using the simulation described later in this paper.

Trends in Demand and Congestion

Traffic Demand Levels

The number of flights during summer at JFK declined by 4% from 2009 to 2012, as shown in Table 1. Most of this decline was between 2011 and 2012.

Table 1. Average number of daily departures at JFK in summer.

	2009	2011	2012
Departures Per Day	585	582	560

Surface Traffic Levels

The most noticeable impact of departure metering is a reduction in the number of active departures on the surface, sometimes known as the departure queue length.
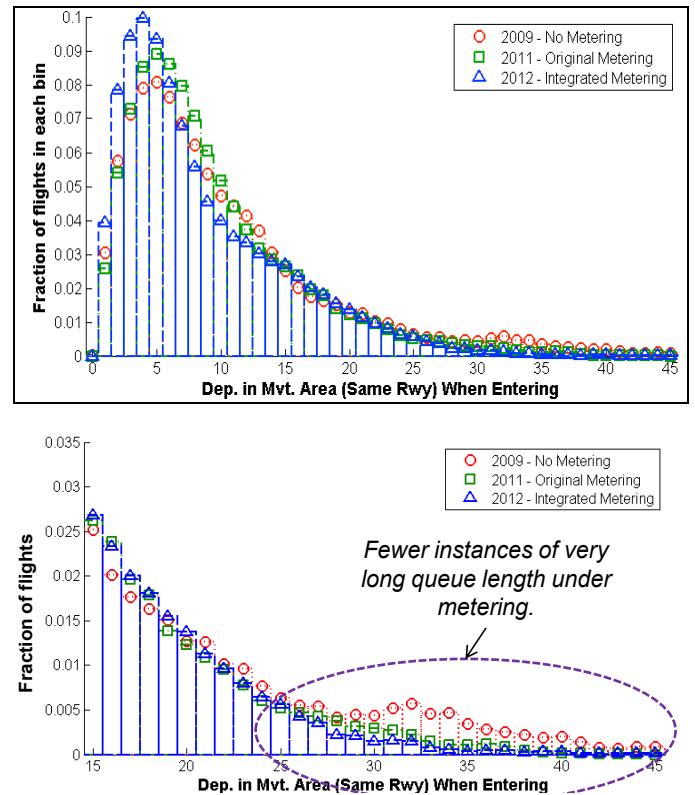

Figure 1. Relative frequency of various departure queue lengths, comparing 2009 (red), 2011 (green), and 2012 (blue). The upper plot shows the entire distribution, and the lower plot shows the tail at long queue lengths. Long queues are much less common in 2011 and 2012 than in 2009.

Figure 1 shows the frequencies with which different levels of departure traffic bound for the same runway were observed by departures as they

entered the movement area. It shows that departure queue lengths have indeed decreased since 2009, and extremely long queues (30 or more aircraft) are now much less common. In other words, there are fewer instances of extreme surface congestion under metering. The same trend is observed when the number of departures lined up at the runway is used as the measure of queue length.

Time Spent in Departure Runway Queue

Figure 2 (top) shows the average time spent by a flight in the departure runway queue, as a function of the runway queue length when it enters the queue. Controlling for the number of aircraft, aircraft spent less time in the runway queue in 2011 and 2012, when compared to 2009. This could be either because runway throughput has increased, or because flights were sent to the runway only when it was expected that the queue would move quickly. Figure 2 (bottom) shows that the number of instances of large departure runway queues (more than 20 aircraft) have decreased significantly after metering.
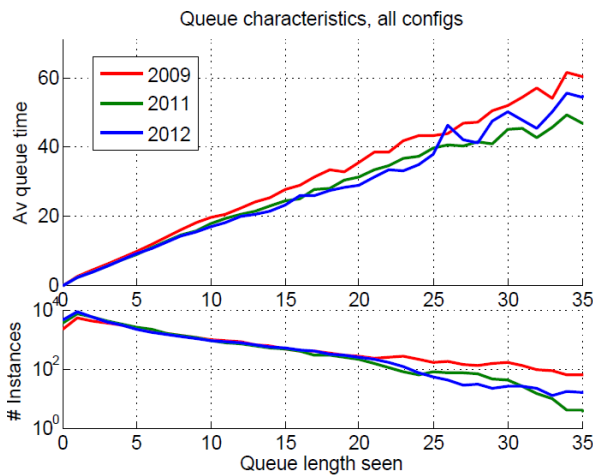

Figure 2. Average time in departure runway queue vs. runway queue length.

