AIRPORT SURFACE OPERATIONS MANAGEMENT AT LAGUARDIA AIRPORT: METERING THE DEPARTURE TRAFFIC

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1. INTRODUCTION TO THE REPORT

This report analyzes the characteristics of the LaGuardia airport in New York and then describes the advantages of applying a metering strategy to the departure traffic at that airport. The main goal is to reduce the congestion at one of the most congested airports in the U.S. This work is supervised by Prof. Hamsa Balakrishnan and builds upon the work of two for MIT PhD students in the Department of AeroAstro, Ioannis Simaiakis (Simaiakis 2013) and Harshad Khadilkar (Khadilkar 2011). Based on these two thesis and the models developed there and particularly the development of the metering strategy at Boston Logan Airport, my research concerns the implementation of the conceptual framework of metering at LaGuardia Airport. In this context, this report contains the details and considerations I am working on. I have worked on all the data presented in this report except for the model that was developed by the two authors and I just describe it.

This report has five section structured as follows: section 2 describes the current situation at LGA that explains why it is relevant to reduce congestion; section 3 describes the metering model. Then section 4 calibrates some of the parameters and values that the model requires. Finally, section 5 presents the results and performance indicators.

2. CURRENT SITUATION AT LGA

LaGuardia Airport is the closest Airport to Manhattan, and thus, is the most convenient. Consequently, it is very congested and during long periods during the day airlines schedule operations above the airport VFR capacity. In Figure 1 readers can see that the airport has four terminals and two crossing runways. The terminal on the lower right side is Terminal A and operates Delta shuttle flights; the Central terminal operates flights from all the airlines except Delta and US Airways; the US Airways terminal also has some Delta flights (there was a transfer of some gates from US Airways to Delta); finally, the Delta terminal only serves Delta flights. As for the runways, they are intersecting, which is not optimal but that was the only way to build the airport given the constraints imposed by the city; in fact, part of the airside is built in a landfill. The intersection of runways reduces the capacity of the runway system given the fact that each runway affects the throughput of the other. In this regard, the maximum capacity that the system of runways can achieve is twice
the capacity of arrivals in one runway. Another detail worth pointing out from Figure 1 is the large density of taxiways. In congested airports like LaGuardia, where there are many operations concentrated in a relatively small area, having redundant paths is essential to ensure smooth operations.

![Figure 1: Airport layout of LaGuardia Airport. Source: faa.gov](image)

The distribution of terminals already indicates that Delta has an important presence at the airport; it has presence in three out the four terminals. The presence at the airport in this case seems to have a direct correlation with the market share. Figure 2 depicts a pie chart with the market shares of each airline.

From all the airlines, Delta and its affiliates represent 47% of the traffic at LaGuardia. From the airport management perspective it does not make much difference if flights are mainline or they are regional as they occupy Delta gates. The same argument holds for American Airline and its subsidiary American Eagle that together account for 19% of the traffic, being the second biggest carriers. These two are followed by US Airways (who used to have a larger share but sold some of the airport slots to Delta) and United.
At this point it is important to plunge in the way the tower manages (or does not) surface operations at LaGuardia. The steps are:

- During the last steps before the aircraft is ready the airlines check with the tower if the flight has all the paperwork ready to take-off and be routed to the destination (Clearance).
- The aircraft is ready to pushback and call the ramp tower. The ramp tower is a coordination center managed by airlines that coordinate the surface operations in some ramp areas. Usually there is one ramp tower for each terminal or pier. In the case of LaGuardia the reader may see the ramp towers in red in Figure 3. There are six ramp towers at LaGuardia. The ones in Terminal A and Terminal B are under the responsibility of Delta. The ramp tower in terminal C has people from US Airways and Delta. The ramp towers in Terminal B have staff from different airlines that operate in each ramp area.
- Ramp towers coordinate arrivals and pushbacks in the ramp to avoid mishaps.
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- When the ramp tower releases the ramp area, the aircraft enters the taxiway system and circulates to the departure runway until it stops in the departing queue.
- The aircraft takes-off when all the aircrafts in front have already taken-off.

A short summary of this system is that the sooner the pushback the sooner the aircraft will get to the departure queue. This creates an incentive to the creation of long departure queues with the consequences that those lines entail.

