Design Issues in the Development of a Distributed Adaptive Planning System for Airport Surface Management

DISSERTATION

Presented in Partial Fulfillment of the Requirements for the Degree Doctor of Philosophy in the Graduate School of The Ohio State University

By

Alicia Borgman Fernandes, M.S.

Graduate Program in Industrial and Systems Engineering

The Ohio State University

2012

Dissertation Committee:

Philip J. Smith, Advisor

David D. Woods

Emily S. Patterson
Abstract

Departure demand routinely exceeds capacity at several airports in the United States. Under traditional “first-come, first-served” approaches to airport surface management, demand exceeding capacity can cause longer departure queues than necessary to maintain efficient traffic flow. Long queues can lead to longer taxi out times and greater fuel burn than necessary, and can increase uncertainty and limit flexibility for flight operators while increasing workload for air traffic control personnel.

Departure metering is one alternative approach that controls access to the active movement area relative to expected departure capacity and the desired number of aircraft in the departure queue (or similar measures). While the main goal is to control the number of aircraft in the departure queue, metering also can increase flexibility, reduce emissions, and improve information about the time a flight is likely to take off.

Managing a departure metering procedure is a new role that is an example of a distributed adaptive planning task. This research examined human-centered design concepts for supporting people responsible for such tasks. In particular, the project developed information requirements and prototype displays to support a human agent(s) responsible for managing a departure metering procedure.

These information requirements are intended to support proactive efforts to adapt a surface management plan under evolving conditions, appropriately modifying the plan, and scheduling implementation of the new plan. Departure metering procedure management requires re-planning in response to events that impact the departure process (such as an unexpected temporary runway closure). It also may require adapting the plan before any change in the departure process takes place and when information indicating
the trajectory of the departure process is uncertain (such as a forecast change in weather conditions). Rather than always implementing the new plan immediately, a person may schedule the new plan to take effect at a later time.

The research included two related studies. The first had two main objectives. One was to develop a realistic set of airspace constraints and surface management strategies that could be used in follow-on simulation studies. The second goal was to determine more generally what surface management strategies should be supported in a departure metering procedure and to evaluate their implications for the design of software to support surface management. Key components of surface management strategies were identified, including evidence that air traffic control tower personnel automatically transform mental representations of departure constraints between airspace-centric and surface-centric domain representations in order to develop and implement airport surface management plans.

The objective of the second study was to explore information requirements for supporting a human agent(s) responsible for managing a departure metering procedure and to evaluate display concepts. Participants performed the departure metering procedure management task in a simulated environment and provided feedback on the departure metering procedure concept and on the usefulness of the displays. Participants provided feedback that can inform industry efforts to refine departure metering procedure design concepts (Surface CDM Team, 2011) as well as designs for displays and other tools to support these distributed adaptive planning systems.
To my parents, who taught me how to get here.

And to Andrew, who saw me through.
Acknowledgments

I thank my adviser, Dr. Philip J. Smith, for his excellent teaching, mentorship, and guidance. I also thank Dr. David D. Woods for his teaching. The work of Dr. Emily S. Patterson has provided examples of situated research and insights into cognitive systems engineering principles in practice.

In addition, Roger Beatty, Mark Evans, and Ken Durham provided valuable introductions to aviation from the practitioner’s perspective and strongly influenced the concept development. Dustin Johnson of AMT Machine Systems provided software engineering expertise. There was no problem he could not solve. Amy Spencer and Kristen Weaver also made valuable contributions to the research. I thank the many practitioners who welcomed me into their workplaces to observe and to learn, and the study participants who provided many useful insights.

I appreciate the support of the FAA Human Factors Research & Engineering Group, which coordinated the research requirement, and its principal representative who acquired, funded, and technically managed execution of the research service.

Finally, I thank my family, who has always been a source of strength, and my husband, Andrew, who has been incredibly supportive and extremely patient throughout.
Vita

2001 ................................................. B.S. Applied Mathematics
California State University at Long Beach

2001-2003 ........................................ Graduate Research Assistant
Quality and Productivity Laboratory
Northeastern University

2003 ............................................... M.S. Operations Research
Northeastern University

General Dynamics Information Technology
Natick, Massachusetts

2007 .................................................. Director of Research and Development
Technology Solutions Experts, Inc.
Natick, Massachusetts

2007 .................................................. Presidential Fellow
The Ohio State University

2008-Present ...................................... Graduate Research Associate
Cognitive Systems Engineering Laboratory
Integrated Systems Engineering
The Ohio State University

Publications

tests and longitudinal surveillance methods. *International Journal for Quality in Health Care, 15*(1), 5-6.


Fields of Study

Major Field: Integrated Systems Engineering

Specialization in Cognitive Systems Engineering

Minor Field: Operations Research

Minor Field: Psychology Modeling
# Table of Contents

Abstract ............................................................................................................................... ii  
Acknowledgments ............................................................................................................... v  
Vita ..................................................................................................................................... vi  
List of Tables ....................................................................................................................... xi  
List of Figures ..................................................................................................................... xiv  
Chapter 1: Introduction and Problem Statement ............................................................... 1  
  Surface Traffic Management when Demand Exceeds Capacity ........................................ 2  
  Problem Statement ........................................................................................................ 6  
  Dissertation Outline ...................................................................................................... 10  
Chapter 2: Background and Literature Review ................................................................ 11  
  The National Air Space ................................................................................................ 12  
  Departure Metering ..................................................................................................... 34  
  Cognitive Systems Engineering Issues in Metering Procedure Design ....................... 64  
  Chapter Summary ......................................................................................................... 88  
Chapter 3: Tools Used to Support Concept Exploration and Evaluation Activities .......... 89
Scenarios and Examples............................................................... 90
Hypothetical Major Airport (MJA).................................................. 90
Airport Surface Diagrams ............................................................ 92
Simulation Environment .............................................................. 93
GoToMeeting Web Conferencing Service ...................................... 98
Chapter Summary........................................................................ 99
Chapter 4: Research Methods and Results...................................... 101
  Observation of Practitioners in the Air Traffic Management System.......... 101
  Air Traffic Management Decision-Making in Dynamic Weather ............ 113
  Air Traffic Control Tower Decision-Making in Dynamic Weather .......... 131
  Departure Metering Concept Evaluation........................................ 155
  Chapter Summary....................................................................... 186
Chapter 5: Departure Reservoir Coordinator Information Requirements.......... 188
  Departure Reservoir Coordinator Role ......................................... 189
  Planning Functions..................................................................... 190
  Monitoring Functions.................................................................. 221
  Diagnosis Functions.................................................................... 231
  Adaptation Functions.................................................................. 240
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coordination and Collaboration Functions</td>
<td>256</td>
</tr>
<tr>
<td>Communication Functions</td>
<td>268</td>
</tr>
<tr>
<td>Chapter Summary</td>
<td>282</td>
</tr>
<tr>
<td>Chapter 6: Conclusions, Emergent Themes and Future Work</td>
<td>284</td>
</tr>
<tr>
<td>Problem Representations</td>
<td>284</td>
</tr>
<tr>
<td>Strategies for Coping with Uncertainty</td>
<td>291</td>
</tr>
<tr>
<td>Strategies for Coping with Complexity</td>
<td>294</td>
</tr>
<tr>
<td>Translation of Weather into Traffic Flow Management Strategies</td>
<td>295</td>
</tr>
<tr>
<td>Conclusion</td>
<td>297</td>
</tr>
<tr>
<td>References</td>
<td>298</td>
</tr>
</tbody>
</table>
List of Tables

Table 1. Examples of departure fix restrictions provided to participants. ............... 117
Table 2. Departure restrictions participants generated at 1800Z. .......................... 121
Table 3. Departure route restrictions for 2030Z. .................................................. 128
Table 4. Summary of participants' air traffic control experience. ............................. 133
Table 5. Strategies for staging departures for runway 18C (no departure restrictions). 137
Table 6. Strategies for staging departures for runway 18C (no departure restrictions). 138
Table 7. Number of aircraft participants wanted active for runway 18C. ................. 139
Table 8. Departure staging strategies for runway 18L with no departure restrictions.... 141
Table 9. Number of aircraft participants said they would want active for runway 18L. 142
Table 10. Time participants would modify strategies.............................................. 144
Table 11. Strategies participants would use to stage 18C departures at 1800Z........ 146
Table 12. Strategies participants would use to stage 18L departures at 1800Z........... 148
Table 13. Strategies for separating two aircraft subject to a 10 MIT restriction. ....... 151
Table 14. Strategies for separating aircraft subject to a 15 MIT restriction.............. 152
Table 15. Strategies for separating aircraft subject to a 20 MIT restriction............. 153
Table 16. Summary of participants' air traffic control experience............................ 156
Table 17. Displays participants said they used to monitor the metering procedure. ..... 170
Table 18. Usefulness ratings of text boxes on airport surface display...................... 172
Table 19. Usefulness ratings of control to modify default expected departure rate. ...... 174
Table 20. Usefulness ratings of control to modify single expected departure rate. ........ 175
Table 21. Usefulness ratings of control to modify target average number active. ....... 176
Table 22. Usefulness ratings of control to modify single target average number active. 176
Table 23. Usefulness ratings of "Adjust" button. ................................................. 177
Table 24. Reasons participants said the DRC should be located in the ATCT. ........... 179
Table 25. Surface constraints that can impact departure rate. ................................ 193
Table 26. Airspace constraints that can impact departure conditions................... 202
Table 27. Surface management impacts of departure demand. ............................ 204
Table 28. ATCT strategies that influence departure metering plan....................... 215
Table 29. DRC information requirements to support estimating departure capacity. ..... 218
Table 30. DRC information requirements to support estimating the departure rate. ..... 219
Table 31. Information requirements for setting departure reservoir characteristics. ...... 220
Table 32. Information requirements to support setting departure reservoir locations. .... 220
Table 33. Information to help DRC detect need to adapt departure metering plan. .... 223
Table 34. Information to help DRC detect need to adapt departure metering plan. ..... 225
Table 35. Information requirements to support the DRC monitoring function. ......... 230
Table 36. Sample events and their impact on departures..................................... 239
Table 37. Information requirements to support the DRC in diagnosis. ................. 240
Table 38. Information requirements for supporting DRC adaptation functions. ........ 255
Table 39. Information requirements for supporting constraint setting for coordination. 265
Table 40. Information requirements for adapting metering parameters. ............... 266
Table 41. Information requirements for coordination in surface management. ............ 267
Table 42. Information requirements for collaboration in surface management............. 267
Table 43. Information requirements for building and maintaining common ground. .... 268
Table 44. Summary of information DRC may require from others............................ 272
Table 45. Summary of information the DRC may have that may be useful to others.... 274
Table 46. Information requirements to support DRC communication with others. .... 281
List of Figures

Figure 1. Excerpt from JFK airport diagram showing ramp control and spots. .......... 3
Figure 2. Aircraft taxiing out for departure viewed from an ATCT. ....................... 6
Figure 3. Semi-hierarchical organization of air traffic control in the FAA. .............. 13
Figure 4. Departures queued on taxiways G and H holding short of F. ................... 21
Figure 5. Portion of IAH airport diagram with ramp area outlined in red. ............... 27
Figure 6. Simplified representation of interactions among NAS roles .................... 31
Figure 7. Example JFK surface display. Permission from Saab Sensis Corporation. ..... 47
Figure 8. Simulated surface display showing (notional) Major Airport (MJA). .......... 59
Figure 9. Independent, coordinated, and collaborative work. Used with permission .... 68
Figure 10. Standard Instrument Departures (SIDs) for Major Airport (MJA). .......... 92
Figure 11. Prototype CATS interface. CIWS weather from MIT Lincoln Laboratory. ... 94
Figure 12. MJA TRACON and departure SIDs. ......................................................... 115
Figure 13. Image of current measure of VIL at 1800Z ............................................. 119
Figure 14. Series of weather images representing the 2-hour forecast at 1800Z ....... 119
Figure 15. Excerpt from interview highlighting collaboration between participants. .... 123
Figure 16. Current VIL image from 1900Z................................................................. 125
Figure 17. Excerpt of participants’ deliberation at 1900Z ......................................... 126
Figure 18. Current measure of VIL at 2030Z ............................................................ 128
Figure 19. Participants might respond differently if MJA was in a different airspace... 129
Figure 20. Difference in participants' approach from the real world......................... 131
Figure 21. Displays similar to those shown to participants at 1800Z......................... 134
Figure 22. Departure route restrictions at 1600Z, 1630Z, and 1700Z......................... 144
Figure 23. Departure route restrictions in effect at 1800Z...................................... 145
Figure 24. Surface Display Only interface. ........................................................... 158
Figure 25. Interface including the Control Chart...................................................... 159
Figure 26. Departure metering management window from scenario DRC A.............. 165
Figure 27. How a local control trainee could slow the departure rate....................... 166
Figure 28. Departure metering management display from scenario DRC B.............. 167
Figure 29. Display similar to RAPT. Adapted from DeLaura, et al. (2008)............... 196
Figure 30. List of current airspace restrictions. ....................................................... 197
Figure 31. List of Runway 18C departures with flights to Wiley highlighted.............. 205
Figure 32. Surface display with flights to Wiley highlighted in Selection Tool......... 210
Figure 33. Prototype interface for departure capacity and target number active........ 216
Figure 34. Notional interface allowing ATCT to communicate surface strategy......... 217
Figure 35. Graph showing an increase in actual number active............................. 234
Figure 36. Graph showing increase in actual number active due to transient event..... 234
Figure 37. Monitoring reservoir size for both runways......................................... 236
Figure 38. Chart with reservoir decomposed by departure direction...................... 237
Figure 39. Queue length change after response within one minute of runway closure.244
Figure 40. Departure metering management window with anticipated reservoir size.248
Figure 41. Airspace restrictions impacting 18C departures........................................... 286
Figure 42. Surface plan based on airspace constraints. ..................................................... 287
Chapter 1: Introduction and Problem Statement

Aviation is undergoing a period of technological change, with the Federal Aviation Administration (FAA) working to exploit new technologies to improve air traffic management. The NextGen program is expected to increase capacity of the National Airspace System (NAS), improve efficiency, and decrease environmental impact. The FAA estimates that NextGen air traffic management improvements between now and 2018 will reduce delays by up to 35%, eliminate 14 million tons of CO$_2$ emissions, and require 1.4 billion fewer gallons of fuel (Federal Aviation Administration, 2011). A variety of technologies are expected to contribute to these savings, ranging from more precise navigation to alternative fuels.

New technologies often inspire new procedures to exploit them in a field of practice and provide both opportunities and challenges for practitioners and designers (Woods & Hollnagel, 2006). It is important to ensure that new technologies and procedures are well suited to the work of practitioners in the domain. It also is important to recognize that introducing new technologies and procedures will change that work (Woods & Hollnagel, 2006), often in surprising ways (Smith, McCoy, & Layton, 1997).

Understanding a domain of practice and the requirements of practitioners in that domain are important first steps in designing artifacts that become useful tools when introduced (Smith, Stone, & Spencer, 2006; Woods & Hollnagel, 2006). Such an understanding facilitates building a set of functional requirements for supporting work in that domain. The process of building that understanding also allows the researcher to use the domain as a natural laboratory that can provide new insights that cognitive systems engineers can use to understand and design artifacts for other domains of practice (Hutchins, 1995a; Woods & Hollnagel, 2006).
The research described in this dissertation aims to improve the current state of understanding of departure management on the airport surface. It provides requirements for designs of new procedures to support that work. Specifically, the dissertation provides information requirements for a new role responsible for effectively managing surface departure traffic flows when departure demand exceeds capacity. It explores a class of Collaborative Air Traffic Management (CATM) procedures – departure metering – and proposes organizational and information requirements for supporting practitioners responsible for such surface traffic management procedures.