Runway Throughput

Previous studies have shown that the departure runway throughput, when plotted as a function of the number of departing active aircraft on the surface, exhibits saturation behavior [5].

Figure 3 and Figure 4 illustrate this phenomenon for JFK using ASDE-X data. The throughput plotted

in these figures is the average number of takeoffs from the airport in a 15-minute period. Figure 3 shows that on average across all configurations, time periods and weather conditions, the runway throughput saturates when there are about 15 active departures on the surface.

There is, however, a noticeable difference between 2009 (pre-metering) and the two years with metering, in the highly congested region (number of aircraft > 25). The throughput in 2009 is seen to decrease with additional aircraft on the surface, possibly because of gridlock. By contrast, the throughput stays stable in 2011 and 2012. Another observation from Figure 3 is the earlier saturation seen in 2012, that is, the airport achieves its maximum departure rate at a lower value of surface traffic. It is unclear whether this is due to the metering program.
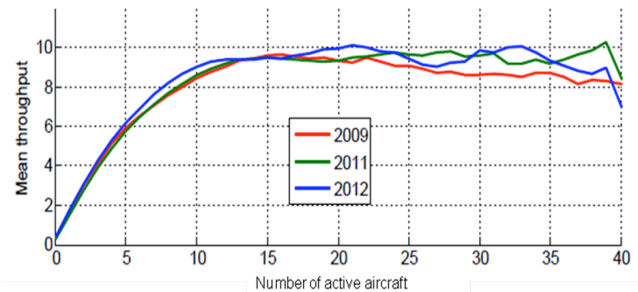

Figure 3. Runway throughput saturation, all configurations and times.
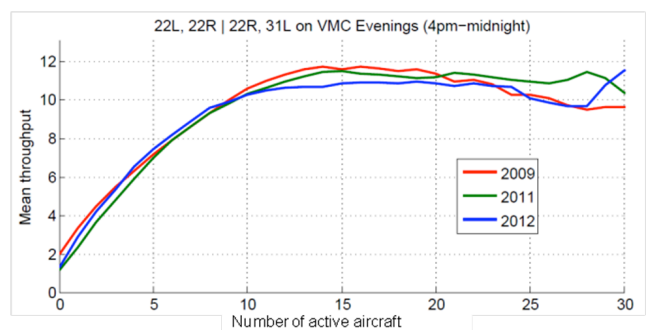

Figure 4. Runway throughput saturation in the 22L, 22R | 22R, 31L configuration, on good weather evenings.

There are differences in the saturation behavior when split by configuration, time of day or weather conditions. For example, Figure 4 shows the runway throughput for the 22L, 22R | 22R, 31L configuration, in the evening time period on clear weather days. The average throughput for medium levels of traffic (about 15 active departures) is found to be lower in 2012 than in 2009 or 2011. Other runway configurations show a reverse trend, with an increase in average throughput in 2012. The changes in throughput could be because of metering, or because of changes in airspace usage in the New York metroplex, or because of changes at the TRACON level.

Quantifying the Impacts of the GMP

Having examined some of the high-level trends at JFK airport, the next sections attempt to quantify the impacts of metering.

BTS Data Analysis

The first step is to quantify the changes in airport performance from year to year. While many factors beyond the GMP influence performance statistics, these statistics do indicate whether overall performance is improving, declining, or staying the same.

This analysis focuses on the changes in three key quantities for departures, namely, the delay taken at the gate, taxi-out times, and the sum of these two quantities. In calculating the delay taken at the gate, any delays due to causes external to the metering program, such as a late-arriving aircraft, maintenance problems, crew availability and security delays are excluded.
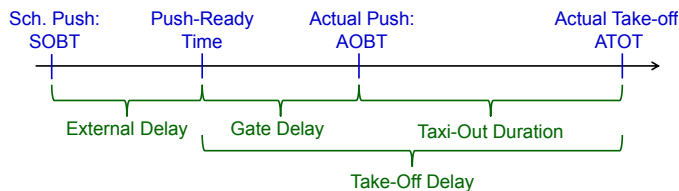

Figure 5. Departure timeline, defining Gate Delay, Taxi-Out Duration, and Take-Off Delay.

Figure 5 illustrates these quantities using a timeline for an individual departure. The departure has a scheduled off-block time (SOBT), actual off-block time (AOBT), and actual take-off time (ATOT). These event times are provided by the BTS on-time performance dataset. This dataset also provides an estimate of the causes of delay between SOBT and AOBT. External Delay is estimated by summing delays caused by late arriving aircraft, maintenance, crew, or security. Finally, adding External Delay to the SOBT provides an estimate of the time that the flight is ready to leave the gate, referred to as the Push-Ready time.