![Figure 3: LaGuardia Airport ramp tower locations. Source: (Khadilkar 2011)](image)

The main and usual consequences of such a pushback policy are the long lines of aircrafts willing to take-off. Figure 4 shows a typical image at LaGuardia, where there are 29 departing aircrafts on the airport surface willing to take-off. Doing a quick math exercise, a typical departure throughput at LaGuardia with the runway configuration of Figure 4 (31/4) is 10 departures every 15 minutes. With this number, the 29th aircraft in line, which had just joined the line, had, approximately, 45 minutes of taxiing out before taking-off.

The three main bad consequences of such a pushback policy are the following:

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Khadilkar 2011

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- There is a lot of fuel burnt unnecessarily.
- There are plenty of unnecessary gas emissions.
- Queues generate congestion at the airport that affect arriving traffic, in some runway configurations more than others.

![Figure 4: Departure queue with 29 aircrafts waiting to take-off.](image)

*Source: (Balakrishnan 2013)*

In this context, we propose a metering model that will help controllers reduce the congestion on the airport surface. Section 3 explains the metering strategy with further detail.

### 3. METERING STRATEGY. DESCRIPTION OF THE MODEL

The main goal of this model is to reduce the total taxi-out time. By reducing the taxi-out time, we expect to see a reduction of the fuel burn and emissions, which is important from many different perspectives.

This model considers two components of the taxi-out time, the travel time (or unimpeded taxi-out time) and the queuing time that accounts for the congestion time; Figure 5 shows the decoupling of this taxi-out time. The metering strategy aims at bringing the queuing
time as close to zero as possible by holding aircrafts at the gate until it is sure there will be an opportunity for them to take-off.

![Queuing model structure. Source: (Balakrishnan 2013)](image)

In order to effectively reduce the queuing time it is necessary to analyze the current behavior of queues and capacity in the tarmac. That is, we need to understand when congestion starts to appear in the system in order to avoid such a situation. In this direction, we compute the congestion curve by plotting the takeoff rate as a function of the number of aircraft taxiing out (N). The plot we obtain (Figure 6) increases monotonously and has concave shape. In addition, we observe there is a value N* at which departure throughput does not increase even if the number of aircrafts on the ground increase. The values of N above N* constitute the saturation regime and are the values that generate congestion. Therefore, should we want to reduce congestion we need to operate below the N* value. This N* value is a function of the runway configuration; each configuration is restricted by different runway intersections and taxiway lengths that cause saturation in different circumstances.
Recalling the model in Figure 5, the number of aircrafts $N$ is the input of the queuing Module, (Module 2). That is, by controlling $N^*$ we are controlling the number of aircraft that are affecting the queues to take-off.

Another parameter that affects the queuing module is the runway throughput. This throughput also depends on the runway configuration and is used to determine the number of “departure slots” available. Put another way, the throughput is the number of aircrafts that leave the queue. The calculation of this throughput is not straightforward as it depends not only in the runway throughput, but also in the weather conditions around the airport airspace and the number of aircrafts landing. In this research, we compute this throughput with regression trees. Section 4.1 shows an example of the use of a regression tree to calculate the runway throughput.

At this point, the model has the tools to balance the queuing inputs (regulated by the $N^*$) and outputs (throughputs). However, there is one circumstance where this balance needs to be altered for one period: the presence of gate conflicts. As indicated previously, the model avoids congestion in the airport surface by holding aircrafts at the gate, and thus, aircrafts spend more time at the gate. In this context, there is a higher probability that the next aircraft that needs to use a particular gate lands when the previous aircraft is still in the gate (gate conflict). These conflicts occur in airport facilities where terminal gates are a limiting factor and are a clear consequence of over-scheduling or miss-allocation of resources (gates). That is to say that gate conflicts already occur at LaGuardia but it is possible that
the number of instances may increase with the gate holding strategy proposed here. Below we discuss about the additional gate conflicts due to this gate holding procedure.

4. CALIBRATION OF MODEL PARAMETERS
As introduced in the previous section, we need to calibrate two different components of the model before we can obtain the results. The first is the calibration of the regression tree to predict the runway throughput based on the runway configuration, weather and arrival rate. The second is the unimpeded taxi-out time.

