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Human-Centered Design to Support Flexibility and Adaptability in Airport Surface Management

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Airport surface delays can impact airport surface congestion, operational costs, environmental emissions, and passenger satisfaction. We report on structured interviews and observational studies at two US airports with different approaches to managing surface delays. Each approach requires human judgment to set and adapt control parameters to manage departure flows. We contrast these approaches in terms of: 1) distribution of roles and responsibilities; 2) human judgments required; 3) enforcement of flight operator compliance; and 4) tools for coordination and decision support. Guidance is provided for designing and implementing human-centered surface management programs based on an analysis of these approaches.

At the John F. Kennedy International Airport (JFK), the Airport Operator and Ramp Control Tower (RCT) Operators make up a Surface Group that started the metering program in spring 2010. The Surface Group adapted a previously developed winter operations slot allocation program for daily use. The metering program assigns aircraft to 15-minute time windows according to the expected departure rate during the afternoon departure push. Flight crews are not to contact the Air Traffic Control Tower (ATCT) for permission to taxi to the departure runway more than 5 minutes before their time window. Time window allocation and coordination of RCT intent to use their time windows is facilitated by software tools.

The ATCT at the Newark Liberty International Airport (EWR) has used a metering program for several years. ATCT controllers assign a specific metering time to each departure. The flight crew is not to contact the Ground Controller before that time. Times are provided to flight crews via radio, which the RCTs monitor. We visited the ATCT, Airport Operations Center, and one RCT at JFK, and the ATCT and one RCT at EWR.

Both metering programs were developed by local airport stakeholders and rely on a small number of people to meet the challenges of surface and airspace constraints. We observed and interviewed a number of these people to identify some of the judgments they make about capacity, demand, and traffic flow. These judgments help manage traffic on the airport surface in response to changing conditions in the airspace and on the ground. Each program has been locally successful and provides insights into features that facilitate success and contribute to challenges.

The paper is organized as follows: We discuss how human judgments are influenced by system designs in terms of the distribution of roles and responsibilities in the system. We conclude by outlining design considerations for providing flexibility and adaptability in surface departure management programs.

**Impacts of System Design on Human Judgments**

The way in which roles and responsibilities are distributed in a system has strong implications for the judgments and decisions people in the system are called on to make. This and other aspects of system design limits the strategies available to people for identifying constraints in the world and adapting to meet those constraints. In this section we discuss the distribution of roles and responsibilities in the metering programs at JFK and EWR, judgments and decisions made by people in different roles, and some of the tools available to support them.
Distribution of Roles and Responsibilities

Both metering programs have a central authority that monitors the status of traffic on the airport surface and determines how the metering program should be adapted accordingly. We have identified six key responsibilities in managing both metering programs, but the distribution of the responsibilities is different in the two programs. Table 1 provides an overview of the assignment of these responsibilities at the two airports. Note that JFK has created new roles in developing their metering program and has distributed the responsibilities more widely than EWR.

Table 1, Distribution of Judgment Responsibilities in the Metering Programs at JFK and EWR.

<table>
<thead>
<tr>
<th>Judgment Responsibility</th>
<th>JFK</th>
<th>EWR</th>
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<tbody>
<tr>
<td>Determine whether to meter</td>
<td>Surface Group and RCTs</td>
<td>ATCT</td>
</tr>
<tr>
<td>Estimate departure capacity</td>
<td>Metering Desk</td>
<td>ATCT</td>
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<tr>
<td>Allocate capacity to flight operators</td>
<td>RCTs</td>
<td>ATCT and RCTs</td>
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<tr>
<td>Allocate capacity to individual flights</td>
<td>ATCT</td>
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<tr>
<td>Enforce compliance</td>
<td>Surface Group and RCTs</td>
<td>ATCT</td>
</tr>
<tr>
<td>Adjust program to changing conditions</td>
<td>Metering Desk and RCTs</td>
<td>ATCT</td>
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Determine whether to meter. The Surface Group at JFK decided to meter departures every day. The Surface Group meets weekly to discuss issues and refine the program. Metering is likely to remain in daily use as long as Surface Group members agree to participate. In contrast, at EWR the ATCT decides each day whether to meter departures. According to an RCT Manager the decision to meter “depends on the ATIS [weather conditions] and the runway configuration”. It also depends on traffic flow. One ATCT Manager said, “If it’ll take 45 minutes for them to get out of here but they’re moving, I won’t put times on them. Now if they’re taking 45 minutes and they move two feet, I’ll put times on them.” Note that the ATCT does not have specific software tools to support this process.