In the process, the research identifies new insights related to the design of tools to support work that is distributed across different functional perspectives. It uses the distributed task of managing departure traffic on the airport surface when demand exceeds departure capacity as a context for studying distributed work system design.

**Surface Traffic Management when Demand Exceeds Capacity**

There are several airports in the United States where departure demand routinely exceeds capacity. Traditionally, air traffic controllers use an approximately “first-come, first-served” approach to managing air traffic on the airport surface. At a prototypical airport under this approach, flight operators prepare aircraft for departure according to their business priorities and choose when to push each flight back from the gate. Flight operator personnel working in ramp control facilities provide taxi instructions to pre-coordinated locations on the airport surface, called spots (see Figure 1), where control over the aircraft is transferred to the ATCT. Upon arriving to a spot, the flight crew contacts the ATCT to request permission to enter the active movement area. The ATCT grants access to the active movement area in the order in which it receives calls from flight crews and taxis them to the departure runway roughly in that order. They may modify the sequence if they identify an opportunity to improve departure runway throughput.
This prototypical distribution of work is the basis for the concept exploration in this dissertation. However, not all flight operators and airports are operated this way. Not all flight operators maintain ramp control facilities at all airports where they operate. Where they do not have ramp control facilities, their flights may be controlled by another ramp control facility operator or they may be controlled by the ATCT from the gate to the runway. Similarly, not all airports have ramp control facilities at all. At such airports, ATCT controllers manage flight push back from the gate and control aircraft as they taxi from the gate to the runway. At other airports, ramp control facilities manage the area around some gates while the ATCT controls others. While this dissertation discusses surface management under an assumption of a distribution of work in which ramp control facilities manage their own flights in ramp areas, the concepts explored here do not preclude other distributed control structures.

A major advantage of the “first-come, first-served” approach is that it is perceived to be equitable to flight operators. ATCT controllers can provide taxi instructions to flight crews in the order they receive flight crew calls, and flight operators can push back their aircraft at a time of their choosing. This represents a distributed control architecture
(Smith, Spencer, & Billings, 2007) in which ATCT controllers manage aircraft in proximity to other flight operators’ aircraft and to runways, while flight operators maintain control over activities in the proximity of their gates and ground resources.

However, the “first-come, first-served” model requires aircraft to physically join the departure queue in order to secure a place in the departure sequence. When departure demand exceeds capacity, departure queues begin to form. Flight operators continue to push back their flights and taxi them to the spots for handover to ATCT control in order to secure a place in the departure queue. This can lead to longer queues of aircraft at the departure runway than necessary to maintain an efficient flow of departure traffic. Such long queues can lead to longer taxi out times than necessary, reflected in poor performance metrics for these airports and the threat of heavy fines for flight operators (Department of Transportation, 2009). While aircraft are actively taxiing out for departure they are expending fuel and when progress is slow due to long queues they may expend more fuel than necessary. This can result in increased operational cost for flight operators and unnecessary environmental emissions (Brinton, Lent, & Provan, 2010).

Long departure runway queues also limit flexibility available to flight operators’ departure operations. Once aircraft are in the physical departure queue they are under the control of the ATCT, and their priority for departure is set by their position in the departure sequence developed by the ATCT. At some airports, the time flights spend taxiing out for departure\(^1\) routinely averages 30 minutes (Goldberg & Chesser, 2008), and can grow longer during irregular operations such as due to weather. During that time there are many reasons why a flight operator’s measure of priority for a number of flights might change.

Once aircraft are in the physical departure queue the flight operator has little opportunity to modify their flights’ relative priority for departure. The flight operator

---

\(^1\) Taxi-out time roughly defines the amount of time a flight spends taxiing to the runway for departure. It is measured in one of two ways: as the time between the handoff of control to the ATCT and the time the aircraft departs the runway (wheels-up), or as the time between the handoff of control to the ATCT and the time the aircraft registers its first radar signal after it becomes airborne.
may identify a small number of high priority flights and telephone the ATCT to request that the ATCT expedite the departure of those flights. However, flight operator personnel have remarked that they feel as though such requests should be reserved for only really high-priority flights, such as a flight whose crew will be illegal to fly if the aircraft is not off the ground within a short period of time (Obradovich, et al., 1998). The Federal Aviation Administration (FAA), acting through ATCTs, could provide an improved level of service to flight operators if the airport surface management system could better accommodate flight operator priorities (Smith, Pear, Spencer, & Billings, 2001).

The work of the ATCT also can be made more difficult with long departure queues. Air traffic control is a memory-intensive task (Borgman & Smith, 2010; Shorrock, 2005; Mackay, 1999), and more aircraft on the surface means that controllers must simultaneously manage the safe and expeditious movement of more aircraft and sequence them for departure. The memory aids currently available to controllers in most ATCTs, such as flight progress strips, provide specific information about flights as well as information about an aircraft’s position relative to other aircraft (Mackay, 1999). However, the controller must mentally correlate that relative position with an aircraft’s absolute position on the airport surface. From the vantage point provided by the ATCT, one aircraft can be difficult to distinguish from another (see Figure 2). When circumstances require a small number aircraft to receive special attention, such as requiring new routes due to changing weather conditions, a large number of additional aircraft on the airport surface can make it more difficult for the ATCT controller to remember the status of each aircraft.

In addition, in the event that several flights need to be moved from one location on the airport surface to another – such as when the airport runway configuration must change due to shifting winds – the ATCT must move the aircraft as efficiently as possible while maintaining the departure sequence. The longer the departure queue, the more time such a process can take, possibly delaying the ability to use a departure runway while the aircraft are re-sequenced.
In order to limit the growth of departure queues when demand exceeds runway departure capacity, either the number of departures flight operators may schedule during busy periods would have to be limited, or an alternative to the “first-come, first-served” approach is needed. It can be difficult to ensure that the number of scheduled flights does not exceed capacity because airport departure capacity for a given time period can be difficult to predict far in advance – airport capacity can vary greatly due to weather and overhead traffic conditions. Therefore, alternatives to “first-come, first-served” should be explored for alleviating the impacts of longer departure queues than necessary.

**Problem Statement**

The research described in this dissertation applied cognitive systems engineering principles to the design of a departure metering procedure, which represents one class of approaches to more active management of departures on the airport surface. Specifically, the main goal was to use principles from the cognitive systems engineering and related fields to identify functional and information requirements for an agent(s) responsible for effectively managing a departure metering procedure. It also proposes some design solutions and first-cut evaluations of those solutions.

This process identified additional cognitive systems engineering themes in airport surface management. From these themes emerged additional insights into ways in which practitioners have adapted to cope with uncertainty and complexity associated with the
constraints of their domain (Woods & Hollnagel, 2006) and the design of the distributed system in which they work (Smith, Spencer, & Billings, 2007). In turn, these insights pointed to additional consequences for departure metering procedure design.

This dissertation addresses the following key questions in airport surface management and the design of departure metering procedures:

**Question 1:** What are the functional and information requirements for supporting an agent(s) responsible for managing a departure metering procedure?

In order to define information and support requirements for an envisioned role, we must first define characteristics of the task of managing a departure metering procedure. In this research, we conceptualize managing a departure metering procedure as a distributed adaptive planning task. Therefore, a person or team of people responsible for managing a departure metering procedure must engage in activities such as:

- Planning (Hayes-Roth & Hayes-Roth, 1979; Kolodner, 1992; Klein, 1997; Smith, Beatty, Spencer, & Billings, 2003; Suchman, 1987).
- Monitoring (Hayes-Roth & Hayes-Roth, 1979; Hollnagel & Woods, 2005; Sheridan, 2002; Vicente, Mumaw, & Roth, 2004; Woods & Shattuck, 2000).
- Diagnosis (Peirce, 1955; Smith, et al., 2012; Woods & Hollnagel, 2006).
- Adaptation (Hutchins, 1995a; Sheridan, 2002; Woods & Hollnagel, 2006; Woods & Shattuck, 2000; Smith, Beatty, Spencer, & Billings, 2003; Suchman, 1987).
- Collaboration, coordination, and communication with others in the distributed system (Baecker, Grudin, Buxton, & Greenberg, 1995; Klein, et al., 2005; Patterson, Watts-Perotti, & Woods, 1999; Salas, Cooke, & Rosen, 2008; Smith, 2011; Smith, Spencer, & Billings, 2007).
These literatures are informative for defining information requirements and conceptual tools and displays for supporting this role. Information requirements are presented in Chapter 5.

One contribution of this dissertation is a suggestion that these information requirements include the anticipated surface management strategies of the ATCT. Multiple departure metering concept descriptions expect information about airspace constraints such as miles in trail restrictions to support departure metering procedure management (Borgman & Smith, 2010; Surface CDM Team, 2011). However, ATCT personnel must develop surface management strategies that go beyond the simple direct application of these airspace constraints, allowing them to manage uncertainty by creating appropriate reservoirs. We suggest that planning in departure metering procedure management should be aligned with these surface management strategies.

**Question 2:** How should a “departure reservoir” be parameterized to ensure that the ATCT has an appropriate inventory of aircraft for departure, even in dynamic conditions?

A departure reservoir is a set of flights available as “inventory” for departure (Surface CDM Team, 2011). It may include departing aircraft located in the runway departure queue, in a holding area on the movement surface, in the ramp area, or even at the gate (Borgman, et al., 2010b).

We hypothesized that departure rate and target average departure reservoir size would be appropriate parameters for building and maintaining a departure reservoir that would support the ATCT in coping with dynamic departure conditions. Departure capacity and target average departure reservoir size (often defined as departure queue length) are, or are closely related to, the control parameters defined for a number of departure metering concepts (Borgman & Smith, 2010; Brinton, Lent, & Provan, 2010; Surface CDM Team, 2011). But it is not clear whether these parameters are cognitively compatible with the demands of managing a departure metering procedure.
While the main goal of the research was to develop recommendations for departure metering procedure design, part of applying cognitive systems engineering to system design is to understand the larger domain in which the system is to be embedded (Smith, et al., 2012; Smith, Bennett, & Stone, 2006; Vicente, 1999; Woods & Hollnagel, 2006). To ensure that our recommendations for designing a departure metering procedure and a role responsible for managing the procedure fit into the distributed surface management environment, we examined surface management from a cognitive systems engineering perspective.

In our investigations, we focused on departure route constraints caused by dynamic weather conditions. Such constraints require practitioners to manage decreased departure capacity, often creating conditions in which demand exceeds capacity. They also require practitioners to manage uncertainty due to constraints that change over time. In particular, we were interested in strategies ATCT personnel use to manage departure inventory during dynamic conditions so as to design a departure reservoir that maintains an appropriate inventory of departures to support the ATCT during such conditions.

**Question 3:** What strategies and problem representations do ATCT personnel use to manage departure traffic on the airport surface when departure conditions are dynamic?

We hypothesized that ATCT personnel would vary their surface management strategies with time, departure demand, and changes in departure conditions such as weather. Further, we hypothesized that ATCT traffic managers and ground controllers would use locations on the airport surface (such as taxiways), aircraft departure fix, and aircraft type as parameters to define their surface management strategies.

These hypotheses were examined via a series of structured interviews with current and former ATCT ground controllers, traffic management coordinators (TMCs), and supervisors. Participants employed surface management strategies that created opportunities to modify the departure sequence such as at taxiway intersections.
A key insight related to this research question emerged: ATCT personnel very quickly – and likely automatically – transformed the representation of domain constraints to perform their planning activities. ATCT personnel used a different internal problem representation in their planning than the external representations to which they have access and the language they use in discussing constraints with others. In particular, when they discuss departure constraints, they typically use airspace-centric language such as “miles in trail” restrictions. In fact, they managed miles in trail restrictions by specifying the number of aircraft that should split any two aircraft subject to that restriction.

This reflects the hierarchical distribution of decision-making authority in the NAS in which airspace constraints are propagated to the surface where ATCT personnel must accommodate them. This implies that distributed design requires the designer to simultaneously consider individual system perspectives as well as mechanisms for distributed personnel with varying perspectives to coordinate with each other.

Dissertation Outline

The remainder of this dissertation explores departure metering procedures in general and describes a series of research activities performed in the development of requirements for supporting a person or team of people responsible for managing such a procedure. In the process, the dissertation introduces some concepts for display and procedure design to support this envisioned role.

In the next chapter we provide background on the NAS and departure metering. We also discuss the various aspects of the cognitive systems engineering literature that have informed the design requirements developed and tested in this research. In Chapter 3, we describe some of the tools used in the course of this research. Chapter 4 describes the research activities undertaken over the course of this project to understand and define the requirements for supporting a person or team of people responsible for managing a departure metering procedure, while Chapter 5 presents those requirements.
Chapter 2: Background and Literature Review

This chapter provides background on air traffic management as a work domain, with a focus on surface management. It also discusses some of the cognitive systems engineering and design themes explored in the effort to identify effective support for those responsible for the safe and efficient flow of traffic on the airport surface.

In this dissertation, surface management is mainly viewed from the perspective of a traffic manager in an ATCT and that of an envisioned role responsible for managing a departure metering procedure. However, the ATCT is just one of many facilities in the highly distributed system of the NAS. Within the NAS, agents in different roles must develop coordinated plans and adapt those plans to meet changes in constraints such as weather and traffic congestion. Coordination efforts must cross functional and organizational boundaries, and the advent of new technologies creates additional requirements for computer-mediated coordination in addition to direct human-human coordination. In some cases, adequate information sharing (and effective display of that information) allows agents to coordinate effectively, while in other cases more active collaboration is required.

The chapter begins with a basic introduction to the NAS roles that will be encountered later in the dissertation and discusses some key interactions among those roles. It then introduces the concept of departure metering, an approach to managing departure traffic on the airport surface in the face of airspace constraints. It follows with a discussion of the literature informing knowledge about the cognitive systems engineering issues encountered in designing for surface traffic management, including adaptive planning under uncertainty, coordination and collaboration across functions and organizations, information sharing, and display design.
The National Air Space

Understanding air traffic management requires a basic understanding of the organization of the NAS and relationships among various organizations within the NAS. The three main sets of actors considered in this dissertation are the Air Traffic Control Organization within the Federal Aviation Administration (FAA), flight operators, and airport operators. There is more differentiation among the roles than described here. Indeed, there are roles that are not discussed here at all. The discussion here is limited to those roles and relationships most pertinent to the discussions later in this dissertation.

FAA Air Traffic Control Organization

The ATCT is just one of many air traffic control and management facilities that make up the Air Traffic Control Organization within the FAA. These facilities are organized into a semi-hierarchical arrangement in which each facility is responsible for the safety and efficiency of air traffic operations in a specific geographic area. Roughly speaking, each facility’s geographic area is fully contained within that of another facility (see Figure 3). While each facility is responsible for operations in its geographic area, operations are impacted by conditions in other locations.

Air Traffic Control System Command Center

The Air Traffic Control System Command Center (ATCSCC) does not directly control aircraft. Instead, it is responsible for facilitating safe and efficient traffic flows throughout the entire NAS. ATCSCC traffic management specialists monitor conditions across Air Route Traffic Control Centers (ARTCCs) and facilitate coordination across ARTCC boundaries when conditions threaten to interrupt traffic flows. For example, when weather threatens to impact traffic flow in multiple ARTCCs the ATCSCC facilitates programs such as reroutes across ARTCCs (Smith, et al., 1995; 2003; Smith, Spencer, & Billings, 2007) and Ground Delay Programs (Smith, et al., 2012).
Air Route Traffic Control Center

The United States is divided into 22 regions, each of which defines an Air Route Traffic Control Center (ARTCC). Typically, ARTCCs are responsible for providing air traffic control services to aircraft flying at higher altitudes within their geographic boundaries.