4.1. REGRESSION TREE
The model uses a regression tree as a data-mining tool to predict the actual departure runway throughput as a function of the runway configuration, the arriving traffic and the weather. These three variables are the most critical variables affecting the throughput in the everyday operations. The interesting side of these variables is that aviation authorities like FAA measure and record them regularly and can eventually be obtained. In this case, we have estimated this regression tree with RAPT data for the weather and ASPM data for airline traffic. Figure 7 depicts the regressions tree.

In order to understand the tree, one has to know that the weather variable (RAPT) adopts ranges of 0 to 1; and the higher the number the worse the weather. Usually values above 0.2 represent bad weather. In addition, as a clarification, the variable arrivals account for the number of arrivals in a 15-minute period.

Based on this we find that for low arrivals we can either see high or low departures. The former situation corresponds to when there is a lot of traffic and there is a strong demand of arrivals and departures, and thus the infrastructure is operating at its capacity. The latter situation corresponds to low traffic when there are few arrivals and few departures.

Another observation is that in bad weather circumstances throughput typically goes slightly down, which is expected.
4.2. **UNIMPEDED TAXI-OUT TIME**

The unimpeded taxi-out time is the time it would require an aircraft to taxi-out if there were no congestion. In airports like LGA with massive and permanent congestion, it is difficult to observe such a situation because other departing aircrafts affect taxi-out operations. The calculation process for this unimpeded taxi-out time is not straightforward. (Simaiakis 2011) suggests to build a scatter plot with the real taxi-out time observations in the y-axis and the adjusted traffic (Nadj) in the x-axis (Figure 8). The definition of adjusted is, for an aircraft \( l \), the sum of the aircrafts taxiing out when aircraft \( l \) pushes back plus the number of aircrafts that pushback while aircraft \( l \) is taxiing out. After plotting taxi-out times and adjusted traffics, we need to run a convex regression to obtain a convex non-decreasing function. In particular, I use the CVX Matlab (Research 2013) code to do this regression. At this point, the unimpeded taxi-out time is the lowest value of the convex non-decreasing function.
A consideration to bear in mind is that the most accurate calculation of unimpeded taxi-out time would provide a different value of such time for each gate position. However, this is not practical given that there are many gates at an airport with a maximum of seven operation in each gate; therefore, we would need many historic data to compute a specific unimpeded taxi-out time for each gate. As a compromise solution, in this research we calculate this time by terminal of departure; the interesting aspect is that this rougher classification allows us determine the performance of the model as discussed in section 5.

Another consideration is that this unimpeded taxi-out time depends on other factors that may be critical to obtain accurate results of the simulation. Among other factors, in addition to the departure terminal, we have decided to use the runway configuration and the visual conditions at the airport (IFR or VFR).

As an example, Figure 10 and Figure 11 depict the unimpeded taxi-out time calculation process for airplanes serviced in Terminal B and Terminal D when the runway configuration is 31/4. Before discussing the results the results in the two scatter plots, it is important to recall the distribution and layout of the airport. As seen in Figure 9, for the configuration 31/4, arrivals land in runway 31 (indicated with a red arrow) and takeoffs take place in runway 4 (indicated with a blue arrow). Hence, every departing aircraft need to taxi to the southwestern most part of the airport. It is obvious then that those aircraft that departed from Terminal B (central terminal) will be in a better position than those in Terminal D (the most eastern one).
Figure 9: Airport layout with indications on the runway configuration 31/4. Landings take place as indicated by the red arrow and takeoffs as indicated by the blue arrow.

This difference in location appears clearly in the convex curve in Figure 10 and Figure 11 that relate to aircrafts from terminal B and D respectively. The former figure shows an unimpeded taxi-out time of approximately 15 minutes, whereas the latter is closer to 18 or 19 minutes. The exact values are 15.7 and 18.5 minutes.

The results make sense, as Terminal B is significantly closer to the departure runway.
Figure 10: Calculation of the unimpeded taxi-out time for terminal B with runway configuration 31/4

Figure 11: Calculation of the unimpeded taxi-out time for terminal D with runway configuration 31/4
5. RESULTS AND PERFORMANCE MEASURES

This section presents the results and performance indicators that reflect the effectiveness of the metering strategy for the case of LGA. The results here could be used to convince airlines, the FAA and the PANYNJ that they would be better off by implementing such strategy as it represents an improvement of all the indicators at the airport.

