Project 016 Airport Surface Movement Optimization

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Project Lead Investigator

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- Tom Reynolds
- FAA Award Number: IA # DTFAWA-11-X-80007, FAA Task # 18
- Period of Performance: 1 September 2014 to 31 October 2015
- Task(s):
    1. Site adaptation to different airports
    2. Analysis of the impacts of departure metering in different operating environments
    3. Identification and evaluation of barriers to implementation
    4. Design of implementation protocols and field-testing at selection of study airports
    5. Coordination with Advances Surface Management Programs

Massachusetts Institute of Technology

- Hamsa Balakrishnan
- Lincoln subcontract number: Purchase Order 7000174664
- Period of Performance: 1 October 2014 to 30 September 2015
    6. See tasking above

Project Funding Level

$170,000

Investigation Team

Hamsa Balakrishnan (PI -- MIT), Tom Reynolds (PI – MIT Lincoln Laboratory), Hector Fornes Martinez (graduate student researcher, MIT), Patrick McFarlane (graduate student researcher, MIT), Armen Samurkashian (undergraduate researcher, MIT), Melanie Sandberg (associate staff, MIT Lincoln Laboratory).

Project Overview

Aircraft taxiing on the surface contribute significantly to fuel burn and emissions at airports. The quantities of fuel burned as well as different pollutants such as carbon dioxide, hydrocarbons, nitrogen oxides, sulfur oxides and particulate matter are proportional to the taxi times of aircraft, in combination with other factors such as the throttle settings, number of engines that are powered, and pilot and airline decisions regarding engine shutdowns during delays. Domestic flights in the United States in 2008 emitted about 6.6 million US tons of CO_2, 49,000 US tons of CO, 8,800 US tons of NOx, and 4,400 US tons of HC taxiing out for takeoff; almost half of these emissions occurred at the 20 most congested airports in the country. Similar trends have been noted at major airports in Europe, where it is estimated that aircraft spend 10-30% of their flight time taxiing, and that a short/medium range A320 expends as much as 5-10% of its fuel on the ground. The purpose of the Airport Surface Movement Optimization study is to show that a significant portion of these impacts can be reduced through "technologically-lightweight" operational measures to limit airport surface congestion.

A simple airport congestion control strategy would be a pushback policy aimed at reducing congestion on the ground that would consider the situation on the airport surface (also called the state). The N-control strategy is one such approach, and was first considered in the Departure Planner project. Several variants of this policy have been studied since in literature. The policy is effectively a simple threshold heuristic: if the total number of departing aircraft on the ground exceeds a certain threshold, further pushbacks are stopped until the number of aircraft on the ground drops below the threshold. In our early analysis we discovered that this form of discrete, on-off control strategy was difficult to implement in practice, and could also be overly reactive, potentially leading to instability. By contrast, the pushback rate control strategy that we have developed and tested at Boston Logan International airport (BOS) does not stop pushbacks once the surface is in a congested state, instead it regulates the rate at which aircraft pushback from their gates during high departure demand periods so that the airport does not reach undesirably high congested states. This document summarizes the Phase 2 efforts, including site selection criteria and developing techniques for characterizing airport surface operations, in order to enable the adaptation of a given congestion management approach to different airports, and the comprehensive evaluation of implementations.

As part of this project, MIT undertook an initial assessment of the applicability and potential benefits of "light-weight" airport-wide surface management control concepts involving minimal levels of automation to complement other Federal Aviation Administration (FAA) surface congestion management programs. It involved defining and modeling surface management control schemes, implementing them in a field demonstration at Boston Logan International airport, and evaluating performance in terms of impacts on taxi time, fuel burn and environmental emissions. During 15 four-hour tests conducted during the summers of 2010 and 2011, fuel use was reduced by an estimated 23-25 US tons (6,600-7,300 US gallons), while carbon dioxide emissions were reduced by an estimated 71-79 US tons. These savings were achieved with average gate-holds of just 4.7 min, and savings of 114-128 lb of fuel per gate-held flight. In addition to these savings achieved during field trials, many important lessons were learned regarding operational implementation of surface management techniques in both nominal and off-nominal conditions.

Most prior research (including this project to date) has focused on demonstrations of a proposed congestion management approach at a particular airport, and not on the adaptation of a particular approach to a range of airport operating environments. The current focus of this project addresses the challenges involved with adapting any class of surface congestion management approaches to different airports. Data and case studies from New York's LaGuardia Airport and Philadelphia International Airport are used to illustrate the diversity in operating environments. In particular, the MIT team has developed techniques for characterizing airport surface operations using site surveys and operational data. These characterizations are used for the adaptation of a given congestion management approach to different airports, and for the comprehensive evaluation of implementations.