A single aircraft may pass through several ARTCCs between its departure and arrival airports. An ARTCC controller may hand off aircraft to neighboring ARTCCs and accept flights handed off from those ARTCCs. They also may hand off aircraft to lower altitude controllers for descent to the arrival airport and accept aircraft from those lower altitudes on ascent from a local airport.

Each ARTCC is further decomposed into geographic areas and sectors. An area is a geographic region within an ARTCC, and a sector is a three-dimensional region of
airspace within an area. A pair of controllers works as a team to ensure safe separation of aircraft in each sector. They monitor the progress of each aircraft through their sector, anticipate potential conflicts between aircraft, and execute instructions to aircraft to prevent conflicts. Area supervisors monitor the status and workload of a number of sector controllers within an area.

An ARTCC also contains a Traffic Management Unit (TMU) responsible for monitoring and managing traffic flows within and through the ARTCC – across sector and area boundaries. Pre-departure, this includes approving or amending flight routes filed by flight operators and considering how those flights will impact traffic flows. A Traffic Management Unit should manage flows such that sectors are not overloaded.

When constraints such as weather are forecast to impact traffic flows in a sector, the Traffic Management Unit has a number of strategies it can use to manage traffic flows into and through the impacted airspace. For example, the Traffic Management Unit might work with the ATCSCC to select a “Playbook,” a set of pre-coordinated alternate routes typically used to route traffic around a weather constraint of that kind in that location (Federal Aviation Administration, 2008). The Traffic Management Unit monitors aircraft behavior and when flight crews begin to deviate in order to avoid the weather system the Traffic Management Unit (through the ATCSCC) invokes the pre-coordinated Playbook.

Pre-coordinating the Playbook is an example of moving collaboration activities forward in time – to a lower-tempo period of operation – in order to relieve workload during higher-tempo periods of operation when the alternate traffic management strategy needs to be invoked. Moving activities forward in time is a common workload management strategy in complex cognitive work (Woods & Hollnagel, 2006).

Playbooks “may be modified tactically to achieve an operational advantage” (FAA, 2008) when they are implemented, providing flexibility for traffic managers to
adapt the procedure to their current situation. Such modifications must be coordinated with impacted facilities, but still represent a set of pre-coordinated routes that reduce the time and effort required to implement a new plan when conditions warrant it.

The Traffic Management Unit also may open a “hotline,” a dedicated teleconference line open to pre-selected organizations that is used to facilitate communications during irregular operations. Each hotline has locally defined rules regarding topics that are appropriate to discuss on the hotline and which organizations are allowed to speak rather than listen only.

Once the weather constraint is relieved in the airspace in question, the Traffic Management Unit carefully reintroduces traffic to the constrained area, often first by identifying “pathfinder” aircraft that provide an updated report of airspace conditions, and then by reopening a route but with a restriction such as Miles In Trail (MIT) that increases the minimum amount of spacing required between two aircraft in the constrained airspace.

The Traffic Management Unit also may close a given portion of airspace, requiring flights to be rerouted around the impacted area. Note that such Traffic Management Initiatives (TMIs) usually are a response to flight crews reporting unsafe conditions and requesting deviations around a weather system. These restrictions are passed to neighboring airspace – ARTCCs and TRACONs. When passed to a TRACON, they are often propagated to the airport, requiring the ATCT to increase the amount of spacing between aircraft departing the airport to the impacted route.

When routes are restricted or closed, flight operators often request pre-departure route amendments. This often allows flights to depart sooner than if they waited for the originally file route to reopen. The ARTCC Traffic Management Unit is responsible for processing these route amendments, often manually typing route strings (or shortened
codes representing pre-coordinated routes) into the Traffic Flow Management System (TFMS) or the Host computer for each flight that needs a route amendment.

Note that the Traffic Management Unit performs additional tasks as well, but the responsibilities mentioned here are the ones most pertinent to the discussion in this dissertation. The Traffic Management Unit represents a boundary between the ARTCC and other NAS facilities and therefore a key point of coordination among NAS organizations. Traffic management personnel there also are responsible for judgments and decisions that affect traffic flows across a wide geographic area and across multiple organizations. The traffic management initiatives they put in place to manage traffic flows can directly impact traffic conditions on the airport surface.

Terminal Radar Approach Control

When aircraft depart from the airport, control is handed off to the Departures sector in the local Terminal Radar Approach Control (TRACON) facility. Similarly, while an aircraft is on approach to the runway, it is controlled by the Approach sector in the TRACON. Most TRACONs are associated with one major airport and several satellite airports that serve mostly small aircraft. They are responsible for the safe and efficient flow of air traffic within their airspace.

TRACONs are organized similarly to ARTCCs. Large TRACONs, in particular, are composed of sectors and areas. TRACONs also have a Traffic Management Unit responsible for monitoring and managing traffic flows through the airspace. As part of their responsibility for planning traffic flows in their airspace, TRACON Traffic Management Units set arrival rates for airports according to the capacity of their sectors, particularly those responsible for merging several arrival flows into a single final approach to an airport. Through these arrival rates, they communicate their expected capacity to the ARTCC to facilitate ARTCC planning of traffic flows into the TRACON airspace. However, this arrival rate is only a guideline to be used for planning, as airspace
restrictions can require the TRACON to tactically reduce the flow of traffic into their airspace. The TRACON Traffic Management Unit uses similar means as the ARTCC to manage traffic flows into and through their airspace.

The TRACON does not typically set airport departure rates. Rather, airport departure capacity for normal operations is determined by the requirement that departing aircraft are separated by 3 nautical miles laterally and 1000 feet vertically when they appear on the TRACON radar. However, when TRACON airspace is impacted by weather and/or traffic constraints, the TRACON Traffic Management Unit can impose restrictions such as miles in trail that, in turn, impact the rate at which flights can depart the airport. Sector controllers can close routes when constraints drastically reduce their ability to manage additional aircraft flying through their sector.

TRACON controllers also must satisfy constraints propagated from the ARTCC, ensuring, for example, that departing aircraft have the required miles in trail when they are handed off to ARTCC sectors. Similarly, when the ARTCC invokes the use of a Playbook to alleviate demand for constrained airspace, the TRACON Traffic Management Unit develops strategies to manage traffic flows within the constraints of that Playbook. The Traffic Management Unit often propagates restrictions from the ARTCC back to the airport surface, helping to ensure that TRACON sector controllers do not have to place aircraft in a holding pattern to achieve the required separation at the boundary with the ARTCC.

The TRACON Traffic Management Unit also plays a big role in setting an airport’s runway configuration and determining which departure routes should be accessible from each runway. Runway configuration changes have to be coordinated with the TRACON because the TRACON has to manage the modified departure and arrival flows. In a metroplex such as New York where runway configurations can interact across airports, the TRACON Traffic Management Unit coordinates simultaneous runway configuration changes at multiple airports.
Similarly to the ARTCC, traffic management personnel represent the TRACON role of most interest to this dissertation because they represent a boundary between NAS organizations – in this case, typically between the TRACON and the ATCT and between the TRACON and the ARTCC. They also must respond to constraints in their airspace such as weather and traffic volume and do so in ways that directly impact traffic conditions on the airport surface.

Air Traffic Control Tower

The Air Traffic Control Tower (ATCT) is located at the airport and is responsible for the safe and efficient operations of aircraft during landing, takeoff, and while on the airport surface. Most ATCTs are staffed by multiple controllers at all times, including one or more local controllers, ground controllers, supervisors, and/or traffic management coordinators. (There are additional positions such as flight data/clearance delivery that are not directly related to topics in this dissertation.) In this section, we discuss aspects of these roles most relevant to this dissertation.

Local Controller

The local controller is responsible for aircraft as they arrive and depart. The local controller determines when it is safe for the next departure to take off, provides arrival clearance when aircraft can safely land on the runway (i.e., the runway is clear of traffic and other obstacles), and directs aircraft to “go around” when the runway is not clear. The local controller also may provide guidance to arrivals as needed to ensure a safe approach and landing (e.g., speed adjustments).

The local control position is most challenging when the airport is operating in a configuration with intersecting runways. One former traffic management coordinator who participated in the ATCT surface management decision making study said that “criss-crossing” runways makes air traffic control complex. She said, “You’d be surprised at the complexity… where you’re always shooting the gap. … When you’re shooting the gap
you have to judge that distance and speed and [aircraft] type, you know, and weather. That’s where the difficulty comes in.”

In such cases, the local controller must anticipate future locations of arrivals and departures and ensure they will remain a safe distance apart on the intersecting runways. Future aircraft locations depend on current aircraft velocity and aircraft performance characteristics on takeoff and landing given the wind and weather conditions. Arrival and departure clearances must be precisely timed in such conditions to maintain safety.

In addition to “shooting the gap” on intersecting runways, the local controller must ensure that all departure restrictions are satisfied when he or she provides a departure clearance. The local controller must ensure:

- No aircraft receives clearance to depart to a closed route.
- The distance between any two departures is sufficient to allow the trailing aircraft to avoid the wake turbulence of the leading aircraft. Aircraft weight class is an important factor in wake turbulence separation requirements.
- The distance between two departures to the same heading and/or departure fix provides at least the minimum procedural spacing when the aircraft appear on the TRACON radar. Aircraft performance characteristics and traffic management restrictions are important factors in the separation they achieve between leaving the runway and appearing on the TRACON radar.

The local controller must evaluate conditions and aircraft pairs quickly enough to make efficient use of the runway(s). Ideally, departures are lined up at the runway such that the local controller can always quickly clear the next aircraft in the set of flight progress strips for departure and maximize departure throughput. If the next aircraft in the list is unable to depart, the local controller quickly identifies the first flight in the lineup that can depart and provides the necessary taxi instructions to get that aircraft to the runway threshold.
Some runways are fed by taxiways that allow multiple departure queues. In such cases, the local control flight progress strip bay may be organized according to the departure lineup that the ground controller believed would be most efficient. However, the local controller still must evaluate whether the plan developed by the ground controller and represented by the order of the flight progress strips is adequate to satisfy departure spacing constraints. If the plan is not adequate, the local controller must adapt the departure lineup as quickly as possible to maintain safe and efficient use of the runway. The local control strip bay, then, is an example of an artifact that the ground controller and local controller use to coordinate their plans (Klein, Woods, Bradshaw, Hoffman, & Feltovich, 2004; Nemeth, Cook, O'Connor, & Klock, 2004).

**Ground Controller**

The ground controller is responsible for providing safe and efficient taxi instructions to aircraft on the airport surface (Obradovich, et al., 1998). The ground controller is responsible for building a “viable lineup” of aircraft for departure that respects all airspace restrictions currently in place and has no back to back flights to a single fix, said one ATCT traffic management coordinator. Such a departure lineup represents a planned departure sequence (Spencer, Smith, Billings, Brinton, & Atkins, 2002) that allows the local controller to make efficient use of the departure runway. The ground controller also provides taxi instructions to arrivals allowing them to move safely and efficiently from the arrival runway exit to the ramp area.

During irregular operations the ground controller is expected to ensure that the local controller always has a flight at the front of the departure lineup that can depart to available airspace. This requires the ground controller to use more refined strategies in staging departures and building a departure sequence. For example, the ground controller must consider airspace traffic management restrictions such as miles in trail restrictions and build queues accordingly. One very common strategy used by participants in an ATCT surface management decision making study (described in Chapter 4) was to
segregate aircraft with route restrictions from unrestricted aircraft on taxiways so that restricted aircraft do not impede the ability of unrestricted aircraft to get to the runway.

In addition, the ground controller uses taxiway intersections to ensure flexibility in adapting the queuing strategy. For example, ground controllers and traffic management coordinators in the ATCT surface management decision making study described in Chapter 4 held aircraft on Taxiways G and H short of F such as shown in Figure 4. They wanted to have the option of directing aircraft to use the intersection with Taxiway F to move from Taxiway G to H (or vice versa). Some also wanted to have the option of allowing aircraft to depart Runway 18C from the intersection with Taxiway F.

Figure 4. Departures queued on taxiways G and H holding short of F.
When building the final departure lineup, ground controllers estimate the amount of time required between two aircraft to achieve any required miles in trail. They use that time to estimate the number of “splitters” that should be between those two aircraft in the departure lineup. Splitters are aircraft to an unconstrained (or less constrained) departure fix that ATCT controllers sequence in between departures to a constrained departure fix. Practitioners interviewed in the ATCT decision-making study described in Chapter 4 were asked to specify the number of splitters they would use to meet certain miles in trail restrictions. In the example shown in Figure 4, splitters for restricted aircraft staged on Taxiway H might be taken from unrestricted aircraft staged on Taxiway G when the aircraft are allowed to cross the intersection with Taxiway F.

The amount of surface traffic management responsibility ascribed to ground controllers in a given facility depends on factors such as level and complexity of traffic and whether the facility has a traffic management coordinator. The traffic management coordinator position is discussed in the next section.

**Supervisor / Traffic Management Coordinator**

The supervisor and traffic management coordinator represent the “Traffic Management Unit” of the ATCT. While they have different roles, for the purposes of this dissertation they perform similar functions. They monitor NAS status, airspace constraints, and surface constraints and develop strategies for coordinating and managing surface traffic accordingly (Spencer, Smith, & Billings, 2004). “The TMC announces the game plan. [Maybe] the game plan is, we’re taking all the west- and northbounds to the center runway… and the eastbounds and certain southbounds to the east runway,” said one former ATCT and TRACON traffic manager. The supervisor or traffic management coordinator monitors departure conditions and determines whether a new strategy is required to alleviate congestion or avoid gridlock (Borgman & Smith, 2010; Spencer, Smith, & Billings, 2004). “If the game plan changes then they [the traffic management coordinator] need to change it,” said the former ATCT and TRACON traffic manager.
The traffic management coordinator or supervisor represents a point of contact for people outside the ATCT, particularly TRACON and ARTCC personnel (Spencer, et al., 2003). They participate in (or at least listen to) regular teleconferences with TRACON, ARTCC, and ATCSCC personnel to collaborate on appropriate traffic management strategies and contribute to decisions on airport arrival rate and runway configuration. They represent the ATCT on hotlines during irregular operations when appropriate, often providing information to other organizations about the status of the airport surface, as in many cases the ATCT is the only organization with direct access to such information. The traffic management coordinator or supervisor ensures that aircraft needing reroutes are made known to the ARTCC and notifies other ATCT personnel, and often also ramp control operator personnel, of departure fix restrictions.

Along with the ground controller, the traffic management coordinator translates airspace traffic management restrictions into actionable plans for staging departures on the airport surface. As highlighted in the ATCT surface management decision-making study described in Chapter 4, the traffic management coordinator may suggest changes in departure runway assignments to ensure there are enough unrestricted aircraft (splitters) staged to depart from each runway to maintain efficient runway use. Spencer, et al. (2002) also found that the traffic management coordinator provided runway and departure queue assignment suggestions during normal operations. Note that changing runway assignments often requires coordination with the TRACON to ensure that TRACON controllers have traffic flows they expect.

The traffic management coordinator also is responsible for monitoring the performance of surface management strategies and adapting them as necessary to maintain traffic movement. In some cases this requires invoking a gate hold or other action to reduce the flow of traffic to the active movement area to prevent gridlock (Borgman & Smith, 2010). A traffic management coordinator may seek an immediate change in flight operator and/or controller behavior. In one example, a former traffic management coordinator objected to the limitations of the departure metering concept
evaluation study described in Chapter 4 when he could not find a “gate hold” option to immediately stop the flow of traffic to a departure queue that was increasing in size.

Note that specific responsibilities are allocated to different roles in some ATCTs because of staffing, traffic volume, complexity, and other factors. In this dissertation, the responsibilities of cab coordinators, controllers in charge, supervisors, frontline managers, and traffic management coordinators are included under the umbrella of “ATCT traffic manager.”