The following analysis focuses on three quantities:

- Take-Off Delay: the time between when a flight is ready to leave the gate and when it takes off
- Taxi-Out Duration: the time between gate departure and take-off
- Gate Delay: the time between when a flight is ready to leave the gate and when it actually leaves the gate

Takeoff Delay and Taxi-Out Duration

Take-Off Delay is primarily determined by the overall demand on and capacity of the runway. If flights wish to take off in excess of the available runway throughput, the Take-Off Delay increases. An increase in throughput (perhaps because of the departure metering program), will reduce Take-Off Delays. However, many other factors independent of departure metering impact Take-Off Delays.

The most noticeable impact of departure metering is expected to be a delay shift, where delay is taken at the gate instead of during taxi-out. Specifically, for any given level of Take-Off Delay, metering is expected to delay gate departure, thereby increasing Gate Delay while decreasing Taxi-Out Duration by an equal amount. By taking delay at the gate with engines off, departures save in fuel burn, emissions, and engine wear.

Gate Delay, Taxi-Out Duration, and Take-Off Delay are measured for all departures in the BTS On-Time Performance dataset. This dataset covers only about 60% of flights at JFK, but it is reasonable to assume that these flights are representative of trends for all flights. Table 2 shows the average Taxi-Out Duration and Take-Off Delay in the summers of 2009, 2011 and 2012, as calculated using the BTS data.

Table 2. Mean values of Taxi-Out Duration and Take-Off Delay across years. Values are shown in minutes per departure.

	2009	2011	2012
Taxi-Out Duration (min)	34.7	29.3	28.0
Take-Off Delay (min)	38.0	32.1	30.1

The bottom row of Table 2 shows that Take-Off Delay, namely, the time between when a flight is ready to leave the gate and when it takes off, decreased substantially with the introduction of metering between 2009 and 2011. Take-Off Delay decreased further in 2012. The reduction in Take-Off Delay resulted in a significant reduction in Taxi-Out Duration, as well.

While the values in Table 2 illustrate the trend for all departures in the BTS dataset, similar trends were observed when the data was filtered for flights departing during severe weather, or for flights during good weather.

The analysis so far demonstrates a significant reduction in Take-Off Delay. However, as mentioned before, many factors contribute to Take-Off Delay since it is a function of overall demand and runway throughput. The next subsection measures the portion of the improvement in Taxi-Out Duration that may be specifically attributed to departure metering. Specifically, it estimates the degree to which metering shifts delay from taxi to the gate.

Gate Delays

The reduction in Take-Off Delay shown in Table 2 naturally tends to reduce Taxi-Out Duration. However, it is desirable to determine whether departure metering has reduced Taxi-Out Duration even further by shifting delay to the gate. One way to estimate this shift is to compare across years to see if for a given level of Take-Off Delay, the Taxi-Out Duration has decreased.

It is expected that, *for a given level of Take-Off Delay*, departure metering should shift delay from taxi to gate. Therefore, flights are grouped into bins of Take-Off Delay (e.g., all flights experiencing between 70 and 80 minutes of Take-Off Delay), and the average Gate Delay and Taxi-Out Duration of these flights are computed.
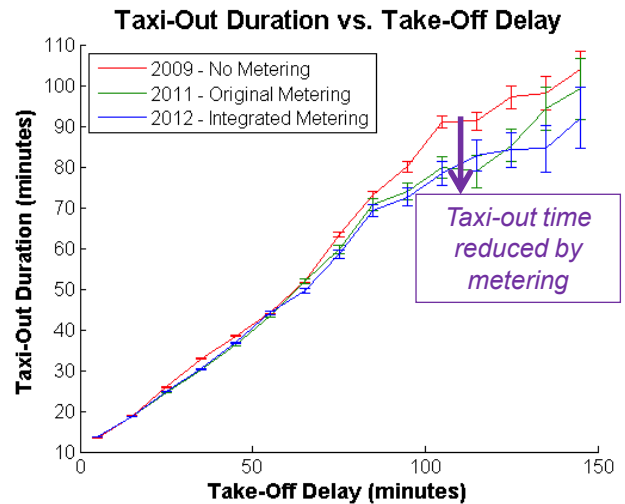