Integration of Departure Metering Concepts into Surface Capabilities

Objective(s)

The objectives of this project are to conduct an initial assessment of the applicability and potential benefits of relatively easy-to-implement airport-wide surface management control concepts involving minimal levels of automation and procedural modifications, to complement other FAA surface congestion management programs. Phase 1 involved defining and modeling surface management control schemes, implementing them in a field demonstration at Boston Logan International airport, and evaluating performance in terms of impacts on taxi time, fuel burn and environmental emissions. Phase 2, conducted during FY14 and 15, is exploring adaptation of the approach to other airport locations with very different operating characteristics to help understand and inform requirements for more general deployment in future FAA decision support tools.

Research Approach

Framework for adapting approaches to different operating environments

This study has identified the overall process for designing a congestion management approach illustrated in Figure 1. The main steps involved in this process are: (1) Airport Selection, where an airport with surface congestion problems are identified; (2) Airport Characterization, where the details of the operation relevant to surface congestion management at an airport are identified; (3) Algorithm Development, where specific surface congestion management approaches are created; (4) Implementation Design, where the protocols of the execution of the algorithms are developed for the airport;

and (5) Operational Testing and Performance Evaluation, where the approach is tested and evaluated in the operational setting.

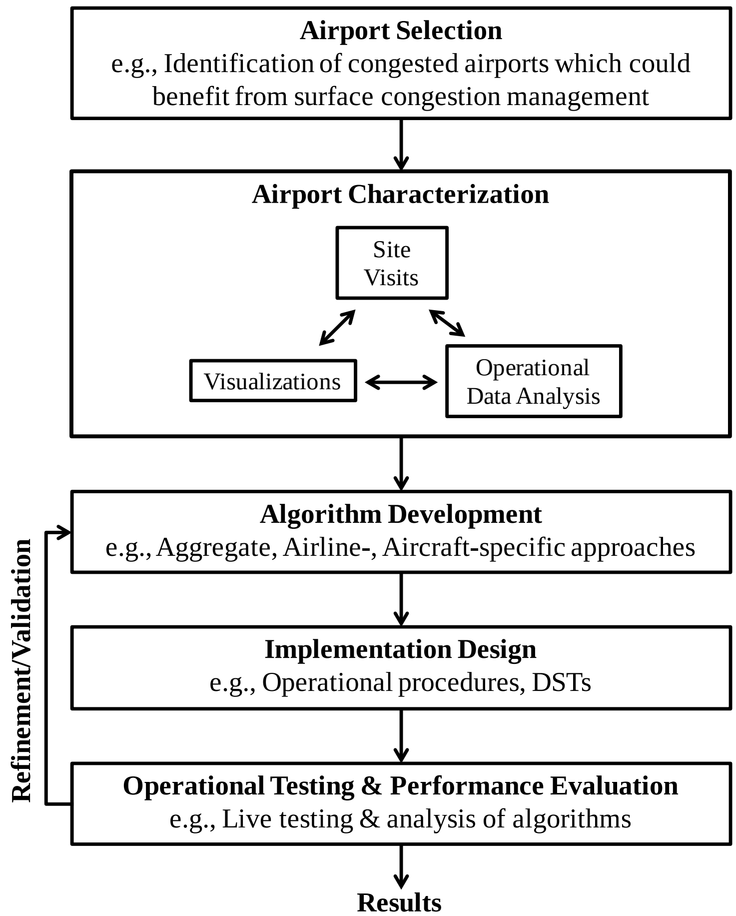

Figure 1. Overall design process for a congestion management approach.

The airport selection step resulted in an analysis focus on LGA and PHL airports during Phase 2 activities.

Analysis of LGA operations

Various sources of operational data have been used to perform analyses relevant to surface congestion management, including ASDE-X archives, the Aviation System Performance Metrics (ASPM) database, and the Route Availability Planning Tool (RAPT) archives. The high accuracy/update rate of ASDE-X allows the surveillance data to be of high value to the airport characterization task. The availability of ASDE-X at the 35 OEP airports in the US makes it particularly attractive for this effort. However, much of the analyses presented below can also be carried out with data from the ASPM database, which provides the Out, Off, On and In (OOOI) times of flights in the US National Airspace System. More detailed analyses, such as the measurement of departure queues and runway utilization, require the high-fidelity of ASDE-X data.