The Air Traffic Control Organization is not the only entity involved in maintaining safe and efficient traffic flows. Flight operators also coordinate with Air Traffic Control Organization roles in order support the safety and efficiency goals of both flight operators and the FAA.

Key Flight Operator Roles

Many practitioners within the Air Traffic Control Organization refer to flight operators as their users. That is, a common view among air traffic controllers and traffic managers is that the flight operators are their customers and they do their best to provide safe, efficient, and equitable service to those customers.

Flight operators come in different sizes and have different organizations to reflect not only their size but also their business organization and priorities. However, there are a number of roles within most flight operator organizations that interact with the Air Traffic Control Organization in consistent ways. The flight operator roles that feature most prominently in this dissertation are discussed below. There are several other flight operator roles that are not discussed. In addition, later discussions in this dissertation assume a distribution of roles and responsibilities similar to that presented here, but do not exclude the idea that some flight operators do not maintain this organization.

General Aviation also is an important consideration in designing processes to support surface traffic management even though they do not figure prominently in the
discussion in this dissertation. Smith, Beatty, Hayes, et al. (2012) discussed some General Aviation issues to be considered in designing traffic management procedures.

Flight Dispatcher

The flight dispatcher, in cooperation with the flight crew, is responsible for the safe, efficient, and timely conduct of a flight from its departure gate to its arrival gate. The flight dispatcher plans and files the intended route of flight with the FAA (Obradovich, et al., 1998) and negotiates with the ATCSCC to find a suitable alternative if the filed route is unacceptable to the FAA. Dispatchers collaborate with flight crews to ensure that a route is acceptable to the flight crew and that the aircraft is adequately fueled and equipped for the route.

Once a flight has started taxiing out for departure, typically the flight dispatcher is the only flight operator role in contact with the flight crew. The dispatcher monitors the progress of the flight (Obradovich, et al., 1998) and works to coordinate route amendments if required to ensure that the flight crew is able to avoid severe weather (Smith, McCoy, & Orasanu, 2001).

Air Traffic Control Coordinator

The Air Traffic Control (ATC) Coordinator often is an experienced dispatcher responsible for interacting with ATCSCC and ARTCC personnel as needed to remain aware of NAS status. When airspace restrictions are expected to require reroutes, the ATC Coordinator negotiates appropriate alternate routes with traffic managers and communicates route availability information to dispatchers. When flights are impacted by a program such as a Ground Delay Program, the ATC Coordinator often coordinates with multiple dispatchers to use the capacity allocated to the flight operator to best carry out flight operator priorities.
Flight and Flight Crew

Flights and flight crews are the unit of analysis for many aviation researchers (Andre, 1995; Hooey, Foyle, & Andre, 2000; Sarter & Woods, 1995). They are, obviously, a critical component of the NAS. But a flight looks different when viewed from the perspective of different roles in the NAS. Flights and flight crews interact with different roles in the NAS in different ways.

The flight crew – typically considered the two pilots manning the flight deck of a given flight – is responsible for the safe travel of the aircraft and its occupants from the departure gate to the arrival gate. The flight crew has a privileged position from which to monitor surface and airspace conditions and has a responsibility to communicate changes in conditions to air traffic controllers (Obradovich, et al., 1998). The flight crew also is responsible for carrying out instructions of air traffic controllers and ramp controllers, as long as those instructions do not impede safe operation of the aircraft.

Ramp Controller

A portion of the surface of many airports is controlled by flight operators rather than the ATCT. Figure 5 shows a diagram of the George H.W. Bush Intercontinental Airport (IAH) in Houston, TX, with the ramp area outlined in red. In the case of IAH, aircraft pushing back or taxiing in the outlined area are controlled by personnel in one of two ramp control towers. Both ramp control towers are operated by United Airlines (formerly Continental Airlines).

Different airports have different configurations of areas controlled by the ATCT versus one or more ramp control organizations (Obradovich, et al., 1998). John F. Kennedy International Airport (JFK) in New York, for example, has seven different ramp controls, each operated by a different organization (six are operated by flight operators and a seventh is operated by the International Air Transport Association). In that case,
each ramp control organization is responsible for the portion of the ramp area surrounding their passenger terminal. On the other hand, Port Columbus International Airport (CMH) does not have ramp control services and therefore flight crews contact the ATCT directly to request permission to push back and taxi out for departure. Even at airports with ramp control facilities, some flights may contact the ATCT to request permission to push back and taxi because of their gate location or because the flight operator does not maintain a ramp control facility and does not have a ramp control services agreement with another ramp control operator.
Ramp controllers are responsible for the safe and efficient movement of traffic into, out of, and through the ramp area (Obradovich, et al., 1998; Spencer, et al., 2003). When a flight is ready to push back from a gate at IAH, the flight crew contacts a ramp controller – typically located in a ramp control tower in the terminal – for permission to push back. The ramp controller gives the flight crew instructions for pushing back from the gate and taxiing to a spot where the flight crew contacts the ATCT ground controller for permission to enter the active movement area and taxi to the runway for departure (Spencer, Smith, & Billings, 2001). Similarly, the ATCT ground controller provides taxi instructions for arrivals to get to a spot where the flight crew contacts the ramp controller for taxi instructions to the arrival gate.

Ramp Control Manager

Ramp controllers talk to flight crews but rarely talk directly to personnel in the ATCT (in a notable exception, ground controllers at Philadelphia International Airport use a two-way radio for talking directly to ramp controllers in the ramp control tower in order to negotiate locations for handing off flights from the ATCT to ramp control and vice versa). Each ramp control organization has personnel in one or more roles – herein referred to collectively as the ramp control manager – that coordinates activities within the ramp control organization, aligns ramp control performance with the flight operator goals, and also coordinates ramp control activities with those of the ATCT.

At some airports, the ramp control manager coordinates directly with ATCT personnel. This is typically the case when an airport has only one ramp control organization for all flights. For example, the ATCT at Newark Liberty International Airport (EWR) in Newark, NJ, was observed to request that the ramp control tower there send certain flights to certain spots (Borgman & Smith, 2010).

When an airport has multiple ramp control organizations it is less likely that there is direct coordination between the ATCT and ramp control organizations. For example,
one participant in the ATCT surface management decision-making study described in
Chapter 4 who had worked at a major airport with multiple ramp control operators stated
that there was little to no coordination with the ramp control organizations at that airport.

Ramp control managers facilitate coordination between ramp controllers and
between the ramp control facility and air traffic control (Spencer, Smith, & Billings,
2005). In rare cases the ramp control manager coordinates with the TRACON or ARTCC
(Borgman & Smith, 2010), but typically the ramp control manager coordinates with the
ATCT. Coordination tasks include (Borgman & Smith, 2010):

- Negotiating handoff locations between the ramp control tower and ATCT for
  arrivals and departures.
- Identifying status of departures requiring reroutes.
- Requesting that a high priority departure be expedited.
- Developing strategies for managing aircraft in danger of experiencing long
  on-board delays.

Some communications between the ramp control manager and the ATCT are for
the purpose of sharing information that facilitates coordination. For example, the ATCT
may communicate route restrictions and taxi strategies to the ramp control manager and
the ramp control manager may notify the ATCT of a gate conflict preventing an arrival
from entering the ramp area. The ATCT then can identify a location on the active
movement area where the arrival can wait – out of the way of other aircraft – until its gate
is available.

However, at some airports with multiple ramp control operators it may be difficult
for the ATCT to keep all ramp control operators up to date on constraints and strategies.
In at least one case, the airport operator has taken on an intermediary role that facilitates
coordination between the ATCT and the several ramp control operators (Borgman &
Smith, 2010).
**Airport Operator**

At most airports the airport operator manages snow plowing services, construction, and other airport maintenance issues. However, some airport operators take a more active role in surface traffic management, such as the Port Authority of New York and New Jersey administration of a departure metering procedure (Borgman & Smith, 2010). In cases where involvement by – and coordination with – the airport operator is required to maintain surface traffic flows, that coordination is typically handled by managers in the ATCT and ramp control facilities.

**Interactions among NAS Roles**

The NAS is a very large, very complex system. It requires work to be distributed because the cognitive complexity is too great for any one person (or facility) to manage alone (Smith, 2011; Smith, Spencer, & Billings, 2007). The approach to distributing work in the NAS is to decompose the system into parts that are as independent as possible with mechanisms to support coordination, collaboration, and communication among distributed agents when necessary (Smith, Spencer, & Billings, 2007). Coordination, collaboration, and communication functions of most interest to this dissertation are those that cross boundaries in the semi-hierarchical organization of the Air Traffic Control Organization and between Air Traffic Control Organization and flight operator and airport operator roles. Figure 6 provides a simplified representation of interactions among NAS roles. For example, the ARTCC controller is shown as communicating directly to the ARTCC traffic manager, when in fact the controller communicates with the supervisor who in turn communicates with the traffic manager. However, the representation in Figure 6 provides a starting point for the discussion in this dissertation.

The gray boxes on the left side of Figure 6 represent FAA roles and the blue boxes on the right side represent flight operator roles. The tan box at the bottom represents multiple roles used by airport operators to support surface traffic management.
Figure 6. Simplified representation of interactions among NAS roles.

Most cross-facility interactions occur at the traffic management level. That is, roles most responsible for coordinating with other facilities do not talk to flight crews. Personnel talking directly to flight crews are chiefly responsible for the safety of all aircraft under their control. They are also expected to maintain efficient flows of traffic; however, their ability to maintain traffic flows that are both safe and efficient depends on conditions in the area under their control (e.g., weather) and the performance of traffic managers.

Planning in the Air Traffic Control Organization occurs in both a top-down and a bottom-up fashion. Most strategic planning occurs in the outer level of the diagram in Figure 6. Programmatic constraints typically flow in a top-down manner from “higher” levels in the semi-hierarchy to lower levels. In addition, “higher” level facilities ensure that strategies employed “below” them in the semi-hierarchy align with larger
organizational goals of safety and efficiency. However, personnel at each level locally develop strategic plans that fit within the framework of the “higher” level constraints. “Lower” level facilities also push information and constraints back up the semi-hierarchy that are considered in “higher” level decision making (Smith, Spencer, & Billings, 2007). This distributed approach to planning separates high-level goal- and constraint-setting from low-level implementation details (Smith, McCoy, & Orasanu, 2001; Woods & Shattuck, 2000; Smith, Spencer, & Billings, 2007; Suchman, 1987).

For example, the ATCSCC implements and manages Ground Delay Programs that can impact traffic flows throughout the NAS. However, the parameters set in such programs are strongly informed by expectations about conditions at the local (typically TRACON) level. On the other hand, when departure airspace is constrained at one airport due to constraints in the ARTCC airspace, personnel there call on the ATCSCC to coordinate a program of alternate routes that avoid the impacted airspace. In this case, the ATCSCC facilitates coordination among several small ATCT and/or TRACON facilities by opening a hotline telephone call to all impacted facilities. The affected facilities either agree to support the alternate routes, refuse, or agree but with some additional constraints.

Tactical constraints flow in a much more bottom-up fashion. Traffic management personnel monitor weather forecasts in an effort to anticipate when airspace is likely to become constrained and controllers receive reports of turbulence and other conditions from flight crews. These flight crews often request deviations from normal traffic flows, requiring controllers to provide them more specific vectoring instructions to avoid the constraint while also maintaining safe separation from other aircraft. Aircraft deviations create irregular traffic patterns, which increase complexity for controllers. Deviating aircraft also require more time from a controller because of the increased number of instructions they need. This, in turn, decreases the number of aircraft that an individual controller can manage simultaneously, thereby decreasing sector capacity.
Such decreases in sector capacity may first be communicated to a controller in a neighboring sector when the first controller refuses to accept an aircraft handoff. Thus, a route is closed and news of the closure travels from one controller to another, sometimes faster than the news travels to the facility Traffic Management Unit. Once the Traffic Management Unit receives the news that the route is closed (or otherwise constrained), personnel there can communicate the constraint to other facilities via the traffic management communication channels.

Airport Surface Management

NASA’s Surface Management System (SMS) project of the late 1990s and early 2000s laid much groundwork for the issues explored in this dissertation (Atkins, Brinton, & Walton, 2002; Billings, Spencer, & Smith, 2001; Smith, Beatty, Spencer, & Billings, 2003; Smith, Pear, et al., 2001; Spencer, et al., 2002). In the process of exploring the design and utility of airport surface display technology, the SMS research and development team contributed to the airport surface management literature in several ways. Among other contributions, they identified:

- Key aspects of the distribution of roles and responsibilities on the airport surface.
- Constraints that can lead to surface congestion.
- Existing programs to alleviate congestion when demand exceeds surface capacity.
- Potential contributions of digital information displays and decision support tools to surface traffic management.
- Key factors to consider in the design of digital information displays and decision support tools for surface traffic management.

Most of the airport surface management literature falls into one of two categories. The first group focuses on aspects of the design of specific digital surface displays and
associated surface management tools (Atkins, Brinton, & Walton, 2002; Nene & Morgan, 2009; Spencer, et al., 2007; Spencer, Smith, & Billings, 2005). The second group focuses on optimization of surface traffic flows (Atkin, Burke, Greenwood, & Reeson, 2008; Balakrishna, Ganesan, & Sherry, 2008; Malik, Gupta, & Jung, 2010). This dissertation is focused more on development of information requirements for digital surface traffic management decision support tools.

Similarly, efforts to alleviate surface delays have largely followed one of two paths. One path has focused on optimizing traffic movements such as taxi routes and departure sequences (Atkin, et al., 2008; Balakrishna, Ganesan, & Sherry, 2008; Malik, Gupta, & Jung, 2010). The second path has focused on the design of coordination processes that facilitate surface management when traffic demand exceeds surface capacity (Brinton, Lent, & Provan, 2010; Burgain, Feron, & Clarke, 2009). Billings, Spencer, and Smith (2001) highlighted some of the constraints that lead to surface congestion. They also provided background on the current distribution of roles and responsibilities on the airport surface and discussed some early approaches to departure metering at two New York airports.

Strategic planning and tactical adaptation often are required because of constraints that reduce airspace capacity. This may create a situation in which demand for the airspace exceeds the current (or anticipated near future) capacity. To relieve demand for the constrained airspace, departures are delayed on the airport surface, thereby creating situations in which departure demand exceeds airport departure capacity. Departure metering is one approach to managing departure demand relative to capacity.

**Departure Metering**

Departure metering procedures control access to the active movement area, either by assigning target push back times or target spot times. Procedures controlling push
back times require flights to remain at their gates until the specified time. Procedures that meter at the spot allow flights to push back from their gates when preferred by the flight operator, but the flights must remain in the ramp area (or a pre-designated holding area) until the specified time. Departure metering procedures have been described by several authors (Borgman & Smith, 2010; Burgain, Feron, & Clarke, 2009; Brinton, Lent, & Provan, 2010; Surface CDM Team, 2011) and implemented at a few airports.

In this document, the time at which a flight should arrive to a spot is called a target spot time, although other departure metering concepts use other labels such as:

- The Surface CDM Team Concept of Operations called this time the Target Movement Area Entry Time. The Surface CDM Team also referred to a Target Movement Area Entry Count that would specify the number of aircraft that should enter the active movement area during a given time interval (Surface CDM Team, 2011).
- Metering at JFK assigns Estimated Taxi Times that refer to 20-minute time windows (Borgman & Smith, 2010).
- Gate hold procedures at EWR assign Taxi Times (Borgman & Smith, 2010).

In practice, there would be some window around the target spot time during which it is acceptable for a flight to arrive at a spot. In this document this time window is called a Target Spot Time Window (Borgman, et al., 2010b), although other labels are used in different concepts. In the two existing examples of this basic approach to metering in practice described below, Target Spot Time Windows (TSTWs) are twenty minutes (Borgman & Smith, 2010) and ten minutes (Brinton, Lent, & Provan, 2010) in length. For consistency, descriptions of those concepts below use the terms “target spot time” and “TSTW” in place of the locally used terms.