Estimate departure capacity. Metering depends on an estimate of the airport departure capacity over some planning horizon. The nature of this estimate differs between the two metering programs. At JFK, departure capacity is defined in terms of the number of aircraft allowed to request entry to the active movement surface during each 15-minute time window. A Metering Desk tactically manages the program and estimates the departure rate. They have tools that aid this estimate such as a historical database suggesting an average rate based on weather conditions and airport configuration. However, they use judgment to adjust the rate to current conditions.

At EWR departure capacity is defined based on the length of time flight crews are told to wait before contacting Ground Control to request entry to the active movement surface. According to RCT personnel at EWR, the length of assigned delays reflects the amount of time that the ATCT expects is required to reduce the departure queue to a manageable length. They said that typically this is 45-60 minutes when metering is in effect. It is not clear that an estimate of departure capacity is ever explicitly made in the context of metering, although an implicit estimate of departure capacity seems necessary to provide useful delay times.

Allocate capacity to flight operators. Each metering program has a different approach to allocating estimated departure capacity to flight operators. At EWR, the ATCT determines the delay to assign to flights. Flight crews call the ATCT to state that they are ready to push back and taxi to the runway for departure. The ATCT tells each flight crew what time to contact Ground Control. The order of metering times is approximately First-Come, First-Served (FCFS) according to the order in which flight crews call. To support this task the ATCT has a control position, Flow Control, which takes the initial radio contact from flight crews and provides metering times to them.

At JFK, the Metering Desk determines how many departures to allocate to each flight operator for each time window. A “Slot Calculator” tool supports this task. They assign individual flights to time windows according to the “Slot Calculator” recommendation and a Ration By Schedule philosophy (Wambsganss, 2001; Smith, Geddes & Beatty, 2008). The software automatically communicates these assignments to the RCT responsible for each flight.

Allocate capacity to individual flights. RCTs at both airports have some control over the order in which flights taxi out for departure, as well as locations of aircraft waiting for their assigned time windows. This is explicitly part of the metering program design at JFK, but is less explicit at EWR. At JFK, each RCT determines which flight should
use each time window. RCTs may request to swap pairs of flights assigned to different time windows in order to
better align the time windows to their business needs. Similarly, if a departure is not expected to be ready in time to
use its time window, the RCT requests a later time for that flight. The software supporting the metering program at
JFK has a group chat window that is the chief tool the RCTs use to request changes in time window assignments
(e.g., “pls swap 4017 with 246”). The Metering Desk is responsible for reviewing the requests. If they determine that
the swap can be made they make the change. If the swap cannot be made, the Metering Desk types that they cannot
make the swap, sometimes adding a reason (e.g., the two flights are assigned to different runways). The software
also supports other ways to request changes in time window assignments. For example, the RCT can drag a flight
from one time window to another to request a change. This action automatically changes the color and location of
the call sign for that flight on the Metering Desk display. The Metering Desk then determines whether the change
can be made and changes the color of the call sign accordingly.

At EWR, the influence of RCTs over the allocation of departure capacity to individual flights is more implicit. That
is, RCTs can control the order in which their flight crews contact Flow Control to receive a metering time, thus
influencing the order of their flights’ metering times under the approximate FCFS system. However, swapping two
flights’ metering times is “not really done in practice,” according to an RCT Manager, although exceptions do occur.
For example, “if a departure had to come back to the gate and we really wanted to get him out we would call the
Tower to ask if we can arrange a swap.” Note that this process of arranging for a flight to be treated as a priority is
similar to that at most airports, where such arrangements occur on a case-by-case basis.