Runway configuration usage

The runway configuration is a considerable factor in determining airport arrival and departure throughput. Similarly, at many airports, the taxi-out times can also vary by configuration. Therefore, departure metering algorithms need to be adapted to different runway configurations. For example, Figure 2 shows the relative frequencies of occurrence of different runway configurations at LGA in January-August 2013.

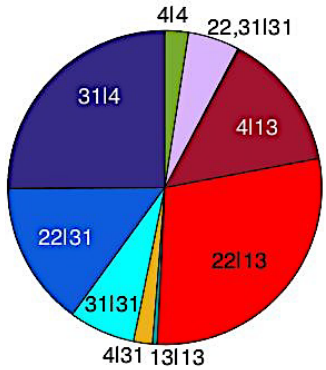

Figure 2. Frequencies of occurrence of different runway configurations at LGA in Jan-Aug 2013.

Departure throughput envelopes

The departure runway throughput varies by configuration, meteorological conditions, etc. For example, Figure 3 shows the departure throughput as a function of the number of active departures, for runway configuration 4|13. The figure shows the observed values, as well as curves that fit to the mean and median of the observed values.

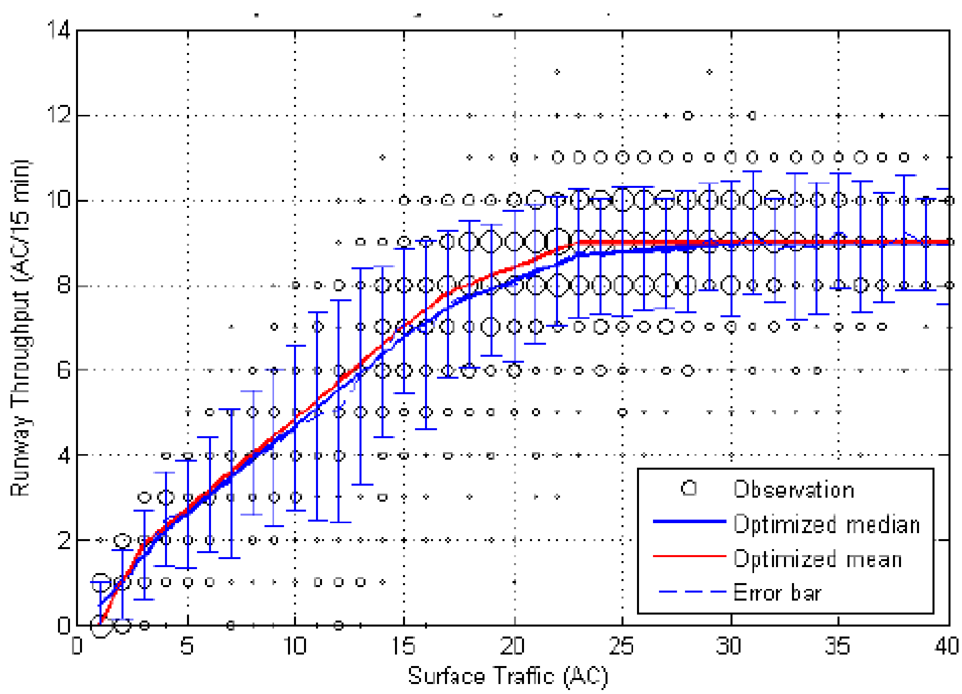

Figure 3. Departure throughput at LGA as a function of the number of taxing departures, for the 4|13 configuration under VMC.

Integration of RAPT data

Information on downstream restrictions is used for more accurate predictions of the operational throughput of an airport by leveraging the Route Availability Planning Tool (RAPT), an automated decision support tool that identifies departure routes that will be impacted by convective weather. Archived RAPT data can be used to predict the impact of route availability on the capacity of the airport. Regression trees are used to predict the departure throughput of LGA in each 15-minute interval as a function of arrival rate and a “RAPT value”, which is used to measure the level of route blockage in the departure airspace. Figure 4 illustrates the regression tree is learned for the 4|4 configuration.