The length of a TSTW for a metering procedure at a given airport should depend on two main factors: the precision that flight operators can meet in delivering aircraft to
the spots at that airport, and the level of precision required to ensure that the system can maintain an adequate level of performance.

The main goal of metering procedures is to reduce the number of aircraft taxiing out for departure at once. Reducing the number of aircraft in the physical departure queue can be considered a surrogate goal for other benefits to airport operation, such as:

- Increased flexibility for ATC and flight operators (Fernandes & Smith, 2011a).
- Reduced emissions from aircraft waiting in the departure runway queue (Brinton, Lent, & Provan, 2010; Nakahara, Reynolds, White, Maccarone, & Dunsky, 2011).
- Improved information for flight operators and ATC about the time at which they can expect an aircraft to be airborne (Fernandes & Smith, 2011a).

Departure metering is not an entirely new concept. In fact, it is common for controlling post-deicing taxi times during winter operations and may be considered a variation on the existing gate hold procedure (FAA, 2008). The intent of gate hold procedures is to limit taxi delay to less than 15 minutes, where taxi delay is defined as time spent taxiing beyond the nominal unimpeded taxi time for the runway configuration currently in use.

FAA procedures allow local actors to develop gate hold procedures appropriate to their airport as long as the following provisions are met (FAA, 2008):

- Flight crews receive their anticipated engine start time or taxi time prior to engine start.
- The departure sequence maintains the order in which flight crews called for a time “unless modified for flow control restrictions.”
- An alternate process exists to notify flight crews of their expected taxi time if they are not equipped to receive the information without engines running.
• Flight operators choose whether to hold delayed aircraft at the gate, tow them to another area, or taxi them to a “delay absorbing area.”
• Flight crews monitor the frequency in case a new taxi time is issued.
• The ATCT issues a new engine start or taxi time if delays change.

A departure metering concept evaluation study described in Chapter 4 found former ground controllers’ and traffic management coordinators’ attitudes toward the need to invoke gate hold procedures were mixed and depended on individual participants’ experience at the airport(s) where they had worked. At some airports, “We don’t do gate holds anymore.” At those airports that do use gate hold procedures, it is used as a last resort because flight operators need to move departures off their gates to allow arrivals into the gates and keep traffic moving.

It is unusual for metering to be applied at times other than during irregular operations. In order for departure metering to be feasible for normal operations, the procedure must be designed to account for several flight operator concerns such as ensuring equitable access to the active movement area (and enforcing the procedure so as to limit gaming). In addition, there must be an organization responsible for monitoring and managing the procedure in a manner that is satisfactory to key problem holders in the airport surface system. That organization should have adequate tools to support decision making, information sharing, and system adaptation.

Existing departure metering procedures have many similarities and differences in their designs. Their common goal is to manage the length of the departure queue, although they go about it by different means. Key differences in their designs include the (Fernandes & Smith, 2011a):

• Way in which roles and responsibilities for managing, monitoring, adapting, and enforcing compliance with the procedure are distributed across the airport
authority, flight and ramp control operators, and the ATCT (Smith, et al., 2012; Smith, McCoy, & Orasanu, 2001; Smith, Spencer, & Billings, 2007).

- Control parameters through which people influence the departure queue length.
- Technology available to support people in carrying out their individual responsibilities, as well as to support coordination and collaboration among people distributed across locations and organizations (Smith, et al., 2012).
- Flexibility provided to flight operators and ATC for carrying out their aviation responsibilities as well as departure management responsibilities imposed by the procedure.
- Design and management of departure reservoirs for absorbing variability.
- Approach to managing the collection and distribution of information (Smith, et al., 2012; Smith, McCoy, & Orasanu, 2001; Smith, Spencer, & Billings, 2007).

Some of the common elements of the metering procedures described here include:

- Many are the result of collaborative effort among ATC, airport operators, and flight operators to address a common issue (Ostrom, 1990).
- They attempt to manage the number of aircraft in the departure runway queue.
- They require some level of information sharing between ATC and flight operators (Smith, et al., 2012; Smith, Spencer, & Billings, 2007).
- They change the nature and location of departure reservoirs on the airport surface.

Each of these aspects of departure metering procedure design contributes to the ability of people at the airport to achieve goals such as reduced surface congestion and improved information about the time at which an aircraft can expect to be airborne. However, many open research questions surround the impact of different interpretations of such design parameters on the ability for people to achieve these goals. In this section,
we explore some existing departure metering procedures in order to provide some background on how aspects of procedure design are manifested in real operations.

*Flow Control at Newark Liberty International Airport (EWR)*

Fernandes & Smith (2011a) described a gate hold procedure as implemented at EWR in which the ATCT assigns metering times to individual aircraft. These metering times correspond to the time that the ATCT believes is required for the departures already in the active movement area to depart. The discussion in Fernandes & Smith (2011a) is based on observations and interviews at the airport in the summer of 2010. Note that this represents a locally developed procedure that is consistent with gate hold procedures as described in the FAA’s order regarding Facility Operation and Administration (FAA, 2008). It represents a real-time ATCT decision-making approach to managing surface congestion as opposed to a coordinated planning approach to surface management like the other examples discussed here. Hence it is fundamentally different from the procedures developed through Collaborative Decision Making processes such as the one described by the Surface CDM Team (2011).

Metering at EWR is controlled entirely by the ATCT, which is responsible for (Fernandes & Smith, 2011a):

- Determining whether metering should be invoked at a given time.
- Selecting an amount of delay to assign to flights when assigning target spot times and communicating those target spot times to flight crews.
- Adjusting the delay amount in response to changing departure conditions.
- Enforcing compliance with assigned target spot times.

According to ramp control personnel at EWR, whether metering is invoked “depends on the ATIS [weather conditions] and the runway configuration,” as well as traffic flow (Fernandes & Smith, 2011a). According to an ATCT manager, “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.” That is, if the ATCT supervisor or traffic management coordinator believes that the spot-to-off time will increase beyond some threshold he or she will assign target spot times to protect against an increase in average spot-to-off time. If the current expected spot-to-off time is 45 minutes, then the ATCT is likely to assign a metering time that is 45 minutes after the time that the flight crew calls for permission to taxi. Thus, the main control parameter for metering at EWR is an estimate of spot-to-off time for flights already in the active movement area. The estimate is made by an ATCT supervisor or traffic management coordinator who relies solely on his or her experience with departure flows at that airport (Fernandes & Smith, 2011a).

Metering times are assigned in the order in which flight crews contact the ATCT in order to maintain the approximately first come, first served approach. Once target spot times are assigned, their order is essentially fixed. Swapping two flights’ target spot times is “not really done in practice,” according to a ramp control 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 [again] we would call the tower to ask if we can arrange a swap” (Fernandes & Smith, 2011a). 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. However, it can be difficult to request such accommodation for multiple flights (Obradovich, et al., 1998).

When a flight is assigned a target spot time by the ATCT, the assigned time is written on the flight progress strip and becomes the key tool for enforcement. “The FAA [ground controller] doesn’t want to hear from you before” the time written on the strip, said a ramp control manager (Fernandes & Smith, 2011a). A flight crew that requests permission to enter the active movement area before their target spot time is told to call back at the assigned time. Enforcement of target spot times by the ATCT is key to ensuring that all flight operators (and flight crews) follow the rules of the procedure, as
the ATCT is the ultimate authority in granting or denying access to the active movement surface (Fernandes & Smith, 2011a). The approach to assigning target spot times taken at EWR, and the lack of target spot time swapping among flights and flight operators, may contribute to the ability of the ground controller to enforce compliance.

An interesting feature of the EWR procedure is that when metering is in effect international departures are exempt. This is because international departures are typically the flight operators’ highest priority flights. However, this policy may increase the difficulty of estimating spot-to-off times because it may be difficult to predict the number of international departures that will start to taxi while a metered flight is waiting for its target spot time. In turn, this also might make it difficult to provide flight operators good information about the time they can expect their flights to actually take off.

EWR has the only metering procedure discussed here that was devised by the ATCT and is managed by ATCT personnel. It also achieves some of the aforementioned goals of departure metering with little or no technology support.

**Collaborative Virtual Queue at Boston Logan International Airport (BOS)**

Burgain, Feron, & Clarke (2009) described a concept for a Collaborative Virtual Queue (CVQ) at Boston Logan International Airport (BOS). The CVQ concept controls flight push back according to the number of aircraft in the departure queue. Burgain, Feron, & Clarke (2009) stated that if the number of aircraft actively taxiing out for departure met or exceeded an “optimal saturation threshold,” any aircraft that requested to push back from the gate should be required to hold at the gate (or in a holding area) until the departure queue length fell below the threshold.

When instructed to hold at the gate, Burgain, Feron, & Clarke (2009) proposed that aircraft should be added to a prioritized list of flights called a collaborative virtual queue. Aircraft would be added to the CVQ in the order in which they contacted the ATCT to request permission to push back and taxi. However, flight operators could swap
flights in the CVQ to accommodate their priorities (Burgain, Feron, & Clarke, 2009). This allows flight operators to express their priorities, but all aircraft must be ready to push back before their priority can be considered. The CVQ concept does not facilitate coordination of departure priorities before aircraft are fully prepared for departure.

The CVQ concept is similar to metering at EWR in that it is controlled by the ATCT. The two procedures also share the expectation that aircraft are ready to push back before they may participate in the metering procedure. However, the CVQ concept explicitly incorporates the notion of flight swapping as an approach to accommodating flight operator preferences.

**Collaborative Departure Queue Management at Memphis International Airport (MEM)**

Brinton, Lent, & Provan (2010) reported on field trials of the Collaborative Departure Queue Management (CDQM) procedure at the Memphis International Airport (MEM). Similar to the CVQ concept, the goal of the CDQM procedure is to manage the length of the runway queue.

CDQM software predicts when departure runway demand is likely to create a queue longer than the target and then invokes metering procedures. It uses expected departure runway throughput and a Ration by Schedule (RBS) approach (Brinton, Atkins, Cook, Lent, & Prevost, 2010; Smith, et al., 2012; Wambsganss, 2001) to allocate the expected capacity to flight operators. Flight operators are allocated a number of departures that may request access to the active movement area during each 10-minute interval and then choose which of their flights should use the allocated capacity.

In contrast to the CVQ (Burgain, Feron, & Clarke, 2009) and metering at EWR (Fernandes & Smith, 2011a), CDQM is not enforced by the ATCT (Brinton, Lent, & Provan, 2010). Instead, surface surveillance software monitors the time at which each flight enters the active movement area and reports violations to the population of flight operators using the airport.
It is not clear whether the CDQM software allocates departure capacity in order to control queue length or the average time spent in the departure queue (Brinton, Atkins, et al., 2010; Brinton, Lent, & Provan, 2010). However, either can be computed from the runway departure rate and the spot metering rate if their probability distributions are known. Therefore the two control parameters are likely to be equivalent in their ability to support the CDQM software in monitoring the metering procedure. However, it is not clear whether one is preferable for supporting humans that may need to intervene in adapting the metering procedure to changing departure conditions.

*Departure Metering at John F. Kennedy International Airport (JFK)*

While the CDQM procedure at MEM is managed and monitored by software, JFK has a departure metering procedure that is monitored and managed by humans with some software support (Fernandes & Smith, 2011a). Departures there have been metered on a daily basis since the spring of 2010. (“Metering is in effect every day,” said one airport operator manager, “but we don’t delay aircraft every day.”) The procedure was developed and is monitored by a Surface Group made up of representatives from the airport operator and ramp control operators. JFK has 90 different airlines that use its 7 terminals, according to one airport operator manager. Each terminal (ramp control) operator is responsible for the metering participation of the flight crews that use its terminal.

The Surface Group developed the procedure by adapting a previously developed winter operations slot allocation procedure for daily use. It is managed by personnel at the Metering Desk who are contracted by the Surface Group through the airport operator (Fernandes & Smith, 2011a).

**Overview**

The metering procedure at JFK assigns aircraft to 15-minute time windows according to the expected departure rate during the afternoon departure push. (An airport
operator manager stated that 15 minutes was the time window the Surface Group originally believed they could manage to, but that a new program implementation would decrease the length of the time windows.) Flight crews are not to contact the ATCT to request permission to taxi to the departure runway more than 5 minutes before their time window begins or more than 15 minutes after the time window ends according to two airport operator managers. The number of flights assigned to each 15-minute window is intended to maintain a departure queue of 10-12 aircraft but no more than 15 aircraft while preventing the queue from ever running dry (Borgman & Smith, 2010).

Software tools facilitate time window allocation and coordination of ramp control operator intent to use their time windows. Metering Desk personnel have tools to help them predict the departure rate for the afternoon, which is translated into an “initial calculation” of the number of aircraft that should be allowed to enter the active movement surface during each 15-minute time window, according to one Metering Desk controller. They then assign each flight in the schedule to a time window according to a Ration by Schedule philosophy (Smith, et al., 2012; Wambsganss, 2001). The Metering Desk controller said the software tools are “good for planning, making an initial allocation.”

The allocation of flights to time windows is automatically communicated to ramp control operators by metering software. Each ramp control operator has a representative who monitors the assigned time windows of flights under their control. In fact, according to the airport operator, all ramp control operators have created a new position that is responsible for monitoring and managing the metering procedure as it applies to their operation. For at least one ramp control operator, the position is staffed by a trained ramp controller who may perform both the ramp controller and metering roles, particularly when traffic volume is low.

The ramp control operator representatives use a group chat window to communicate by text with the Metering Desk. All messages are broadcast to all
participants. The principal use of the group chat window is to request that the Metering Desk personnel swap two of a ramp control operator’s flights across time windows. In this way, metering at JFK includes a procedure explicitly designed to accommodate flight and/or ramp control operator priorities. Ramp control operator representatives also use the group chat window to alert the Metering Desk of expected flight delays, even when they do not have a flight assigned to a later time interval that could take advantage of the newly available target spot time. This ensures the delayed flight a later target spot time. The Metering Desk may move some other flight operators’ flights into earlier target spot times as a result through a manual process with the same effect as adaptive compression in the Ground Delay Program (Smith, et al., 2012). They do not negotiate direct target spot time swaps across ramp control operators.

Metering Desk personnel said they “encourage airlines to request earlier times” if their aircraft can be ready to go. They tell the ramp control operators “if they’re ready and want to move let us know.” In addition, one Metering Desk controller said, “I look at [the airport surface surveillance display] and can see that he’s ready and move him up without asking.” Managing the departure metering procedure requires anticipating the need for more (or fewer) aircraft joining the queue at a future time and translating that need into a specific number of departure slots allocated for a specific time window.

Managing the Procedure

Metering Desk personnel are responsible for monitoring airport departure performance relative to the target spot time allocation and adapt the procedure as necessary to accommodate changes in departure conditions. They have access to information about the status of the whole airport community to support them in this task. For example, an airport operator manager said that if the train linking the terminals is delayed the Metering Desk personnel should consider that in their planning because the ability for passengers to get to their departing aircraft will be impacted.
Metering Desk personnel adapt the procedure by modifying the number of aircraft allowed to enter the active movement area during selected 15-minute intervals. They are responsible for determining which time periods outside the static time horizon\(^2\) (Surface CDM Team, 2011) should have their number of aircraft modified and what the new numbers should be.

Borgman & Smith (2010) described an event they observed in which an emergency landing closed the departure runway for nine minutes. When the runway closed, the Metering Desk knew the emergency landing was due to a hydraulic failure on the aircraft, but did not know how long the runway would remain closed. There were two main sources of uncertainty in the length of time the runway would remain closed:

- Whether the aircraft would be able to taxi off the runway under its own power. If it could not, the runway would remain closed long enough for a tug to reach the aircraft and tow it out of the way of departing aircraft.
- Whether any hydraulic fluid had leaked onto the runway. Such a leak would require the airport operator to clean the runway before it could be reopened for departures. If there was no leak, the airport operator would only need to perform a sweep of the runway to inspect it for fluid.