Figure 6. Average Taxi-Out Duration as a function of Take-Off Delay. Error bars indicate the statistical uncertainty in the average. The difference between the 2009 (red) and 2011 (green) or 2012 (blue) curves is attributed to the delay shift due to metering.
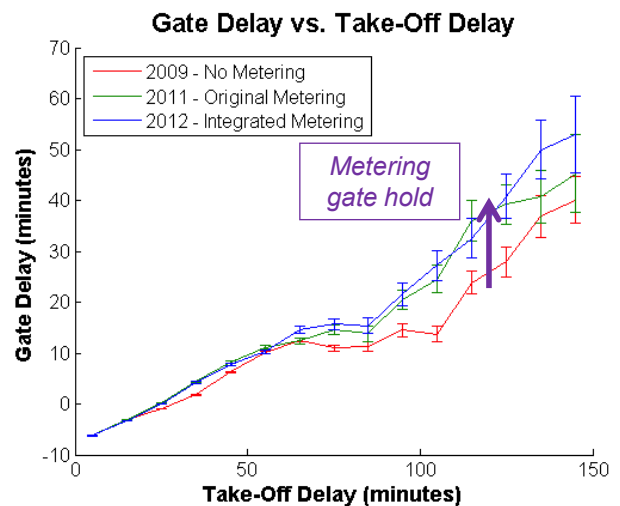

Figure 7. Average Gate Delay as a function of Take-Off Delay. Error bars indicate the statistical uncertainty in the average. The difference between the 2009 (red) and 2011 (green) or 2012 (blue) curves is attributed to the delay shift due to metering.

Figure 6 plots the results for Taxi-Out Duration. It shows that as Take-Off Delay increases along the horizontal axis, the average Taxi-Out Duration also increases. However, the curve for 2009 (red) is found to be significantly above the ones for 2011 (green) and 2012 (blue). In other words, for any given level of Take-Off Delay, the Taxi-Out Duration is found to be significantly lower in 2011 and 2012, when metering was in effect. This difference is estimated to be the delay shift associated with departure metering.

Figure 7 shows the corresponding trend in Gate Delay, and essentially mirrors the trend in Taxi-Out Duration. Once again, the associated Gate Delay increases for any given level of Take-Off Delay.

To determine the average per-flight reduction in taxi duration due to this delay shift, the differences between the 2009 and 2012 plots in Figure 6 (or, equivalently, Figure 7) are calculated and averaged over all departures according to the distribution of Take-Off Delay among all departures. Using this method, the average taxi-out time savings due to the metering delay shift is estimated to be 1.5 minutes per departure.
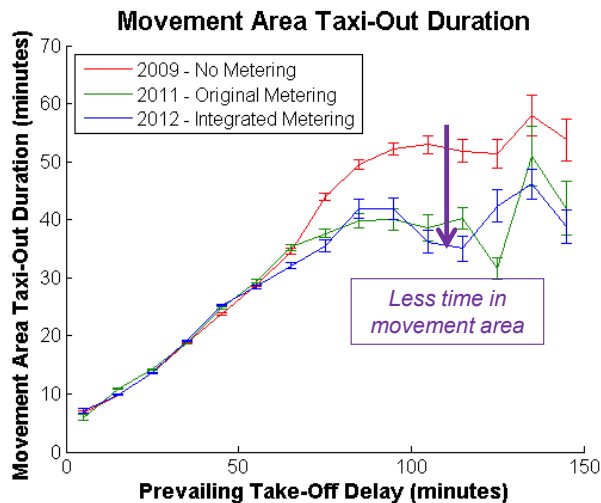

Figure 8. Average movement-area taxi-out duration as a function of Take-Off Delay. Error bars indicate the statistical uncertainty in the average. The difference between 2009 (red) and 2011 (green) or 2012 (blue) is attributed to the delay shift due to metering.

The same trends can be observed by looking at subsets of flights, such as particular weather conditions, times of day, or carriers. The shift in delay to the gate can also be seen looking at movement-area taxi-out duration or queue length. For instance, Figure 8 shows the trends in movement-area taxi-out duration. Similar plots (not shown in this paper) demonstrate that the time spent by aircraft in the queue at the runway, as well as the length of the departure queue, have decreased since the metering program began.

Simulation of 2012 Operations Using Aerobahn Data

This section describes a second approach to quantifying the metering delay shift. The analysis takes advantage of metering data from the Aerobahn system in 2012. This data includes, for about 10% of the flights, the amount of metering delay assigned to each flight and the time when each flight was ready to leave the gate. Using this information plus actual gate departure and take-off times, we compare a simulation of summer 2012 operations without metering to the actual operations. In the simulation, departures leave the gate when ready rather than waiting for metering.