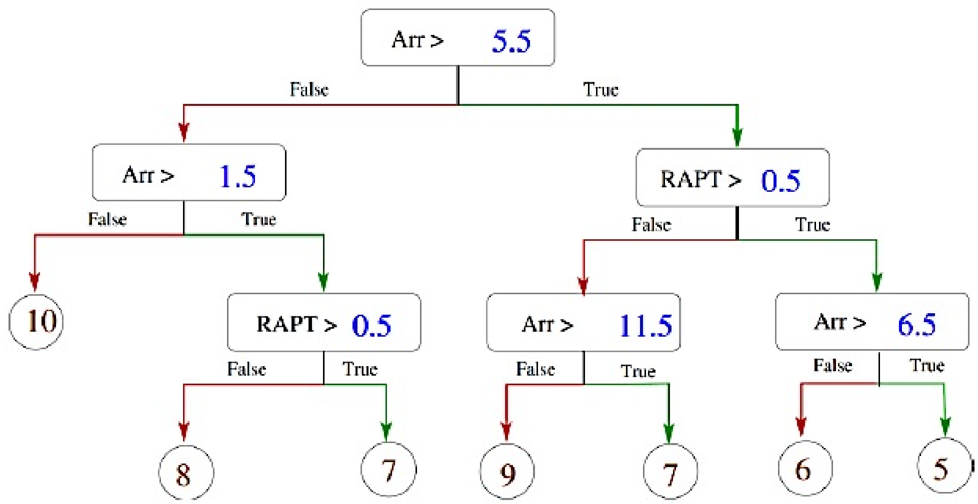

Figure 4. Regression tree for departure throughput (per 15-min) of the 4|4 runway configuration at LGA.

Figure 5 shows the proposed rate determination procedure adapted for LGA operations, which will consider the runway configuration, meteorological conditions, demand and RAPT forecast in a 15-minute period in order to determine the suggested pushback rate for that time period. The red items highlight the adaptations required for the LGA implementation relative to the BOS implementation developed in Phase 1 of the work.

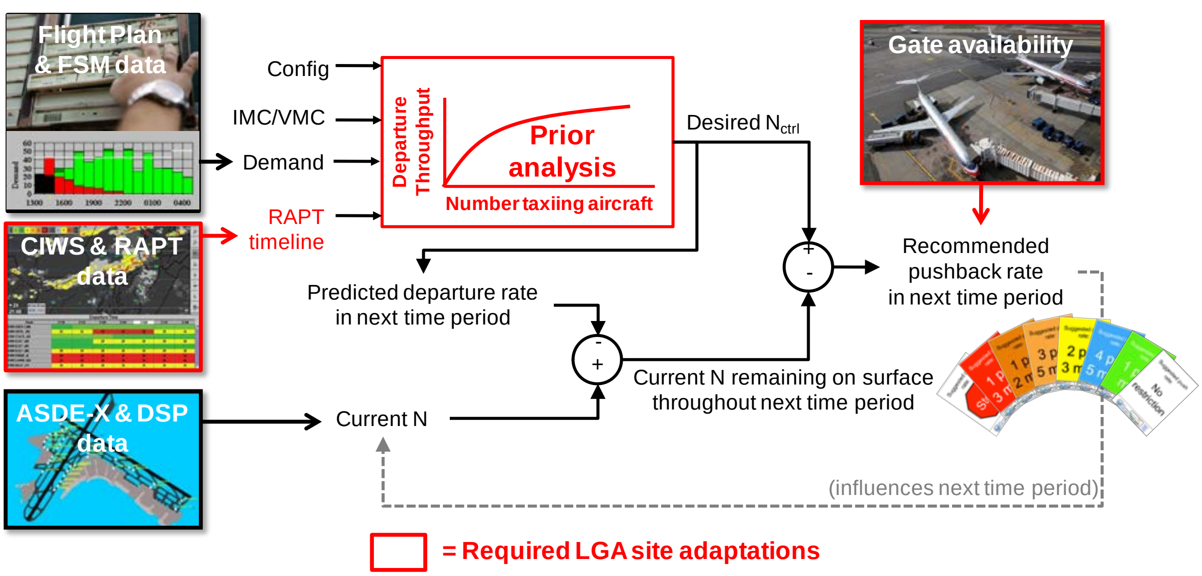

Figure 5. Recommended LGA pushback rate determination procedure.

Implementation protocol
Figure 6 shows the preliminary implementation protocol which was developed in collaboration with the LGA Facility. The dark red text indicates the modifications to the current push-back process. This option involves the creation of an "LGA Gate Controller" position similar to the BOS Gate Controller in the Phase 1 trials. It is possible that the Ground Control 1 position at LGA may potentially be modified to carry out this role.

The suggested pushback rate could be determined using the procedure shown in Figure 6. The RAPT forecasts can be obtained from the displays near the back of the tower; the current level of departing traffic can be determined either through visual observations or by counting flights on the DSP tool in the LGA Tower.