Despite the uncertainty in the time at which the runway would return to operation, the Metering Desk needed to adapt the procedure to ensure that the queue did not grow too big if the runway remained closed for an extended period while also preventing the queue from going dry if the runway did not remain closed very long.

---

\(^2\) The static time horizon is similar to the “freeze horizon” described by Brinton, Lent, and Provan (2010). During normal operations, “no times are shuffled [less than] 30 minutes before” their target spot times, said one JFK airport operator manager. During severe weather events the static time horizon at JFK is increased to 45 minutes, increasing the queue length because “as soon as it [a constrained departure route] starts opening that queue’s going to come down quick.”
The two personnel managing the procedure at the time monitored traffic on a surface surveillance display such as that shown in Figure 7 while they discussed the situation. They decided to move all departures back 15 minutes, starting with the time window 45 minutes after the runway closed. One of the individuals 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 Metering Desk personnel used the software tool to move the aircraft to later slots, automatically communicating the change to the ramp control operators. Note that this delay in applying a change in the target spot time allocation is consistent with an issue discussed by Brinton, Lent, & Provan (2010) regarding stability in the time a flight operator is expected to have a flight ready for departure. This issue was explored further in Fernandes, et al. (2010) and is discussed later in this document.

Figure 7. Example JFK surface display. Permission from Saab Sensis Corporation.
The group chat window that ramp control operators use to request flight swaps is also used to communicate key procedure information such as the reason for a change in time window allocation. The ATCT also uses the chat to announce airport information such as changes in runway configuration. In addition, ramp control operators use the chat to exert peer pressure aimed at enforcing compliance with the metering procedure.

Enforcement

Unlike at EWR where the ATCT enforces compliance with the target spot times, the ATCT at JFK is not responsible for enforcing compliance with the procedure. In fact, participation in metering at JFK is voluntary for ramp control operators. This is similar to the procedure at MEM, except that the group chat window at JFK allows ramp control operators to respond to violations in real time. If a flight enters the active movement area before its assigned time window, the violation is often broadcast by a ramp control operator. Such violations are discussed at regular meetings of the Surface Group and the offending flight operator is scolded.

This approach to enforcement has created some issues in the past, in which participation in the procedure temporarily collapsed because one or more flight operators perceived that they would be at a competitive disadvantage if they continued to participate. However, airport operator personnel reported that personal conversations with ramp control operators and flight operators with repeated instances of non-compliance seem to have resolved the issue such that Metering Desk personnel said they see “pretty much 100% compliance.” Such issues are similar to those reported in studies of common pool resource management (Ostrom, 1990; 2000), in which common pool resources (such as an airport departure runway) must be shared by individuals or organizations that compete for access to the resource.

However, two airport operator managers said that non-compliant aircraft are more likely to be late than early. The “compliance window” starts 5 minutes before the target
spot time window starts and ends 15 minutes after the time window closes, for a total of 35 minutes (they hope to shrink the compliance window). “On a good day,” said one manager, “everyone comes off 5 minutes before the [time window] starts.”

Lessons for Departure Metering from the JFK Example

There are many lessons to be learned from departure metering at JFK, ranging from the process of developing and implementing the procedure to its use.

Collective Action

As an example of collective action to ensure access to a common resource (Ostrom, 1990; 2000), the development of the metering procedure provides some insight into how collective action can be achieved across competing parties. One airport operator manager cited repeated personal visits to decision-makers and other problem-holders in the various stakeholder organizations as a critical factor in the ability to come to agreement on a procedure.

When presented with evidence of non-compliant flight crews, the airport operator manager said that he made additional visits to ramp control operators and supervisors of flight crews. On these visits, he said, he (again) explained the purpose of metering – “to prevent gridlock” – and stressed the importance of everyone’s participation.

This is consistent with the finding that in cooperative games, “face-to-face communication… produces substantial increases in cooperation that are sustained across all periods” of play in the game (Ostrom, 2000, p. 140), even though in laboratory settings communication is only “cheap talk” (i.e., there is no enforcement of verbal agreements). Ostrom (2000) also cited the finding that “the presence of a leader or entrepreneur, who articulates different ways of organizing to improve joint outcomes, is frequently an important initial stimulus” for collective action in practice (Ostrom, 2000, p. 149).
To ensure long-term success of self-organized collectives, Ostrom (1990; 2000) provided a set of design principles including:

- A clearly defined set of users of the common pool resource.
- Rules governing use of the resource that “relate to the specific attributes of the [common pool resource] and the community of” users.
- A regime for designing rules and monitoring conformance by resource users.
- "Graduated” punishments for violating the rules (Ostrom, 1990, pp. 185-186) that consider the context of the infraction.
- Local arenas for resolving conflicts.
- Government recognition of the right for the collective to organize. In the case of departure metering, the ATCT, TRACON, ARTCC, and flight operators needed to accept that their typical performance metrics could no longer apply to JFK.
- Nested layers of governance that allow for polycentric control of distinct portions of a large common pool resource within a set of rules. This may be analogous to allowing each ramp control operator to choose how best to meet its departure metering constraints.

Resistance to Developing the Metering Procedure

Developing the metering procedure was not easy, and resistance came from several different organizations. According to two airport operator managers there were three main sources of resistance to the idea of departure metering:

- Flight operator station managers concerned with their performance measures: closeout and pushback time. If the station managers complied with the metering procedure by holding aircraft at the gate, their superiors would believe that JFK departures were consistently operating behind schedule. According to the airport operator, they had to “shift the whole paradigm.”
The FAA, namely the ATCT. They did not, and do not, want to be responsible for managing a departure metering procedure or enforcing target spot times.

Flight crews (and ostensibly cabin crews), whose paid hours do not start until they release the parking brake.

Some of this resistance has appeared in instances that led to the temporary collapse of the metering procedure. For example, two airport operator managers told of a “bad night” when one pilot who had been given a target spot time called the ATCT to request permission to taxi instead of waiting until his target spot time. The ATCT gave him permission to taxi because they do not enforce target spot times. The pilot then used the ground control frequency to tell all pilots from his company to request taxi rather than wait for their target spot times.

This illustrates the biggest vulnerability of departure metering at JFK and of common pool resource problems in general: if there is one defector, all participants defect because they are at a competitive disadvantage if they continue participating when others do not (Ostrom, 1990; 2000). Rather, successful metering requires “the ramp tower telling pilots the right thing and the pilot doing the right thing,” said one airport operator manager.

One airport operator manager said they have overcome ramp control operator resistance and encouraged their participation by transparency in the design and management of metering. They record chat logs and can replay events when someone raises an issue.

Accommodating Ramp Control Operators with Insufficient Ramp Space

At times a ramp control operator may have more aircraft in metering than it has space on its ramp to accommodate. At first, when a ramp control operator needed to create space in the ramp area, the ATCT would park the departure on a taxiway somewhere out of the way (Borgman & Smith, 2010). However, the ATCT “won’t do
that anymore,” said an airport operator manager. “Now, we have designated spots on the field.” There are 8 pre-coordinated Metering Spots on the active movement area. When a ramp control operator needs a flight crew to meter on the active movement area, said the airport operator manager, “the [Metering Desk] tells the pilot where to go.” The Metering Spots are deliberately located far from the runway to keep metering aircraft out of the way of others and to discourage ramp control operators from using them unless they need to. Aircraft can get to the runway from any of the Metering Spots, meaning that the ATCT can select aircraft from any of these spots when the need arises.

Ensuring a Suitable Departure Inventory

An airport operator manager told of occasions when the ATCT called the airport operator to request that they “turn it off” because the ATCT did not believe the Metering Desk was delivering an appropriate departure inventory. But, he said, “How do you have an orderly stop of metering?”

It is possible that from the perspective of the ATCT metering does not always ensure a desirable departure inventory. However, multiple airport operator and Metering Desk personnel said that when metering does not provide the right inventory it is because there are not enough of the “right” aircraft that are ready to taxi. They cited examples of the departure queue running dry because there were not enough departures scheduled or aircraft were not ready to push back and depart on time. “More often than not,” said one airport operator manager, “Flights are non-compliant because they’re late.” “If there is no departure queue,” said another airport operator manager, “the system defaults to the schedule” and as long as aircraft are ready on time the ATCT has the same departure inventory they would have without metering.

Differing Perceptions of Metering Effectiveness

It is possible that the real issue is differing perceptions of metering performance among different parties, even within the same organization. Airport operator and
Metering Desk personnel cited ATCT expressions of frustration with metering performance when they perceived that metering was “starving the queue.” But, they countered, there is not always sufficient departure demand to maintain a queue, and if “the queue gets small, they [the Metering Desk] can add slots and move people up.” According to Metering Desk personnel, “If everyone’s on time and the queue goes dry, we don’t have enough planes.” In such situations, Metering Desk personnel ask for available flights via the chat window, but the airport operator hopes to speed this sort of adaptation with the new implementation of metering software, which will “shuffle” the list of target spot times every minute.

Ramp control operators have their own perception of metering efficacy, and the perception may differ across roles in the organization. One ramp control operator manager did not perceive that Metering Desk personnel were sufficiently proactive in estimating the actual departure rate in order to build the departure queue, saying, “The published rate says 28 [departures] per hour, [and] they schedule 28 per hour.” That departure rate represents an average and sometimes more than 28 flights are able to depart in an hour. Metering Desk personnel reported that in fact they do try to anticipate when more flights than average will be able to depart during a given time period. They said that they try to be aggressive when they see the departure queue length start to decrease and there are aircraft holding in metering positions.

In particular, there is some inconsistency in perceived effectiveness of metering during irregular operations. One ramp control operator manager did not believe that Metering Desk personnel considered flights’ departure fixes during irregular operations. However, airport operator and Metering Desk personnel stated that during irregular operations they allocate target spot times according to departure fix and not scheduled departure time. Rather than a target of 10-12 aircraft in the departure queue, during irregular operations their target departure reservoir has “3 per [departure] fix,” according to two airport operator managers. Rather than allocating target spot times solely based on scheduled departure time, “when they launch a Bette [flight to the Bette departure fix],
put another Bette into the queue in places where he can get to the runway.” This may result in 15-18 aircraft in the departure queue instead of the typical 10-12. Further, Metering Desk personnel said that if they see that “arrivals are waiting a long time,” they will “increase the queue to let the departures off the ramp so that the arrivals can get into their gates.”

In addition, they credited metering with helping to manage the effects of events requiring a Severe Weather Avoidance Plan (SWAP). In particular, they said that metering allows them to “diminish the queue, and it seems to delay pulling the trigger on the ground stop or the ground delay program.” That is, because metering keeps the departure queue shorter it takes longer for the airport to approach gridlock and require a ground stop or ground delay program to relieve congestion.

Also, they said, “the duration of the SWAP events has decreased.” At the end of the day, “recovery from SWAP events traditionally would last until 1 or 2 in the morning. Now we leave at 10pm” after the airport has recovered from lingering SWAP-related delays “because you’re controlling the rate going out.” They explained, “Most of your delays happen after the thunderstorm has left.”

In addition, flight operators – some of whom are also ramp control operators – approached the airport operator with a request to continue the procedure even after the runway reopened. The airport operator cites this as anecdotal evidence of cost savings. Nakahara, et al. (2011) compared active taxi-out times on days before and after departure metering was implemented and found significant fuel and cost savings.

The analysis performed by Nakahara, et al. (2011) assumed that aircraft waiting for their target spot times are not burning fuel. However, personnel for one ramp control operator reported that while they hold flights waiting for their target spot times in their ramp area, those aircraft have one engine running. If they were taxiing out they also would have one engine running, following a “single-engine taxi” procedure (Deonandan
& Balakrishnan, 2009; Kumar, Sherry, & Thompson, 2008). There may be less fuel conservation resulting from departure metering than Nakahara, et al. (2011) assumed.

Even if aircraft holding in the ramp area are not conserving fuel, they do remain under control of the ramp control operator. The ramp control operator is free to choose which departure should use each of the target spot times assigned to them. However, one ramp control operator reported that aircraft waiting in the ramp area for their target spot times are lined up in first come, first served order. If a flight becomes a high priority while in metering – such as if it has a curfew at its destination airport – the ramp controller can swap that flight’s target spot time with an earlier flight. But, said the ramp control manager, “the schedule is pretty much built to cover” most such events. However, when a flight does need to be expedited it waits in the lineup only long enough for 10-15 flights to depart rather than 30-40 as could be common before departure metering was implemented.

Such differing perspectives of metering performance may be a procedural example of “Grudin’s Law” (Norman, 1993; Woods & Hollnagel, 2006) in which those who see the financial benefits of metering are not those who are responsible for the day to day operation of the procedure (Grudin, 1988). While it may result in significant cost savings as Nakahara, et al. (2011) reported, metering requires a shift in the paradigm for many surface management roles.

Lead Time for Target Spot Time Window Assignments

Metering Desk personnel try to assign target spot times as soon as possible so that ramp control operators have as much planning time as possible. However, when the “flow is good,” according to one ramp control operator manager, the target spot times “don’t really matter” for most flights, but the nature of the schedule causes what to him seemed like unnecessary delays. For example, at 14:30 local time a flight scheduled to taxi at 16:37 was observed to have been assigned a target spot time of 17:00. The ramp control operator manager wondered aloud why, on a day with low departure volume, a
flight would be assigned a delay of more than 20 minutes when it was still 2 hours before its scheduled departure time.

Such early target spot time allocation relies on the Metering Desk estimating impacts of changes in departure capacity over time. For example, at approximately 17:00 local time every day, JFK changes from an arrivals runway configuration (for example with 22L as an arrivals-only runway and 22R as a shared arrivals/departures runway) to a departure configuration (22L as an arrivals-only runway and 22R and 31R as departures-only runways). In fact, the ATCT may change the runway configuration earlier, say at 16:45, and the queue will quickly dwindle because the departure rate can nearly double at that time. So target spot times assigned at 14:30 for the 16:00 hour are likely to be changed. Therefore, the ramp control operator manager indicated that it would make sense to wait until a later time to allocate those target spot times.

It is not known what is the appropriate lead time that provides flight operators sufficient time for planning but also provides them stable target spot times. It seems reasonable to try to provide flight operators an indication of the magnitude of departure delays they can expect before they file their flight plans in case such information will influence the departure route and/or priority they assign to a given flight or set of flights. However, if such information consistently proves to be incorrect it is of little or no help to them. To ensure target spot time stability the Metering Desk could wait until just before the static time horizon (Surface CDM Team, 2011) to allocate target spot times, but then flight operators may not have sufficient time to plan their operation and prioritize departures’ use of target spot times.

Consistency

Situations in which the queue is “starved” imply that perhaps metering is not necessary every day or during all hours of the departure push. However, one airport operator manager stressed the importance of maintaining the procedure so that flight crews (who may not frequent JFK) always know that the procedure is in effect.
Maintaining consistent procedures is one way to reduce the cognitive complexity flight crews may face in preparing for departure because they always know what to expect. It also facilitates synchronization across agents because they know what to expect from others in the distributed work system (Klein, Feltovich, Bradshaw, & Woods, 2005). Consistent use of metering also facilitates traffic management decision-making because they know, for example, why the departure queue at JFK is shorter than that at La Guardia Airport (LGA), as discussed in the next section.

**Maintaining Accurate “Delay” Statistics**

Metering has required organizations to redefine certain performance metrics. The ATCSCC maintains updated delay status for each airport and that information is used in airspace management decision-making at other facilities, including New York TRACON. Airport delay status indicates the current average departure delay for the airport. Departure delays are defined as the time a departure spends on the active movement area – with the flight crew talking to the ATCT – beyond unimpeded taxi time. Since metering delays aircraft before they enter the active movement area, official taxi time is drastically reduced, as is reported average departure delay.