5.1. TRAFFIC

In this part of the results section, we analyze Figure 12 and Figure 13 that compare the surface traffic, the pushback rates and taxi-out times for the two different pushback strategies.

First, I will discuss the black and the blue lines that correspond to the surface traffic under the current and the metering pushback policy strategy, respectively. The first observation is that the black line is always above the blue. Both lines represent airport surface traffic or congestion; therefore, given how the metering model works we were expecting congestion to be equal or lower under metering conditions. The difference between the black and blue curves is particularly salient for those periods of the day when there airport has departure operations above the capacity (broadly defined). In those times when there is not so much traffic the black and blue lines match. A relevant observation is that the blue line rarely goes above the 25 operations, which is the Nctr value for the day of the simulation (August 15 2012). In fact, the blue line would never go above 25 if it were not for the gate conflicts that cause the release of aircraft above the Nctrl value in order to allow arriving aircrafts to taxi-in to the gate. The main lesson from these two lines is that congestion is actually reduced in peak times with the metering strategy proposed.

Second, I will analyze the red and green lines, which correspond to the pushback rates under the current and the proposed metering strategy, respectively. In periods of low traffic, the green curve tracks the red ne perfectly. That is because in periods of low traffic the metering condition allows more operations than there actually are and thus, aircrafts leave when they are ready, as it there were a pushback at discretion policy in place. For the times with more traffic, it is interesting to see how the metering strategy “laminates” pushback peaks through a gate hold. This leads to a phase difference between the green and red.
The plot that better explains what the metering strategy does is Figure 13. The black lines are the average taxi-out times in the current strategy (pushback at discretion). The blue lines are the same as the black lines but for the metering strategy. In all the circumstances, the blue lines are equal or lower than the black lines and that is the consequence of holding some planes at the gate until the number of aircrafts in the airport surface is lower than the Nctrl value. Figure 13 clearly depicts this balance between the reduction of taxi-out time when metering and the gate holding time. There always needs to be a gate holding time in order to reduce the taxi-out time.
Figure 12: Simulated traffic indicators for the current and the metering strategy.

Figure 13: Taxi-out time and gate holding time
5.2. **FUEL CONSUMPTION AND EMISSIONS**

From (Carlier 2006) we obtain the values of fuel consumption and different types of emissions. Values presented differ based on the size. For this research, we assume that on average the values for medium jet accurately represent approximately the values of the fleet composition at LaGuardia. These values are in Table 1.

### Table 1: Unitary values for fuel consumption and emissions. Source: (Carlier 2006)

<table>
<thead>
<tr>
<th>Concept</th>
<th>Value (per minute)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel consumption</td>
<td>3.0 Kg</td>
</tr>
<tr>
<td>NOx emissions</td>
<td>30 g</td>
</tr>
<tr>
<td>HC emissions</td>
<td>12.2 g</td>
</tr>
<tr>
<td>CO emissions</td>
<td>67 g</td>
</tr>
</tbody>
</table>

Based on the values shown in Figure 12 and Figure 13, we can calculate the total difference between taxi-out time for the current pushback and the metering strategy for all the flights. Now we compute the total taxi-out difference, taking into account all the flights and the specific taxi-out times, and we obtain a taxi-out reduction of approximately 3,996 minutes in one day; Table 2 shows the specific values:

### Table 2: Total taxi-out values.

<table>
<thead>
<tr>
<th>Concept</th>
<th>Value (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total taxi in the current strategy</td>
<td>21,505</td>
</tr>
<tr>
<td>(pushback at discretion)</td>
<td></td>
</tr>
<tr>
<td>Total taxi with the metering strategy</td>
<td>17,509</td>
</tr>
<tr>
<td>(pushback at discretion)</td>
<td></td>
</tr>
<tr>
<td>Difference</td>
<td>3,996</td>
</tr>
</tbody>
</table>
This difference represents an 18.5% reduction with respect to the original. This number is a first estimate, as the model still needs some adjustments in accuracy. However, this number tells us that it is possible to reduce the values of all these concepts. In fact, for August 15 the reductions are the following:

<table>
<thead>
<tr>
<th>Concept</th>
<th>Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel consumption</td>
<td>11,988 Kg</td>
</tr>
<tr>
<td>NOx emissions</td>
<td>119,880 g</td>
</tr>
<tr>
<td>HC emissions</td>
<td>48,751 g</td>
</tr>
<tr>
<td>CO emissions</td>
<td>267,732 g</td>
</tr>
</tbody>
</table>

These numbers are just an indication of what it is possible to achieve with metering in one particular day. The extrapolation of this number to a week, month or year is complicated because traffic varies significantly from day to day and from month to month. Nevertheless, the main message here is that there actually is an important reduction of fuel consumption and emissions.

5.3. GATE CONFLICTS

As described in Section 2, the model considers the additional gate conflicts caused by the metering strategy. The key point is to analyze whether these additional conflicts are significant or not. To assess this issue we will analyze the additional conflicts in absolute terms. Figure 14 depicts the total number of additional gate conflicts for all airlines by time of the day (time division is 15 minutes) over a period of 15 days (August 1 2012 to August 15 2012)
The first observation is that the numbers are rather low for a 15-day period. For instance, for the 10 to 10:15 AM period we encounter 6 additional gate conflicts over 15 days; assuming that these 6 cases will not correspond to one same day, it is possible to state that the additional number of conflicts is not particularly relevant. These conflicts are even less relevant when we look at the outcomes of the metering.

5.4. COMPLIANCE WITH THE FIRST COME FIRST SERVE POLICY

One of the most important characteristics that airlines require from the airport is a fair First Come First Served policy at the tarmac. That is, the first aircraft that finishes the push back is expected to be the first to take-off and subsequently. Airlines think that the current pushback at discretion policy follows this requirement but just by the fact that each airline operates in a different terminal puts them in a better or worse situation based on the most common runway configuration. In this section, we analyze whether the FCFS policy is
followed in the current pushback strategy and then we do the same exercise for the metering strategy. The indicator that we use to discern whether each strategy follows a FCFS policy we assign a classification order based on the pushback time and another classification order based on the time they take off. If the pushback strategies respected the FCFS policy this two classification orders should be the same. In order to check this statement we create a variable defined as the takeoff order minus the pushback order. Negative values in such a variable mean that the pushback number is larger than the takeoff number. Put another way, negative values represent that the flight has moved forward in the queue whereas positive values are associated to movements backwards.

The first indicator that we obtain is the number of flights that move forward or backward, no matter how many positions they move. Table 4 and Table 5 show the results for the current pushback strategy (pushback at discretion) and for the metering strategy (gate holding), respectively.

*Table 4: Percentage of flight that move forward or move back in the queuing process for the pushback at discretion policy. The last column is just the difference between the second and third column.*

<table>
<thead>
<tr>
<th>Airline</th>
<th>Percentage of flights moving forward</th>
<th>Percentage of flights moving back</th>
<th>% change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delta &amp; Regionals</td>
<td>15,7</td>
<td>34,1</td>
<td>-18,4</td>
</tr>
<tr>
<td>American and Eagle</td>
<td>28,7</td>
<td>2,1</td>
<td>26,6</td>
</tr>
<tr>
<td>Us Air &amp; Regional</td>
<td>6,6</td>
<td>25,7</td>
<td>-19,1</td>
</tr>
<tr>
<td>United</td>
<td>30,1</td>
<td>2,6</td>
<td>27,5</td>
</tr>
<tr>
<td>Spirit</td>
<td>30,5</td>
<td>0,0</td>
<td>30,5</td>
</tr>
<tr>
<td>Southwest/AirTran</td>
<td>24,1</td>
<td>1,3</td>
<td>22,8</td>
</tr>
<tr>
<td>Jetblue</td>
<td>20,4</td>
<td>1,7</td>
<td>18,7</td>
</tr>
<tr>
<td>Others</td>
<td>26,8</td>
<td>5,4</td>
<td>21,4</td>
</tr>
</tbody>
</table>
Table 5: Percentage of flight that move forward or move back in the queuing process for the gate holding policy. The last column is just the difference between the second and third column.