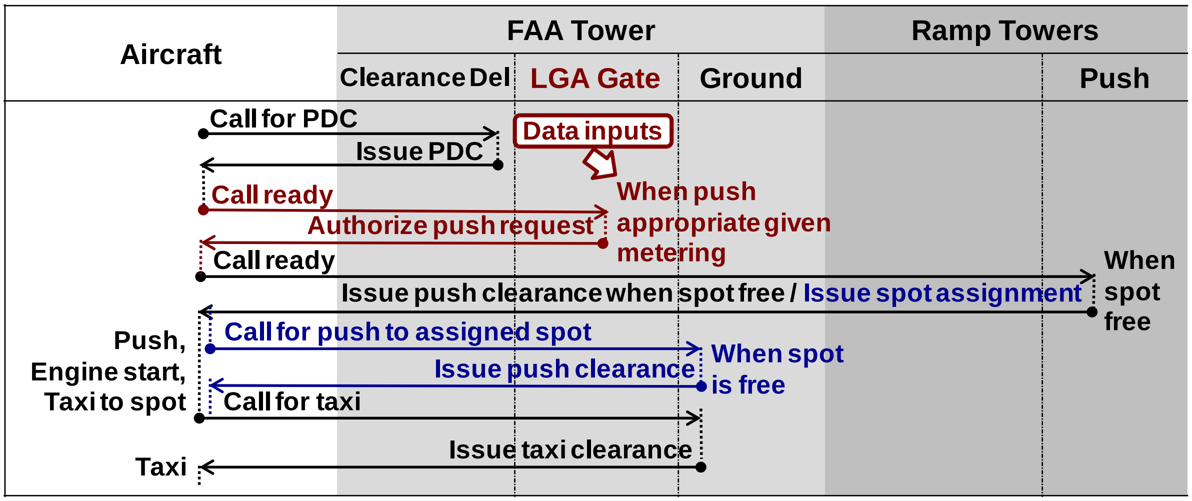

Figure 6. Potential implementation procedure.

Analysis of gate conflicts
Departure metering can potentially lead to additional gate conflicts: these are situations in which an arriving aircraft touches down when the gate it is assigned to is still being used by the previous (departure) aircraft. These conflicts could also be the result of the late departure of the departing aircraft and/or an early arrival of the arriving aircrafts. In the subsequent simulations of departure metering procedures such a N-control, a departure is released from its gate (virtual queue) when the arrival assigned to that gate touches down.

One of the LGA stakeholders requested an analysis of the gate conflict situation with and without metering in place. Figure 7 shows the impact of N-control on gate conflicts, by showing the average number of gate conflicts expected with and without metering at LGA. Metering (N-control) is seen to result in a small number of additional gate conflicts. However, the simulations also suggest that despite departures being released from the virtual queue because of gate conflicts, significant benefits can be expected to be gained from departure metering at LGA (Figure 8).