When they first started metering, said one airport operator manager, “the TRACON would give La Guardia the airspace because the lineup at JFK was so short.” Now, the airport operator provides the TRACON with a list of aircraft in metering and the length of metering-assigned delays. They also communicate the metering delays to the ATCSCC so they have a realistic understanding of the status of departures at JFK.

Traffic management personnel at the New York TRACON used reported taxi times from the major New York airports in their decision-making. For example, if one airport was experiencing high taxi times TRACON personnel might allow that airport to increase its departure rate. Traffic management personnel at the JFK ATCT said that their reported taxi times had decreased since the departure metering procedure was implemented because aircraft were delayed in entering the active movement area and the
control of the ground controller. However, the lower taxi times reported by JFK led the TRACON to assume that JFK was experiencing low departure demand and therefore gave priority to departures from other airports. Taxi-out time and departure queue length no longer constituted sufficient information for a TRACON or ARTCC traffic manager to determine the status of JFK departures.

Delaying aircraft entry into the active movement area also conflicted with FAA and flight operator metrics. The FAA requires flight operators to report delays for departures that do not push back within 15 minutes of their scheduled departure time. Airport operator managers said that flight operator policies required the aircraft to push back from the gate before flight crews were “on the clock.” Thus, ramp control facilities and flight crews had strong incentives to push flights back at the scheduled time to be credited for having started their work shift and to avoid delay penalties for waiting until their target spot time. The airport operator managers indicated that they had to educate the FAA and individual flight operators on the impact of the procedure on their departure metrics. Similarly personnel from at least one ramp control operator were responsible for balancing reported flight delays with gate management needs and metering procedure-related delays. These are examples of requirements to shift responsibilities, performance metrics, and priorities when new work systems are introduced (Woods & Hollnagel, 2006). It is not clear whether these organizations have modified incentives to better align with the specifics of metering at JFK.

Successes and challenges in metering at JFK, along with concepts and lessons learned from the other departure metering procedures discussed here, have informed the design of the departure metering procedure used as the basis for study in this dissertation. This concept is similar to that described by the Surface CDM Team (2011) and was designed for the notional Major Airport (MJA). It is described in the next section.
Departure Metering at (Notional) “Major Airport” (MJA)

The departure metering procedure explored in most detail in this dissertation is implemented at a notional airport called “Major Airport” (MJA). A diagram of MJA is shown in Figure 8. The notional departure metering procedure closely parallels that developed by the Surface CDM Team (2011); key differences are highlighted as those features are discussed here and in later chapters.

Figure 8. Simulated surface display showing (notional) Major Airport (MJA).
Metering at MJA employs technology and processes assumed to have been agreed upon by ATCT, flight operator, ramp control operator, and airport operator representatives. It is assumed to have been reviewed by Enroute and Systems Operations staff to make sure it is compatible with other operations. The purpose of the program is to meter the flow of departures to the movement area in a manner that is suitably equitable and efficient. It shares many characteristics with the JFK and MEM departure metering procedures.

It also is assumed that an individual or team of individuals, called the Departure Reservoir Coordinator (DRC), administers the departure metering procedure. The DRC is responsible for managing the flow of aircraft to spots for handoff to the ATCT. The role involves a new function that may be added to the ATCT traffic management coordinator role or may be a separate role not located in the ATCT. It is possible that some of the functions ascribed here to the DRC should be distributed among traffic managers at the ATCT, TRACON, and/or ARTCC. The DRC role described here expands on the role of the same name described in the Surface CDM Team Concept of Operations (2011). Key differences between the roles are noted where they are discussed. The DRC is so-called because this role is responsible for managing the departure reservoir.

Departure metering at MJA is controlled by two main parameters: 1) the number of aircraft expected to be able to depart from the runway during each 15-minute period and 2) the desired average length of the departure queue for that runway. The target average departure reservoir size may be a complex parameter, composed of desired characteristics of multiple departure reservoirs. Note that the runways at MJA are sufficiently far from each other that operations can almost always be scheduled separately for each departure runway. In addition, the DRC may place constraints on the flights that can use a target spot time such as on the departure fixes that a flight is able to use.

The DRC sets these parameters using available information and personal experience regarding sources of uncertainty and variability and their impact on
departures. He or she may also receive input from others such as a TRACON traffic manager. It is assumed that the DRC has expertise in estimating the approximate average departure rate over the planning horizon under different conditions and appropriate tools to support such planning. The DRC also is assumed to have expertise in determining the average departure reservoir size and makeup that will provide a sufficient buffer in case the actual departure rate is different than expected (or if the rate at which flights join the departure reservoir differs from the plan). Appropriate decision support tools aid the DRC in making these estimates and revising them when necessary.

Based on the parameter values set by the DRC, departure metering procedure management software assigns a target spot time to each scheduled departure using an algorithm very similar to Ration by Schedule (Smith, et al., 2012; Wambsganss, 2001) and the Generalized Ration by Schedule (GRBS) algorithm described in Brinton, et al. (2010). Conceptually, the algorithm works as follows:

1. The estimated time of departure and terminal parking gate of each flight reported by flight operators are used to compute a “scheduled” off time that considers the taxi distance from the expected spot to the departure runway.
2. The RBS-like process allocates controlled expected runway departure times using these “scheduled” off times.
3. Target spot times are computed for each flight using the taxi distance from the expected spot to the departure runway.
4. Flight operators are notified of the target spot time for each of their departures. The target spot time window for each flight is computed from its target spot time according to the length of the target spot time window agreed upon by local stakeholders.

The use of software allows the allocated target spot time windows to be as narrow as desired. A target spot time window might be a 10- or 15-minute time period similar to the time windows used in the metering procedures at JFK and MEM. Alternatively, flight
operators might be assigned a target spot time window that is the target spot time plus or minus a few minutes (similar to the assignment of arrival slots in the Ground Delay Program). The best approach will depend on several factors, such as:

- The cognitive complexity of the DRC’s task of managing the allocation of target spot times and adjusting the program as conditions change.
- The ability of flight and ramp control operators to meet the time window.
- The ability of the program to build a departure reservoir that allows ATCT controllers to build an efficient departure sequence.

To achieve the Collaborative Air Traffic Management goal of accommodating flight operator preferences (Federal Aviation Administration, 2010a), flight operators are allowed to use each target spot time allocated to them for any of their flights as long as no constraints associated with a target spot time are violated. In addition, if a flight operator will be unable to use a target spot time allocated to them, they can make that target spot time available for another flight operator to use with the understanding that in return they will receive a target spot time that they can use. This is similar to the notions of slot swapping and slot credit substitution in the Ground Delay Program (Smith, et al., 2012).

Flight operators and ramp control operators participate in collaborative departure management planning in several ways. First, flight operators are expected to keep the program informed of their flights’ earliest spot times. Flight operators should update the earliest spot time whenever new information becomes available about the time at which a flight will be able to arrive to a spot, ready for handoff to ATCT control. Providing better information allows the departure metering procedure to better meet flight operators’ priorities. The DRC and/or the departure metering procedure management software uses these updated earliest spot times to maintain an accurate model of departure metering procedure status relative to departure conditions. Up to date earliest spot times help the DRC and/or departure metering procedure management software anticipate when the
departure reservoir may shrink below the target average size and identify aircraft that can be offered earlier target spot times to maintain a desirable departure reservoir size.

When the flight operator identifies that a flight will not meet its target spot time, they are responsible for proposing to swap that flight with another of their flights. In addition, if a high-priority flight is assigned a later target spot time than a lower-priority flight, the flight operator or ramp control operator is expected to propose a swap to help ensure higher priority flights are able to depart with less delay than lower priority flights.

If the flight operator or ramp control operator detects that a flight will not meet its target spot time, they are responsible for requesting a later target spot time for that flight if they have no other flights that can use it. If a suitable “bridge” can be found (Beatty, 2001), the delayed flight will be offered a later target spot time, another of their flights will be offered an earlier target spot time that it can use, and one or more flights operated by others will also be offered earlier target spot times to fill out the schedule.

This dissertation acknowledges that different flight operators distribute responsibilities differently across dispatchers in flight operations centers and ramp control facilities. This dissertation attempts to describe the departure metering procedure concepts in a manner that allows them to apply to flight operators with different organizations. Recognizing that not all flight operators maintain ramp control facilities at a given airport and that not all ramp control operators represent flight operators, this dissertation largely uses the two terms interchangeably in describing the distribution of roles and responsibilities in the departure metering procedure at MJA.

MJA provides a context for studying departure metering procedures. As distributed work systems in which agents must cope with uncertainty, departure metering procedure design bears several cognitive systems engineering themes. Some of these are discussed in the next section.
Cognitive Systems Engineering Issues in Metering Procedure Design

Cognitive systems engineering and related disciplines have produced literatures that can provide guidance for the design of departure metering procedures and support for people responsible for making them successful. They are part of a distributed work system or joint cognitive system in the phrasing of Woods and Hollnagel (2006). Literatures with lessons from distributed system design have informed our work. Generic tasks required of people in the joint cognitive system provide another set of literatures that inform the design of tools to support people in carrying out their responsibilities.

Distributed System Design Issues

The NAS has a long tradition as a complex distributed work system (Smith, McCoy, & Orasanu, 2001; Smith, Spencer, & Billings, 2007). Therefore, concepts designed to be implemented in the NAS are necessarily distributed work systems. There are several different literatures that examine aspects of distributed work system design. Among the issues to be considered are:

- The distribution of roles and responsibilities (Smith, Spencer, & Billings, 2007).
- Coordination, collaboration, and communication across distributed agents (Woods & Hollnagel, 2006).
- Incorporating multiple system perspectives in design (Smith, et al., 2012).
- Computer-supported cooperative work (Norman, 1993; Olson & Olson, 2000).
- Representation design (Smith, Stone, & Spencer, 2006).

Of these issues in distributed work system design, the distribution of roles and responsibilities is often overlooked.
Distribution of Roles and Responsibilities

The distribution of roles and responsibilities is an important design decision. Smith, Spencer, and Billings (2007) stressed the importance of distributing authority and decision-making according to access to knowledge and data as well as according to goals and priorities. They used the distribution of work in the NAS relative to these characteristics as a basis for identifying vulnerabilities and opportunities for redesigning procedures via a new distribution of work or new control parameters. They provided examples illustrating how each of the impacted agents has access to different data about airspace conditions and aircraft capabilities. Each agent may interpret that information differently because they have different perspectives on how it may help them achieve their goals (Smith, Spencer, & Billings, 2007). However, the distribution of authority (or control) along with responsibility provides constraints on the actions each agent is allowed to take based on their interpretation of the information available to them.

Smith, McCoy, and Orasanu (2001) characterized different approaches to distributing control in the NAS as “control by directive,” “control by permission,” and “control by exception.” They described how one air traffic management program evolved in its distribution of control and examined the resulting influence on decision-making behaviors exhibited by different agents in the system. Shifting from control by directive to control by permission did not modify the locus of control but did require changes in communication across organizations that facilitated “a shared understanding of goals, problems, constraints, and solutions” (Smith, McCoy, & Orasanu, 2001, p. 373). Shifting from control by permission to control by exception also required a shift in the distribution of responsibilities as well as in access to knowledge and data. But it decreased the occurrence of interactions that could have facilitated a shared understanding.

Control by exception gives flight operators the greatest amount of local authority to balance their goals, priorities, and the tradeoffs involved. But it requires them to have access to information about constraints and bottlenecks that impact the ability of the FAA
to facilitate their preferences (Smith, McCoy, & Orasanu, 2001). Smith, Spencer, and Billings (2007) described a modification to the control by exception paradigm that distributed decision-making across agents, time, and uncertainty in an approach they called coordinated contingency planning. In this case, the FAA attempted to publish the best available information about constraints and flight operators indicated their strategic preferences – and constraints – given that information. The FAA then tactically determined whether the flight operator preferences could be honored after even better information became available (Smith, Spencer, & Billings, 2007). This allowed them to utilize a planning strategy of delaying commitment to a course of action as an approach to cope with uncertainty (Weld, 1994).

Inappropriate distribution of responsibility relative to authority and control can leave practitioners in double binds, wherein they have a responsibility to “do the right thing” but not the authority to make the “right” decision (Woods & Hollnagel, 2006). Woods and Hollnagel (2006) pointed out that many system models represent over-simplifications that ignore the potential for such double binds and therefore are used to create distributed system control structures that provide inadequate procedures. Smith (2011) noted that expertise in a domain often involves knowing these procedures but also knowing important exceptions when the procedures are inadequate and an alternative course of action is needed. An appropriate distribution of control acknowledges such expertise and provides authority to act as appropriate for the local situation.

Woods and Shattuck (2000) identified “commander’s intent” as a key concept that allowed military commanders to successfully distribute authority along with constraints to lower echelon units. Commander’s intent provides local authority to personnel to make decisions based on their interpretation of a situation and to act on those decisions in a manner that achieves higher-level system goals. The hierarchical military control structure provides constraints on local decision-making authority while the commander’s intent provides high-level goals to be used for planning and decision-making.
Responsibility also should be distributed according to the motivations and incentives faced by each agent in the distributed system (Smith, Spencer, & Billings, 2007). Norman (1993) and Woods and Hollnagel (2006) cited “Grudin’s Law,” in which additional responsibility associated with a new system (typically technology) is disproportionately borne by agents that do not benefit from the work (Grudin, 1988). Such misaligned work distributions often lead to unused technology (Parasuraman & Riley, 1997) or technology used only because it is required by management (Woods & Hollnagel, 2006). It may not be the technology that is at fault, but rather a poor distribution of responsibilities relative to motivation to use the technology. Often some incentive can be introduced for carrying out the responsibility, such as allowing flight operators to keep slots in a Ground Delay Program when they cancel flights (Beatty, 2001; Smith, et al., 2012; Smith, Spencer, & Billings, 2007). In such ways, a good distribution of roles and responsibilities can facilitate coordination, collaboration, and communication by incentivizing agents to participate.

Coordination, Collaboration, and Communication

Distributed work systems require a certain amount of coordination, collaboration, and communication to function. One goal in this work has been to develop a distribution of work that allows relatively independent subtasks to be performed that together accomplish system goals. Figure 9 shows a concept outlined by Smith (2011).

Smith (2011) noted that there may be an appropriate way to decompose the system such that some subtasks can be performed through independent work. Salas, Cooke, and Rosen (2008) referred to such independent work as “taskwork,” defined as “the components of a team member’s performance that do not require interdependent interaction with other team members” (Salas, Cooke, & Rosen, 2008, p. 541). At times, however, independent work is inappropriate and therefore agents must work in a coordinated manner. In coordinated work, agents may work relatively independently
Figure 9. Independent, coordinated, and collaborative work.\textsuperscript{3} Used with permission.

from one another but need access to information about aspects of other agents’ subtasks such as intent, progress, and impact (Smith, 2011).

For example, Smith, Spencer, and Billings (2007) described the propagation of constraints from one NAS organization to another as a form of coordinated activity. In particular, constraints often represent the result of traffic management decisions that constrain the solution space for flight operators (and other air traffic management facilities) in processes such as selecting a route to file for each flight. Patterson, Watts-Perotti, and Woods (1999) highlighted the importance of voice loops for space shuttle mission control. Voice loops allow agents to listen in on the activities of others to develop an understanding of their status without interrupting their problem solving process. Monitoring radio frequencies is a similar method used in the NAS (Patterson, Watts-Perotti, & Woods, 1999), in firefighting (Branlat, Fern, Voshell, & Trent, 2009), and in other domains to develop an understanding of the status of other agents in the distributed work system. Klein, et al (2005) described salient events such as “exposure of a certain element of anatomy in the course of pursuing a particular surgical goal” as coordinating events that indicate to all team members what they should do next.