Modeling Assumptions

This analysis relies entirely on data from the Aerobahn system, which includes all flights operating at JFK in summer 2012. Three key assumptions were made while setting up the simulations. The first assumption was that the throughput characteristics at JFK would have been the same in 2012, even without departure metering.

The second assumption is used to estimate the gate hold assigned to each aircraft, namely, the difference between when the flight was ready to leave the gate and its assigned pushback time. Since information on when the flight was ready to leave the gate was available for only about 10% of flights, other flights leaving around the same time were assumed to experience similar gate holds, on average. Specifically, flights lacking information on when they were ready to leave the gate were assigned gate holds using the average gate hold durations assigned to other flights in the same 15-minute period.

Taxi-out times were then predicted for each aircraft, based on the estimated or reported time at

which they were ready, and the predicted level of surface congestion. The third modeling assumption was that taxi-out times at JFK vary linearly with the takeoff queue size seen by each aircraft, where the "takeoff queue" of a given aircraft is defined as the number of other aircraft that take off while the aircraft is taxiing out [1]. Figure 9 illustrates the validity of this assumption for the 22L, 22R | 22R, 31L configuration. A similar quality of fit was seen for all other commonly used configurations.
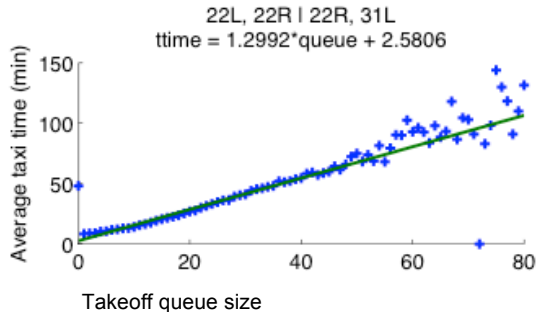

Figure 9. Regression from takeoff queue to taxi time, in the 22L, 22R | 22R, 31L configuration.

Figure 10 shows a comparison of the variation of average surface traffic (average number of active departing aircraft) with the time of day, with and without metering. Here, the plot with metering is determined from actual operations, and the plot without metering is determined from the simulation. These plots are averaged over all days in the simulation (summer 2012). It can be seen that metering reduces the level of surface traffic during the morning and evening high-demand periods, at 0800 and 2000 hours, respectively. The decreased traffic levels yield significant decreases in taxi-out times and fuel consumption: The total surface fuel burn is reduced because there are fewer aircraft with their engines on, and each aircraft also burns less fuel during taxi-out. The small period of time around 1600 hours, when the actual surface traffic with metering is more than the predicted traffic without metering, is likely to be due to the configuration changes at JFK frequently seen at this time of the day. A change in configuration slows down departure operations, causing some buildup of traffic which is not captured by the simulations.
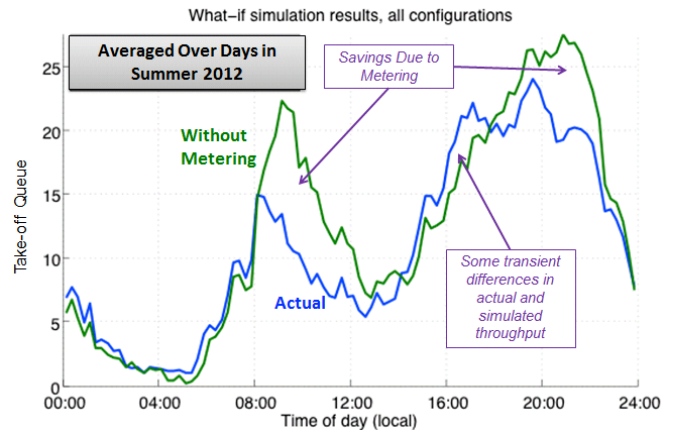

Figure 10. Comparison of surface traffic with and without metering.

Table 3. Reported gate hold times and predicted reduction in taxi-out times due to metering.