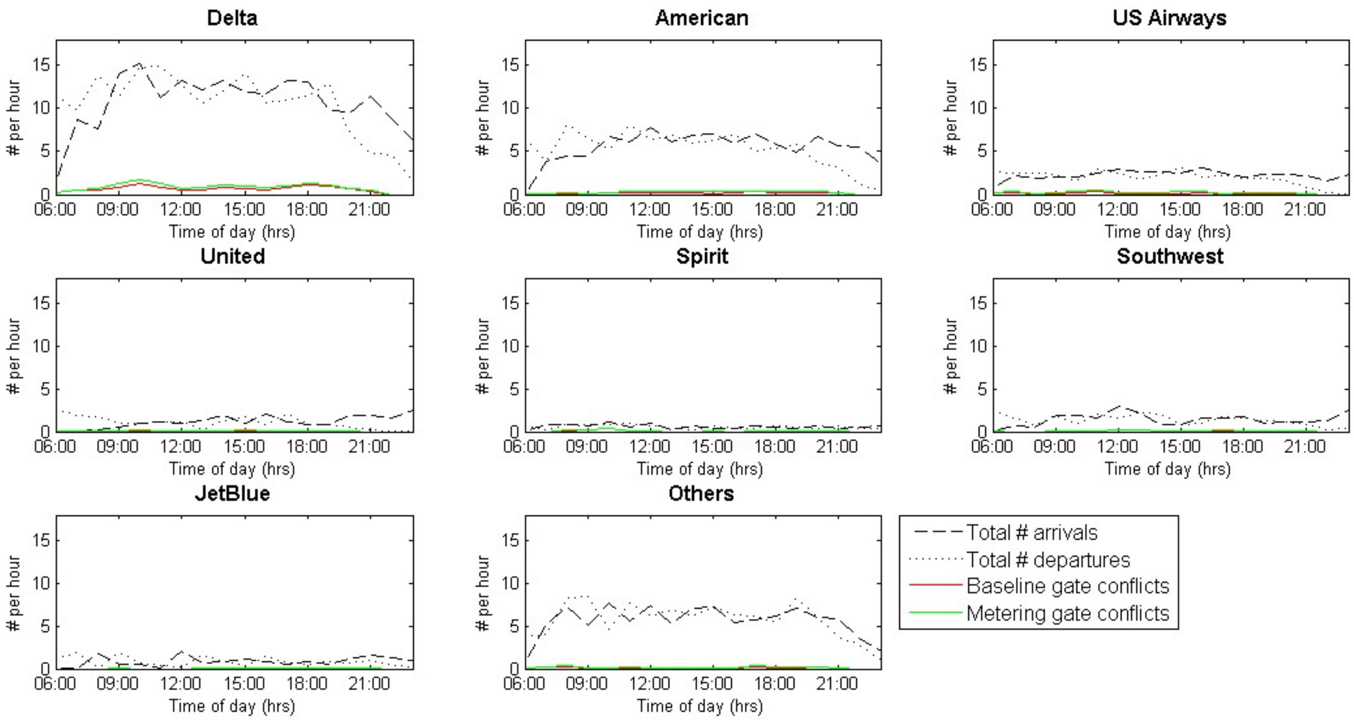

Figure 7. Average number of gate conflicts by time-of-day, for airlines at LGA, with and without departure metering.

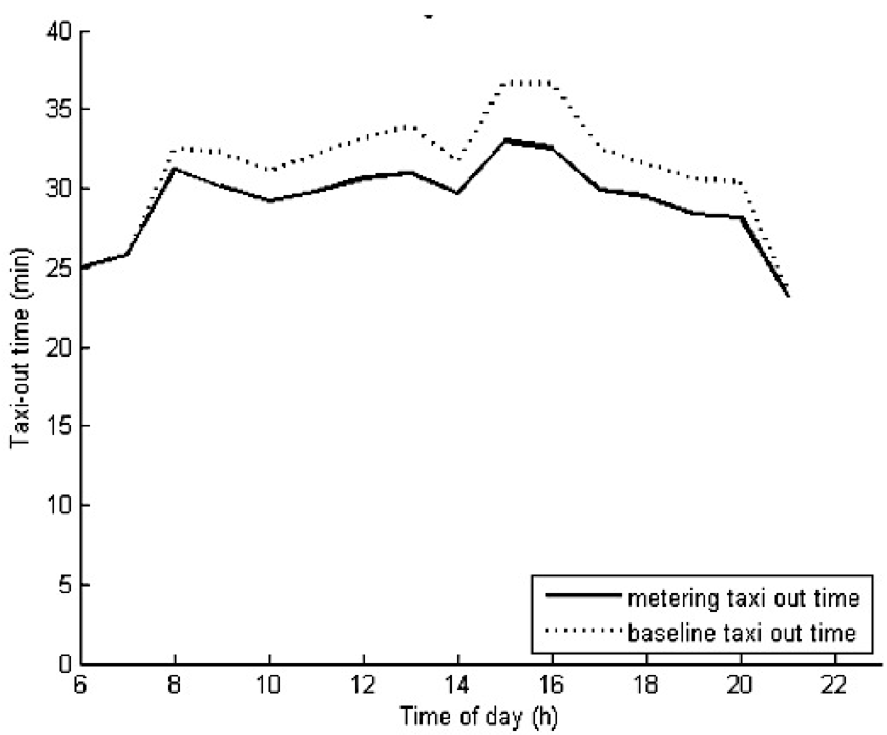

Figure 8. Average taxi-out imes by time-of-day at LGA, with and without departure metering, using simulations based on schedules from Jul-Aug 2013.

Analysis and simulation of PHL operations

Similar modeling and analyses to the ones presented above were also conducted for operations at Philadelphia International Airport (PHL). Figure 9 shows the relative frequencies of occurrence of different runway configurations at LGA in Jun-Jul 2014.

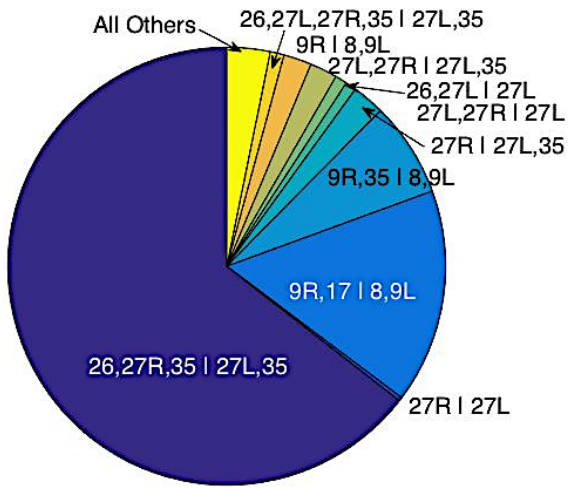

Figure 9. Frequencies of occurrence of different runway configurations at PHL in Jun-Jul 2014.