**Enforce compliance.** The metering programs are enforced differently. When the Flow Controller at EWR assigns a
time window to a flight, he or she writes that time on the flight progress strip before handing off the strip to the
Ground Controller. When the flight crew contacts the Ground Controller to request entry to the active movement
surface, the Ground Controller checks the metering time written on the flight strip. “The FAA [Ground Controller]
doesn’t want to hear from you before” the time written on the strip, said an RCT Manager.

Because participation at JFK is voluntary, RCTs are responsible for ensuring that flight crews do not contact the
ATCT early to request entry to the active movement surface. However, sometimes a flight crew requests to taxi
early and the ATCT may grant this request. When this happens it is typical for other RCTs to note the early
departure in the chat window. For example, during our observation a flight departed roughly thirty minutes before its
time window. Immediately, an RCT wrote a chat message noting the occurrence. The offending RCT Operator then
receives a “slap on the wrist” at the next Surface Group meeting in an effort to eliminate such behavior. However,
because participation is voluntary, if one or more RCTs perceive that participation puts them at a competitive
disadvantage the process can break down.

**Adjust program to changing conditions.** It might be necessary to adjust metering program parameters such as due
to changes in weather conditions or aircraft maintenance problems that impact surface traffic. This task requires
expertise in judging the departure capacity as well as how changes in the departure capacity are likely to impact
traffic on the active movement surface. It also requires judging how actions taken to modify the time window
allocations are likely to impact surface traffic. The ATCT at EWR monitors departure traffic and modifies metering
times if necessary. An RCT Manager said, “Sometimes the FAA [ATCT] will get behind and they’ll add 10 minutes
to the taxi times. … They do adjust taxi times up if the queue gets too short.” The ATCT does not have tools to
explicitly support them in this task and therefore must rely on ATCT Managers’ and Controllers’ expertise.

The Metering Desk adjusts the program at JFK when necessary. When they identify conditions that are likely to
cause a change in the departure rate they determine how to adjust the time window allocation. Although they have
the departure queue as a reservoir to absorb incorrect judgments, they do not receive immediate feedback on their
actions because of the time required for the length of the departure queue to adjust to changes. For example, during
our observation an emergency landing closed the departure runway for nine minutes. As soon as the runway closed
(and before they knew how long it would remain closed), the Metering Desk needed to modify the time windows
such that the runway queue would not grow too big if the runway remained closed for an extended period. They also
needed to ensure that the queue would not run dry if the runway did not remain closed very long. They discussed the
situation as they monitored traffic on the surface display and decided to move all departures back 15 minutes,
starting with the time window 45 minutes after the runway was closed. One of the individuals involved in the
decision reported the following reasoning for selecting that time window: “I know they’re probably not ready, and
it’s far enough into the future that if they are ready and we do have slots available we can move them up.” The
surface display is a key tool allowing the Metering Desk to view the status of traffic on the airport surface.
RCTs at JFK decide how to use time windows to best meet their organizational goals. They may use any of their time windows for nearly any of their departures. The Metering Desk must approve any changes to the original allocation. The RCTs have a software tool showing the current allocation, and most have towers allowing them to see at least their ramp areas. They also have strategies for identifying high priority flights and monitoring the metering program. For example, the RCT observed at JFK has its own metering desk for managing that RCT’s time windows and communicating with the Airport Operator Metering Desk. One employee staffing this desk said they monitor “times, changes in times, and which flights have [time windows]. … good [time windows] are within ten or 15 minutes” of the scheduled departure time, and, “I ask what’s going on when it’s more than thirty minutes.”

RCTs at both airports choose what time each flight should push back relative to its time window based on gate availability, the metering time, and current delay metrics for the flight according to the Department of Transportation (DOT). “If the [time window] is more than about 70 minutes” after the flight’s scheduled departure time, individuals at one RCT at JFK delay boarding if possible. However, if another flight needs the gate, the RCT boards the aircraft and holds it in the ramp area until its time window arrives. If the aircraft is to remain at the gate the RCT must also decide at what time passengers should board the aircraft and at what time the aircraft should push back in order to make the gate available to other aircraft.