Configuration	# flights	Gate-hold (min)	Taxi savings (min)
All	37,494	100,221	102,162
22L, 22R	22R, 31L	11,465	39,354	49,829
31R, 31L	31L	6,275	15,223	15,694
4R, 4L	4L, 31L	4,994	12,757	6,441
22L	22R	4,228	13,717	12,049
13L, 22L	13R	2,594	2,576	4,592
13L	13R	2,034	4,992	4,963
4R	4L	1,971	6,357	3,424
VMC, 4-10 PM	17,992	70,813	84,894
IMC, 4-10 PM	1,831	6,508	3,140

A summary of the estimated taxi time savings, aggregated over all flights, is given in Table 3. In the table, "gate hold" is the delay prescribed by the metering system (either recorded on Aerobahn or estimated), and "taxi savings" is the simulated reduction in taxi-out duration. Across all configurations, gate hold and taxi savings are about equal, so 1 minute of gate hold corresponds to approximately 1 minute of taxi-out time reduction. There are, however, differences in the savings when split by configuration. The analysis also showed that

greater savings are realized on good weather (VMC) days than on bad weather (IMC) days.

Averaged over all flights in the simulation, per-flight taxi-out duration is estimated to have reduced by 2.7 minutes. In other words, departure metering is estimated to shift 2.7 minutes of delay from the taxiways to the gates. This may be compared with the estimate of 1.5 minutes per flight determined from changes across years in BTS data. Considering the uncertainties and assumptions in the two analysis techniques, and the differences between the BTS and Aerobahn datasets, these values are in reasonable agreement. Both approaches indicate that departure metering has shifted delays to the gate, and saves about two minutes of taxi-out time per flight.

Distribution of Benefits Among Airlines

While the analysis in the previous section showed that 1 minute of gate-hold yielded approximately a minute in taxi-out time savings, Figure 11 shows the distribution of these benefits among the major air carriers at JFK. It is seen that the percentage of gate-hold times and taxi-out time savings received by an airline are not exactly the same as the percentage of departures associated with it. Differences in per-flight savings among carriers may be due to differences in the time of day at which schedule peaks occur, as well as variations in prioritization and flight-swapping practices.
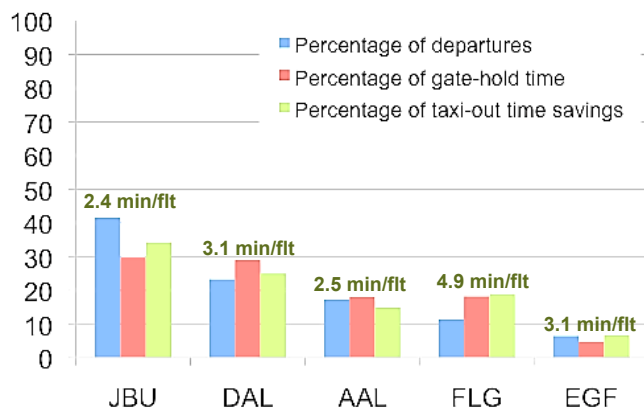
Figure 11. Distribution of departure demand, gate-hold times and taxi-out savings among the major carriers at JFK.

Other Potential Impacts of the GMP

Additional analyses were also conducted using the available datasets, in order to ensure that the

metering had not had any adverse effects elsewhere at the airport.

Ramp-Area Taxi-Out Times

Figure 12 presents the empirical distributions of time taken by aircraft to taxi from the gate to their spots, for the three years being considered. It is noted that the ramp-area times are generally lower for 2011 and 2012 as compared to 2009. This effect could be because of less complex operations in the congested ramp regions, since metering reduces the number of aircraft in the active movement areas. This data also suggests that the target pushback times are being communicated in a timely manner to the aircraft, since otherwise, aircraft would likely pushback early and as a result, have large ramp area taxi-out times.
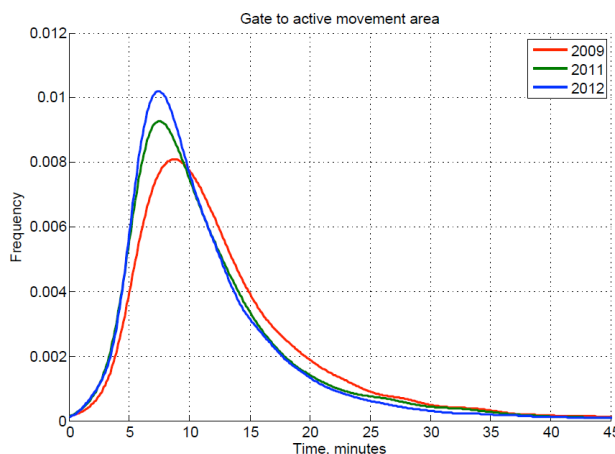
Figure 12. Distribution of time spent taxiing from gate to stop.