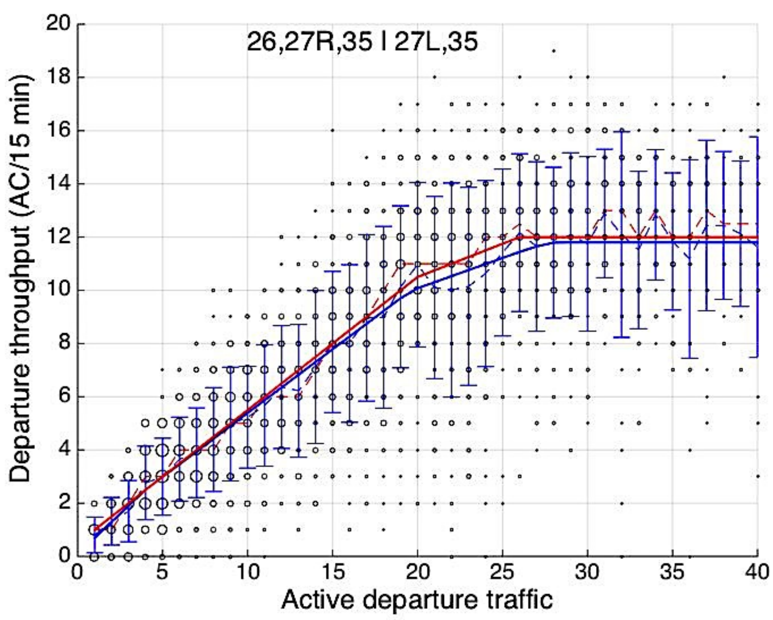

Figure 10. Departure throughput at PHL as a function of the number of taxing departures, for the 26,27R,35 | 27L,35 configuration under VMC.

Figure 10 shows the departure throughput as a function of the number of active departures, for runway configuration 26,27R,35 | 27L,35 at PHL. The figure shows the observed values, as well as curves that fit to the mean and median of the observed values.

Simulations of departure metering at PHL show that even after accounting for gate conflicts, significant reductions in taxi-out time may be realized. The total taxi-out time savings at PHL with N-control over a simulated two-month period (Jun-Jul

2014) with metering is estimated to be nearly 592 hours. In addition, as shown in Figure 11, the proposed approach is fair: the shares of taxi-out time reduction, gate-holding times and departure operations between airlines are all commensurate with one another during the departure metering times.

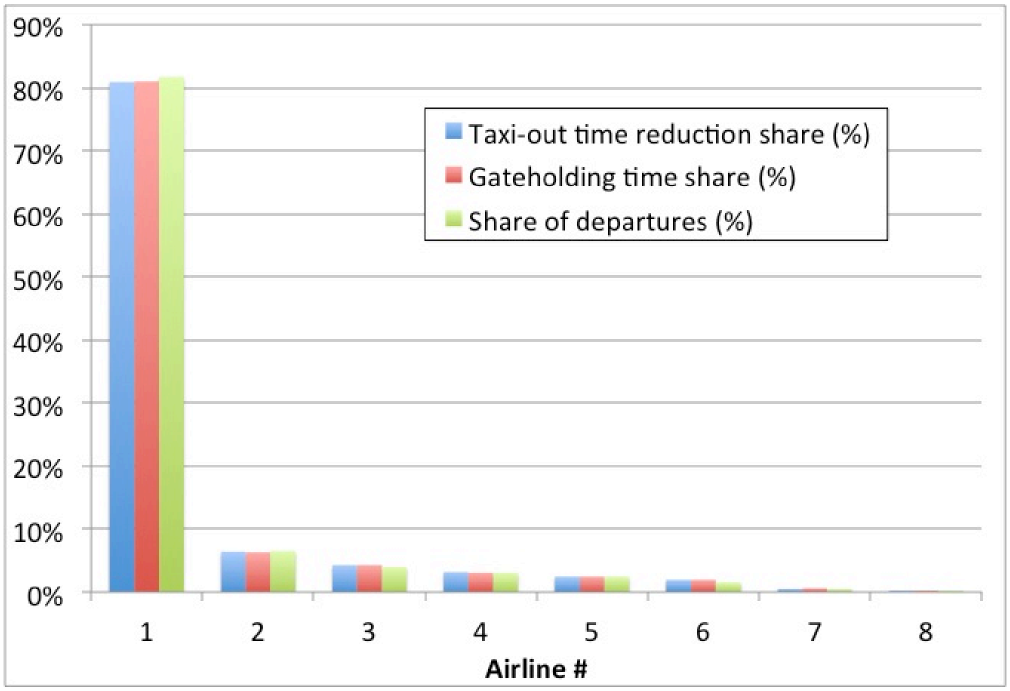

Figure 11. Shares of taxi-out time reduction, gate-holding times and departure operations, which are all found to be commensurate with one another during the departure metering times (simulated for Jun-Jul 2014).