**Design Considerations for Surface Departure Metering Programs**

Design guidelines for surface departure metering programs can be derived from many sources. There are several general distributed work system design guidelines (e.g., Bowers, Salas, & Jentsch, 2006; Hinds & Kiesler, 2002; Smith, McCoy, & Orasanu, 2001; Smith, Spencer, & Billings, 2007). Successes and challenges in existing metering programs provide additional considerations. Our study of the programs discussed here leads us to posit several such design considerations, including: program status visibility, enforcement, flexibility, physical constraints, perception of equity, reservoirs for absorbing variability, information management, and technology support.

**Program status visibility.** The Metering Desk at JFK has a surface display showing the locations of all aircraft on the airport surface. In addition, they listen to the Ground Control radio frequency. Similarly, the location of the ATCT at EWR provides a view of all aircraft on the active movement surface. This visibility of the airport surface enables those responsible for monitoring and adapting the metering programs to view the number of aircraft currently in the departure queue. They also can detect patterns in surface traffic and take steps to avoid congestion. Without such visibility, the Metering Desk would be “blind,” according to one member of the JFK Surface Group. Airport surface displays seem to be very useful tools in guiding departure management decision-making. These displays also can include user-customized alerts that can help with attention management issues associated with monitoring surface traffic and other competing tasks (Spencer, et al., 2005).

**Enforcement.** Our observations, interviews, and additional discussions with participants in these metering programs lead us to believe that enforcement by the ATCT as demonstrated at EWR is important to ensure success. The ATCT is the only true authority in allowing or denying access to the active movement surface.

**Flexibility.** A key goal of Collaborative Air Traffic Management is to “accommodate flight operator preferences to the maximum extent possible” (FAA, 2010). Typically this is implemented as procedures for flight operators to swap departure time windows as at JFK. However, RCT Managers at EWR reported that even without such processes the metering program there usually provides them sufficient flexibility to ensure that their highest priority flights are accommodated. When necessary, they contact the ATCT by phone to make requests to expedite specific flights. This works adequately for cases where a single high priority flight is involved, but may be problematic if an RCT Manager would like to expedite several high priority flights. A useful feature for departure management programs seems to be mechanisms for RCTs to express a set of high priority flights to the ATCT, and for the ATCT to expedite those departures without giving that flight operator a competitive advantage.

The Federal Aviation Administration (FAA) reports a goal of flight operator flexibility (FAA, 2010). ATC flexibility also can be important. Tools to support flight operators in communicating their priorities can make it easier for ATC to accommodate them. An ATCT Manager at JFK said that under the metering program, “There aren’t as many aircraft out there so they [ATCT controllers] have more flexibility to move them around.” Reducing the number of flights on the active movement surface (and hence in the departure queue) improves the ability of ATCT controllers to manage the departure sequence. This can provide them with more flexibility to deal with dynamic departure fix constraints. In addition, the reduced number of taxiing flights increases ATC flexibility by
decreasing the time required to change the runway configuration at JFK. During two days of observations the change from one to two departure runways was accomplished in 7 and 9 minutes respectively. Metering Desk, ATCT, and Airport Operator personnel said that 30 to 40 minutes was typical before the metering program.

**Physical constraints.** If an airport faces congestion on the active movement surface, a metering program can manage the flow of departures to the active movement surface and help avoid gridlock. At both airports discussed here, personnel credit the metering program with decreasing surface congestion. However, it must be noted that those flights whose entry to the active movement surface is delayed by metering must be held somewhere. The physical geography of the airport may cause congestion to be moved from one place to another (such as from the departure queue to an ad hoc holding area as at JFK). Even if physical space is limited, ad hoc holding areas can have advantages. For example, aircraft in holding areas are, for the most part, out of the way of other aircraft that are actively taxiing to the runway for departure. In addition, aircraft in the holding area can have one or both engines off, reducing fuel burn. This reduces emissions and potentially can decrease flight operator operating costs. Mechanisms for creating and using holding areas, whether ad hoc or permanent, can help to ease surface congestion.