<table>
<thead>
<tr>
<th>Airline</th>
<th>Percentage of flights moving forward</th>
<th>Percentage of flights moving back</th>
<th>% difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delta &amp; Regionals</td>
<td>7,4</td>
<td>16,0</td>
<td>-8,6</td>
</tr>
<tr>
<td>American and Eagle</td>
<td>13,3</td>
<td>2,1</td>
<td>11,3</td>
</tr>
<tr>
<td>Us Air &amp; Regional</td>
<td>7,0</td>
<td>13,1</td>
<td>-6,1</td>
</tr>
<tr>
<td>United</td>
<td>13,7</td>
<td>2,0</td>
<td>11,7</td>
</tr>
<tr>
<td>Spirit</td>
<td>17,5</td>
<td>0,0</td>
<td>17,5</td>
</tr>
<tr>
<td>Southwest/AirTran</td>
<td>10,3</td>
<td>1,6</td>
<td>8,7</td>
</tr>
<tr>
<td>Jetblue</td>
<td>11,1</td>
<td>1,3</td>
<td>9,8</td>
</tr>
<tr>
<td>Others</td>
<td>12,7</td>
<td>2,5</td>
<td>10,3</td>
</tr>
</tbody>
</table>

Comparing Table 4 with Table 5, one can state that the current situation is far from following a FCFS policy. Indeed, we see airlines like Delta or US Airways with large percentages of their flights moving back in the queuing process. On the contrary, all the other airlines typically see their flights moving forward in the queue. This is uniquely due to the physical location of the terminals. Indeed, Delta and US Airways operate in Terminal C and D, which are significantly further from runway 4 than the other airlines that operate in Terminal B.

The good news is that with the metering strategy this vast difference between the flights moving forward and backward is reduced by a considerable amount. For the case of Delta, the major airlines at LGA, the percentage of flights that move back halves, from 34% to 16%.

The rationale behind this fact is that the metering strategy respects the FCFS policy by definition together with the fact that the model is holding aircrafts at the gate. For the case
of holding aircrafts from Terminal B, we are avoiding that this flight snicks in in from of a Delta flight that is supposed to go first.

A visual indicator of the movements back and forward is the histogram with the real movement in order. That is, we compute the differences in classification order for all the flights and we draw a histogram with those differences for each airline. As a reminder, negative values are associated with flights moving forward as opposed to positive values that correspond to flight that move forward. The ideal situation would have a value of zero. A suboptimal situation would accept swaps in the queuing system but we would expect to balance swaps forwards with swaps backward; this would translate to a symmetric histogram. In this case, we present two histograms for Delta and two for America. The topmost histograms correspond to the current strategy (no control). For the case of Delta, we see that there are a disproportionate number of flights in the positive side, whereas for American we see the opposite. Figure 15 and Figure 16 are the final evidence that the location of the Terminals actually matters in the process of not following the FCFS policy.

![Histograms of FCFS swaps for current pushback strategy](image.png)

**Figure 15: FCFS swaps for the current pushback strategy.**
However, it is interesting to see that although the FCFS policy is not followed in the current schedule, it can be significantly improved with the implementation of the metering strategy. Indeed, a first observation is that when looking at the y-axis the number of flights with zero swaps has changed, for the case of Delta, from around 2300 to 2850 instances. In the case of positive values of 1 swap the change is from 700 to 400. For American a similar argument holds but with negative swaps.

In conclusion, we can state that the metering is an efficient strategy to impose the FCFS policy and compensate the potential differences in distances run from different terminals.
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BIBLIOGRAPHY

Balakrishnan, Hamsa; Hansman, R. John; Reynolds, Tom G. 2013. Reduced Taxi Congestion at LGA through Airport Surface Movement Optimization. Massachusetts Institute of Technology; MIT Lincoln Laboratory.

Carlier, Sandrine; Hustache, Jean-Claude. 2006. Project GAES - Environmental Impact of Delay. edited by EUROCONTROL


Simaiakis, Ioannis. 2013. Analysis, modeling and control of the airport departure process, Department of Aeronautics and Astronautics, Massachusetts Institute of Technology.