Arrival Taxi-In Times

While the primary impact of the Ground Management Program is on departures, there may be secondary effects on arrivals. In particular, one potential concern in implementing a departure metering program is that departures holding longer at the gate may block gate access for incoming arrivals. On the other hand, with fewer departures taxiing, there is less congestion in the movement area to impede arrivals; this may improve arrival performance.

To check the impact on arrivals, taxi-in durations are calculated using the BTS on-time performance data. The average taxi-in duration is

found to have decreased by a couple minutes since 2009, as shown in Table 4.

Table 4. Mean values of Taxi-In Duration across years. Values are shown in minutes per arrival.

	2009	2011	2012
Taxi-In Duration (min)	11.7	10.3	9.4

An examination of the trends in arrival taxi-in duration, as a function of the prevailing level of Take-Off Delay experienced by departures around the same time (Figure 13), finds that taxi-in durations have also decreased consistently across all levels of Take-Off Delay.

The improvement in arrival taxi-in performance is likely due to many factors. The extent to which the Ground Management Program contributes is unknown. However, this positive trend in arrival performance indicates that the gains in departure performance are not coming at the expense of arrivals.
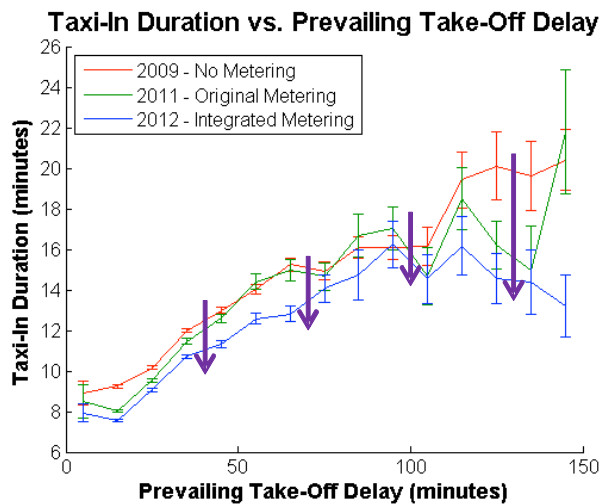

Figure 13. Average arrival Taxi-In Duration as a function of concurrent departure Take-Off Delay. Error bars indicate the statistical uncertainty in the average.

Risk of Runway Starvation

Reduction in the size of the departure queue is a characteristic of any metering program. A consequence of reduced runway queue sizes is the risk of runway starvation, where aircraft are not available at the runway threshold even though there is departure demand at the gates. A well-designed metering program would maintain pressure on the runway (as long as demand exists) and avoid starving the runway.

This risk can be quantified by looking at the ratio of the number of aircraft in the runway departure queue to the total number of active departures on the surface, as shown in Figure 14 for various runway configurations. The effect of metering is to reduce the frequency of instances in which nearly all the aircraft on the surface are in the departure queue (ratio > 0.8). On the other hand, the frequency of instances when the queue is nearly empty (ratio < 0.1) is higher in both 2011 and 2012.
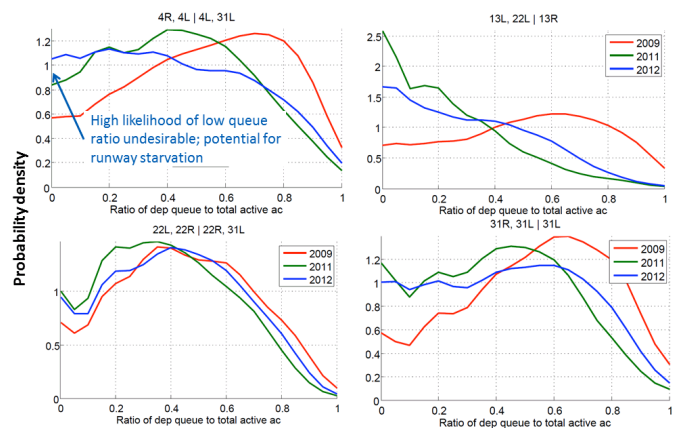

Figure 14. Distribution of the ratio of aircraft in departure queue to the total number on the surface, for various configurations.