**Perception of equity.** Most ATCTs manage departures according to an approximate FCFS process because it is perceived to provide equitable access to all flight operators. The ATCT sequences flights for departure according to the order in which flight crews call to request access to the active movement surface, with minor exceptions to increase runway throughput. ATCT personnel at both airports stated that ensuring that the flight operators perceive equitable treatment is important. A modified version of Ration By Schedule (Wambgsanss, 2001; Smith, Geddes & Beatty, 2008) has largely been accepted by the aviation community as a useful surrogate to FCFS for other air traffic management programs (such as ground delay and airspace flow programs). This approach offers a potential alternative to allow better airport surface management while still providing equitable treatment to flight operators.

**Reservoirs for absorbing variability.** At both airports, the departure queue acts as a reservoir to absorb variability in the departure rate and uncertainty in departure capacity estimates. That is, if the Metering Desk at JFK or the ATCT at EWR overestimates the departure capacity and allows more aircraft onto the active movement surface than necessary, the departure queue will increase in length. Those responsible for managing the program then can take action to decrease the length of the departure queue. In addition, RCTs at both airports provide an additional reservoir with departures that are ready and waiting for their time windows to arrive. If the Metering Desk at JFK or the ATCT at EWR underestimates the departure capacity and allows fewer departures onto the active movement surface than necessary, there are departures that can quickly be allowed to enter the active movement surface before their time windows to quickly feed flights to the departure queue. Such reservoirs seem to be an important feature of departure management programs.

**Information management.** Information requirements should be identified in the design process and supported in technologies and processes built into the system. One major benefit of the metering program at JFK is that RCTs have better information about the time at which each flight is likely to actually take off. The metering program allows RCTs to make a more informed decision as to whether flights should be delayed at the gate or whether the flight should be delayed with the passengers on board and the aircraft pushed back from the gate. In addition, the ability to swap flights with different time windows allows RCTs to prioritize departures so that higher priority flights can depart sooner than they would in a typical FCFS system. Metering at EWR improves ATCT information management. According to an RCT Manager, metering can “help the Ground Controller… [so] they know what to expect… [by] managing who’s coming out.” The ATCT sees an advantage in using the Flow Control position, whether or not they are metering: “We may not issue [metering] times, but we’ll have them [flight crews] monitor the frequency. It helps manage the Ground frequency because the aircraft aren’t all calling at once.” Program designs should include processes for communicating information to those that need it, when they need it.

**Technology support.** Understanding the tasks people perform in existing collaborative departure management programs helps in developing technology to support them. For example, surface displays showing the locations of aircraft on the surface seem to be a key technology, particularly if the departure management program is managed by personnel who are not located in the ATCT. In addition, people working in such systems today perform some low level tasks that can be automated, such as assigning individual flights to time windows at JFK (e.g., see Brinton, Lent, & Provan, 2010). They perform these tasks to achieve higher level goals, such as increasing or decreasing the length of the departure queue. It would be possible for a person to set a target queue size and have software develop a plan to achieve that goal. Software might also detect that conditions have shifted and support people in determining the best way to adapt the plan. Technology can help ensure that parties are kept appropriately informed...
of program status and the activities of others, while also reducing the effort involved in managing priorities and adapting to changing conditions. User-customized alerts can help people manage their attention and workload when they can be faced with several competing tasks (Spencer, et al., 2005).

**Conclusion**

Departure metering programs can help people to better manage departure demand when it exceeds airport capacity. These programs require humans with sufficient expertise to make predictions about airport departure capacity on a given day and to determine how that capacity should be allocated to flight operators and individual departures. They also require humans to monitor the programs and determine how best to adapt them to changing conditions. The design of such systems strongly influences the judgments people are called on to make. For example, the distribution of roles and responsibilities in the system determines who is required to make each judgment as well as strategies available to them to make and carry out decisions. They need to have tools that support them in these judgments. To complement general design guidelines for distributed work systems, we provide design considerations specific to departure metering programs. The overall theme of these guidelines is that the assignment of roles and responsibilities to different people and decision support technologies need to provide the people involved with appropriate individual and shared situation awareness. People also need the ability to communicate their plans to each other and to the decision support tools that they are using to help manage airport surface traffic.

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**References**