Milestone(s)

- Site selection [Complete]
- Framework to adapt departure metering concepts to different operating environments [Complete]
- Gate conflict analysis [Complete]
- Impact of 2012-2013 LGA gate changes [Complete]
- Initial protocol designs (multiple) [Complete]
- Initial stakeholder engagement [Complete]
- Integration of LGA route availability information [Complete]
- Incorporation of gatehold time limits in simulations [Complete]
- Modeling and simulation of departure metering at PHL [Complete]
- Identification of air carrier impact metrics [Complete]
- Engagement/coordination with TFDM benefits analysis [Ongoing]
- Investigation of benefits of incorporation of S-CDM data elements (e.g. EOBT) [Planned]
- Identification of most appropriate departure metering algorithm for different airports and operating conditions and levels of uncertainty/ data accuracy [Planned]
- Identification of metrics to assess and refine strategic/ tactical departure metering performance [Planned]
- Coordination with Advanced Surface Management Programs [Planned]

Publications

Peer-reviewed journals:

M. Sandberg, I. Simaiakis, H. Balakrishnan, T.G. Reynolds and R.J. Hansman. "A Decision Support Tool for the Pushback Rate Control of Airport Departures," IEEE Transactions on Human-Machine Systems, Vol. 44, No. 3, pp. 416-421, June 2014.
I. Simaiakis, H. Khadilkar, H. Balakrishnan, T. G. Reynolds and R. J. Hansman. "Demonstration of Reduced Airport Congestion through Pushback Rate Control," Transportation Research Part A: Policy and Practice, Vol. 66, pp. 251-267, August 2014.

Other Reports
"Demonstration of Reduced Airport Congestion through Pushback Rate Control." I. Simaiakis, H.Khadilkar, H. Balakrishnan, T. G. Reynolds, R. J. Hansman, B. Reilly and S. Urlass. Proceedings of the 9th USA/Europe ATM R&D Seminar, June 2011.
"Dynamic Control of Airport Departures: Algorithm Development and Field Evaluation." I. Simaiakis and H. Balakrishnan. Proceedings of the American Control Conference, July 2012.
"Design, Testing and Evaluation of a Pushback Rate Control Strategy." I. Simaiakis, M. Sandberg, H. Balakrishnan and R. J. Hansman. Proceedings of the International Conference on Research in Air Transportation, May 2012.
"Airport Characterization for the Adaptation of Surface Congestion Management Approaches." M. Sandberg, T. G. Reynolds, H. Khadilkar and H. Balakrishnan. Proceedings of the 10th USA/Europe ATM R&D Seminar, June 2013.
"Dynamic Control of Airport Departures: Algorithm Development and Field Evaluation." I. Simaiakis, M. Sandberg and H. Balakrishnan. IEEE Transactions on Intelligent Transportation Systems, Vol. 15, No. 1, pp. 285-295, February 2014. DOI:10.1109/TITS.2013.2278484

Presentations
INFORMS Annual Meeting, November 2015
Transportation Research Board (TRB) Annual Meeting, January 2015

Outreach Efforts
Transportation Research Board (TRB) Annual Meeting, January 2015
INFORMS Annual Meeting, November 2015

Student Involvement
Hector Fornes Martinez, modeling of LGA operations and implementation design. Graduated with Masters degree, Jan 2015. Currently a Senior Aviation Analyst at ALG Global, Barcelona.
Patrick McFarlane, currently a Masters student at MIT. Modeling and simulation of PHL operations as well as uncertainty analysis.

Plans for Next Period

Task 1: Investigate effect on departure metering algorithms/benefits of incorporation of S-CDM data elements (e.g., EOBT, gate information, etc)

Task 2: Investigate most appropriate departure metering algorithm for different types of airports and operating conditions.

Task 3: Determine what metrics should be collected to assess and refine strategic and tactical departure metering performance.

Task 4: Coordination with Advanced Surface Management Programs (S-CDM and TFDM)