Potential runway starvation events that occurred in 2012 can be further investigated by looking for flights which were delayed by the metering program (according to Aerobahn data), but which encountered no departure queue upon reaching the runway. (Such an analysis is not feasible for 2011; access to metering data is unavailable.) In the three-month summer period studied in 2012, 35 candidate events were found. However, upon further examination of surveillance data playback, most of these candidates do not appear to have been runway starvation events. Instead, the departure may have reached the runway as the previous flight is in the process of taking off, or there may be a data processing anomaly. Preliminary investigations indicate that a couple of instances of runway starvation may have occurred

when multiple departure runways were in use, or when a runway started being used after a hiatus. Events such as these, as well as the possibility of runway starvation in general, are directions for further study.

Overall Benefits of the GMP

To further quantify the improvements in performance, Table 5 shows the aggregate monthly improvement across all departures from JFK for the summer months. The years 2011 and 2012 are both compared to 2009. The significant improvement in taxi-out duration translates directly to savings in fuel burn, fuel cost, and emissions. As seen before, the overall Take-Off Delay, namely, the time between when a departure is ready to leave the gate and when it takes off, has decreased significantly. These reduced Take-Off Delays save a large amount of passenger time, valued at millions of dollars per month using a standard measure of the value of passenger time ($30 / hour) [11].

Table 5. Departure performance improvement at JFK airport since 2009. Values shown are the aggregate improvement per month during summer.

Improvement Type	2011	2012
Taxi-Out Time	1,700 hours	2,100 hours
Fuel	0.8 million kg	1.0 million kg
Fuel Cost	$0.8 million	$1.0 million
CO_2 Emissions	2,600 metric tons	3,200 metric tons
Take-Off Delay	1,800 hours	2,400 hours
Passenger Time	9,400 person-days	12,600 person-days
Passenger Time @ $30/hr	$6.8 million	$9.0 million

The values in Table 5 were derived from per-flight improvements seen in BTS data (Table 2). To determine the aggregate value of these performance improvements over the summer periods, we take the differences in per-flight values between 2011 and 2009, or between 2012 and 2009, and multiply these by the number of departures per month at JFK. The values listed in Table 5 were determined using a study period covering the summer months only. It is

likely that the improvement in other months is somewhat lower due to lower traffic demand and fewer weather disruptions. Therefore, a reasonable order-of-magnitude estimate of annual values may be obtained by multiplying the values in Table 5 by 10 (rather than by 12).

The improvements seen in Table 5 are due to many factors, not just departure metering or the Ground Management Program. However, the analyses of metering delay shift found direct savings of 1.5-2.7 minutes per flight, or 20-40% of the overall reduction in taxi-out duration. That is, 20-40% of the taxi-out time savings are due to metering gate holds. Therefore, metering is responsible for at least this portion of the improvement, and may contribute more improvement if it also enables an increase in runway throughput and a reduction in overall delay. Concurrent initiatives by carriers, the Port Authority, and air traffic control may also contribute to the improvement.

Table 6. Arrival performance improvement at JFK airport since 2009. Values shown are the aggregate improvement per month during summer.

Improvement Type	2011	2012
Taxi-In Time	400 hours	700 hours
Fuel	0.2 million kg	0.3 million kg
Fuel Cost	$0.2 million	$0.3 million
CO_2 Emissions	700 metric tons	1,100 metric tons
Passenger Time	2,200 person-days	3,700 person-days
Passenger Time @ $30/hr	$1.6 million	$2.6 million

Arrival taxi-in times have decreased since 2009. Aggregate arrival performance improvement values are shown in Table 6. The differences between years were multiplied by the number of arrivals per month to determine the monthly improvement values shown. As in the case of departures, many factors contribute to improved arrival performance, and it is not known how much effect departure metering may have had. Despite this uncertainty, these statistics demonstrate that the improved departure performance has not been achieved at the expense of arrival performance.

Conclusions

This paper analyzed the effect of ground management at John F. Kennedy International Airport, by comparing a pre-metering period in 2009 with the original metering in 2011 and the Ground Management Program that was introduced in 2012. Various metrics of airport performance were used to show that there were significant improvements in performance from 2009 to 2011, and these improvements were maintained in 2012. Through the analysis of operational data including from BTS, ASDE-X, and the Aerobahn system, the paper estimated that the total taxi-out time reduction at JFK in the summer of 2012 compared to the summer of 2009 is about 2,100 hours per month, with departure metering being responsible for saving 1.5-2.7 minutes per flight. The analyses also found that the arrival performance was not negatively impacted. The on-time performance of departures during the metering periods, the risk of runway starvation, changes in departure throughput, and runway sequence changes have been identified as areas for further investigation.

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