Some authors have emphasized the interdependencies among different agents’ roles in discussions of coordinated activity (Branlat, et al., 2009; Klein, et al., 2005).

\textsuperscript{3} From (Smith, 2011)
Branlat, et al. (2009) defined coordination as “the various mechanisms that allow team members to manage interdependencies between their roles and tasks, and conflicts between their goals.” This definition is similar to the definition of teamwork provided by Salas, Cooke, and Rosen (2008, p. 541): “the interdependent components of performance required to effectively coordinate the performance of multiple individuals.” Klein, et al. (2005) focused on the role of coordination in performing joint activity, defined as “an extended set of behaviors that are carried out by an ensemble of people who are coordinating with each other” to perform an activity that is “different from what any one person could do working alone” (Klein, et al., 2005, p. 142). Successful coordination, they said, requires that team members are interpredictable, have sufficient common ground, and can redirect each other as needed (Klein, et al., 2005).

It is important to support the interactions among agents that are required to achieve well-coordinated activity and to signal the need for a transition from coordinated work to collaborative work (Smith, 2011). Smith (2011) distinguished collaborative work from coordinated work by a need for more rich interaction in collaborative work. Collaboration is often assumed to require synchronous communications (Olson & Olson, 2000), particularly in high tempo domains (Branlat, et al., 2009).

Olson and Olson (2000) described a number of characteristics of collocated synchronous (i.e., face to face) interactions. These characteristics contribute to building shared cognition (Salas, Cooke, & Rosen, 2008) and maintaining common ground (Klein, et al., 2005) and are considered the gold standard in collaboration and communication. When agents are distributed, collaborative activities often involve synchronous voice conversations such as via telephone or teleconference (Smith, Spencer, & Billings, 2007) or asynchronous conversations such as via e-mail (Klein, et al., 2005).

Rich communications such as collocated conversations can be useful in measuring shared cognition and team information processing (Salas, Cooke, & Rosen, 2008). Such interactions can be ideal for creative activities such as brainstorming, but can be more
time- and resource-intensive than is desirable for tactical planning activities sometimes required in air traffic management (Smith, 2011; Smith, Beatty, Spencer, & Billings, 2003; Smith, Spencer, & Billings, 2007; Spencer, et al., 2007). Much research has been devoted to trying to design technology that can capture the benefits of colocated synchronous interaction for agents that must collaborate despite being distributed in space and time (Baecker, et al., 1995; Olson & Olson, 2000).

However, some challenges impact collaborative activities regardless of the technology used to facilitate them. Salas, Cooke, and Rosen (2008) identified factors such as team composition, work structure, and task characteristics as important factors in team effectiveness. Joint activity requires continual effort from agents to accomplish the taskwork (and teamwork) as well as the coordination itself (Klein, et al., 2005). Klein, et al. (2005) referred to this effort as the “coordination overhead.” This effort includes an investment in maintaining common ground and shared cognition because common ground is always breaking down and in need of repair (Klein, et al., 2005; Salas, Cooke, & Rosen, 2008). One approach to designing this overhead into the workflow of the distributed system is to craft activities as collaborative when they could be performed as coordinated work in order to facilitate collaboration when it is necessary (Smith, 2011).

The need to design for interdependent roles implies that agents need to interact at least some of the time to accomplish all of the system’s goals. Smith (2011) highlighted the need to design for transitions among independent, coordinated, and collaborative work. Transitions among types of work require agents to detect the need for a different level of interaction and signal their intent to other agents (Klein, et al., 2005). These signals, as well as coordination and collaboration activities, require agents to have tools and processes for communicating with each other.

Communications may need to be cross-functional and cross-organizational, which creates requirements for connectivity but also for tools other than communication technology. For example, Klein, et al (2005) asserted that common ground allows
communications to be short and coded, yet easily understood in context. Alternatively, procedures dictating when and with whom to communicate can facilitate common ground while also managing cognitive complexity for the agents involved. These procedures provide an opportunity for agents to signal their progress to others (Klein, et al., 2005) and also signal the need for adaptation in coordinated contingency planning (Smith, et al., 1995; 2003; Smith, Spencer, & Billings, 2007).

Much research into supporting collaborative and coordinated activity focuses on designing communication technologies that capture at least some of the benefits of collocated synchronous interaction (Olson & Olson, 2000). In reality, these technologies should be designed specifically to support the interactions required for the collaborative and/or coordinated activity. This requires information sharing tools and information displays that invoke appropriate cognitive processes in each agent to accomplish their portion of the work (Smith, Stone, & Spencer, 2006). The field of computer-supported cooperative work focuses on the design of technologies to support distributed work.

Computer-Supported Cooperative Work

Baecker, et al. (1995) defined computer-supported cooperative work as “computer-assisted coordinated activity carried out by groups of collaborating individuals” (p. 741). The chief focus of the discipline is the design and development of software tools that support coordinated human-human activity and lessons derived from successes and failures of such tools (Baecker, et al., 1995; Norman, 1993; Olson & Olson, 2000). Baecker, et al. (1995) classified the nature of group work, and therefore the requirements of groupware, according to the need for synchronous versus asynchronous communication and to the collocation or remoteness of group members. One challenge they noted in building groupware was that of providing the software a sufficient understanding of the work domain that it could be an effective medium for supporting coordinated and collaborative work (Baecker, et al., 1995).
Among the challenges in adoption of groupware that Baecker, et al. (1995) attributed to Grudin included the well-known “Grudin’s Law” stating that many groupware applications do not appropriately distribute the effort required to use them with the benefit of their use (Grudin, 1988; Norman, 1993; Woods & Hollnagel, 2006). In addition, Grudin found that organizations had difficulty in selecting and evaluating groupware applications because the requirements were different than for single-user applications (Baecker, et al., 1995). Grudin also has found that it could be challenging for groupware applications to reach a “critical mass” of users, avoiding situations in which one or more users lost their competitive edge by participating in the groupware, and supporting – rather than threatening – existing social structures and conventions (Baecker, et al., 1995). Note that these issues are also found in collective action and managing common pool resources (Ostrom, 1990; 2000).

Grudin and others also have identified issues in the ability for groupware to fit into the natural ways in which group activities flow. For example, Baecker, et al. (1995) cited Grudin in pointing out that group activity often includes a great deal of improvisation and “exception handling.” Olson and Olson (2000) identified similar characteristics of collocated collaborative activity as difficult to replicate in groupware for remote actors. Most of the failures they documented occurred because the technology was not well suited to the existing workflows (Olson & Olson, 2000). When work teams were successful in using the technology it was because they adjusted their behaviors to accommodate the technology (Olson & Olson, 2000), a phenomenon also discussed by other authors (Hollnagel & Woods, 2005; Norman, 1993; Sarter & Woods, 1995; Sheridan, 2002; Smith, McCoy, & Layton, 1997; Woods & Hollnagel, 2006). Most strikingly, Olson and Olson (2000) observed at least one team re-distribute work such that distant agents would not have to collaborate with each other.

Usability is another software characteristic that Grudin identified as more difficult to achieve in groupware than in single-user applications (Baecker, et al., 1995). If groupware is to fit into the workflow of the distributed work system, features allowing
access to other group members and their work should be accessible when they are needed but otherwise should not disturb users (Baecker, et al., 1995).

Goals of groupware should not only include facilitating interaction among group members, but also should support aspects of joint activity such as building and maintaining common ground, observability, and gauging interruptability and competence (Klein, et al., 2005). Salas, Cooke, and Rosen (2008) asserted that if properly designed, technology could support team performance. They credited tools that supported shared situation awareness by promoting observability of team members’ progress, behaviors, and intentions (Klein, et al., 2005; Salas, Cooke, & Rosen, 2008). Such shared displays can come in a variety of forms, from auditory “displays” such as voice loops in space shuttle mission control (Patterson, Watts-Perotti, & Woods, 1999) to shared airport surface displays (Fernandes & Smith, 2011b; Spencer, Smith, & Billings, 2005; 2004). One aspect of their design is that they facilitate diversity in team members’ perspectives.

Incorporating Multiple Perspectives

Each agent in the distributed work system has a different perspective on the system (Klein, et al., 2005; Woods & Hollnagel, 2006) that is intertwined with their responsibilities, goals, priorities, incentives, expertise, authority, and access to knowledge and data (Smith, Spencer, & Billings, 2007). Differences in agents’ responsibilities and expertise are likely to lead to different knowledge representations (Chase & Simon, 1973; Ericsson, 2005; Rasmussen, 1983; Vicente & Wang, 1998) and may lead them to develop different situation models (Vicente, Mumaw, & Roth, 2004) from the same data. Even in a tightly coupled team, diverse perspectives yield improved performance, particularly on problem solving tasks (Hong & Page, 2004).

Information displays should be designed to support the responsibilities and goals of each agent and should be cognitively compatible with their knowledge representations (Smith, Bennett, & Stone, 2006; Smith, Stone, & Spencer, 2006). Different agents may
require different displays even though information may overlap across agents. Thus, “shared” displays may not be identical, although when used for collaborative activity they should support compatible task and situation models in different agents. Compatible mental models support common ground and related characteristics of well-coordinated joint activity (Cannon-Bowers & Salas, 2001; Klein, et al., 2005; Salas, Cooke, & Rosen, 2008).

In addition to designing information displays that facilitate compatible task and situation models across agents, Salas, Cooke, and Rosen (2008) suggested developing cross-training programs in which agents learn about other team members’ roles. Salas, Cooke, and Rosen (2008) cited research showing that such cross-training improves team performance by increasing agents’ understanding of other roles in the system. This facilitates the development of compatible situation models and can improve the effectiveness of coordination, thereby potentially reducing the need for time-consuming collaborative activities (Smith, 2011).

Information and Display Requirements Development

Supporting distributed agents in coordinated activity necessarily requires supporting individual agents in carrying out their individual responsibilities. Such support often involves displays that provide the agents access to information they need to develop and maintain an adequate situation model (Vicente, Mumaw, & Roth, 2004). Effective display design then requires a good understanding of the information that agents need to effectively perform their duties. It also requires an approach to displaying that information in a way that is compatible with the cognitive processes the user needs to invoke in order to effectively accomplish their tasks (Smith, Stone, & Spencer, 2006).

The label “human-centered design” encompasses a variety of related design approaches, many of which focus on supporting high-level cognitive processes such as
planning, problem solving, and decision making in the design of visual displays (Smith, Bennett, & Stone, 2006; Smith, et al., 2012; Vicente & Rasmussen, 1990).

Smith, Bennett, and Stone (2006) emphasized the importance of using displays to communicate the current and anticipated future state of domain constraints and relationships among those constraints. In doing so, displays should support skill-, rule-, and knowledge-based behaviors (Rasmussen, 1983; Smith, Bennett, & Stone, 2006). That is, stimuli that produce an automated response (skill-based) should be represented in a way that automatically calls to mind the correct response. Similarly, stimuli that require the practitioner to choose from a set of well-defined responses (rule-based) should easily call to mind the set of responses and point to the correct choice. However, when faced with a scenario that was not specifically considered in the design or for which the agent was not specifically trained the display should support “actual problem-solving behavior (knowledge-based behaviors)” (Smith, Bennett, & Stone, 2006, p. 81).

Smith, Bennett, and Stone (2006) further argued that representing the constraints in a useful way is critical to supporting the knowledge-based processing required to solve problems that were not anticipated by display designers. They contrasted an abstract representation of domain constraints, which would require interpretation by the user for all scenarios, with an expert system that biased human experts’ problem-solving behaviors when it encountered a case in which its own behavior was brittle (Smith, McCoy, & Layton, 1997).

However, understanding proposed models of expert reasoning and problem-solving does not, in itself, produce a good design. Understanding user needs also requires knowledge of how they currently perform the tasks for which the proposed system is to be used (Smith, Stone, & Spencer, 2006). Methodologies such as cognitive task analysis and cognitive work analysis, among others, can be useful for developing such knowledge (Annett, 2004; Burns & Vicente, 2001; Gordon & Gill, 1997; Hoffman, Shadbolt, Burton, & Klein, 1995; Klein & Militello, 2001; Miller, Patterson, & Woods, 2006; Roth, 2008).
Similarly to work domain analysis (Smith, Bennett, & Stone, 2006; Vicente & Rasmussen, 1990), understanding a variety of system users, their environment, and their needs helps the designer to appropriately define the design problem (Smith, Stone, & Spencer, 2006). User needs are often specified through use cases that are based on the analysis discussed above and that situate the design in the context of the work environment and specific user goals and tasks (Carroll, 2000). Use cases are design-independent (Smith, Stone, & Spencer, 2006), focusing instead on functions the tool needs to support.

Smith, Stone, and Spencer (2006) suggested considering how certain cognitive processes might impact performance. For example, humans are not able to attend to all things all of the time and therefore it is important that a display guides the user’s attention to the information and/or actions required to accomplish the task. Similarly, characteristics of perception influence how users are likely to interpret information in a display (Norman, 2002; Tufte, 1990). The data that the user perceives and processes from the display interacts with knowledge that he or she already has in the form of a situation model (Vicente, Mumaw, & Roth, 2004), mental model (Gentner & Stevens, 1983), or situation awareness (Endsley, Bolte, & Jones, 2003).

Smith, Bennett, and Stone (2006) provided some concrete design guidelines compiled from a variety of display design literatures, including:

- Use graphical rather than analog representations where possible.
- Avoid distracting the user with unrelated or unimportant data.
- Provide access to the data at multiple levels of detail (and abstraction).
- Support relative comparisons rather than “absolute judgment limits.”
- Support top-down, model-driven processing.
- Minimize the cost of accessing information.
- Support anticipation of the future course of the system and its constraints.
- Ensure consistent representations and interactions across display elements.
• Consider experts’ likely mental models of the current and future course of system constraints and support them in developing a correct mental model.
• Direct the user’s attention to data and information that support achieving the current goal.
• Provide landmarks and external memory aids that remind the user of the steps in a complex process, steps that have been completed, where they are within the navigational structure of the system, etc.
• Group elements in the display according to their function.
• Support multi-threaded problem-solving, including allowing the user to complete “alternative tasks” while helping “the user navigate along the correct paths without getting lost.”

The literature on display evaluation also provides guidance for display design. Lewis and Wharton (1997) described an analytical approach to evaluating usability that was explained and expanded upon by Smith, Stone, and Spencer (2006). In particular, Lewis and Wharton (1997) stressed that a user should be able to quickly assess how to use an interface to accomplish his or her goal, that it should be clear what goal(s) the user can achieve using the interface, and that they should receive appropriate feedback when they perform an action. Other literature describing usability analysis and testing also can be used to derive interface design guidelines (Nielsen, 1997; Norman, 2002).

Domain-independent interaction design guidelines are helpful, but system design is not context-free. It is important to understand how the system is to fit into the work domain (Vicente & Rasmussen, 1990) and the nature of the tasks it is to support (Hollnagel & Woods, 2005; Smith, Stone, & Spencer, 2006). Some generic tasks that the system of most interest to this dissertation is expected to support are discussed next.
Tasks to be Supported

One major goal of this dissertation is to explore departure metering procedures and identify information requirements for the human agent(s) responsible for managing a metering procedure. Analysis of this envisioned role has identified several generic tasks whose literatures can help inform these information requirements and display concepts to satisfy those requirements.

The distributed control architecture of the NAS impacts the nature of adaptive planning in airport surface management. Surface management plans are made by traffic managers in the ATCT and are subject to constraints set at the TRACON, ARTCC, and/or ATCSCC. Surface management plans must be developed, implemented, monitored, and adapted in an environment where constraints can change quickly.

Tools to support human problem solving in complex environments typically include some automation that is built on a computational model of the domain and the world. The computational model driving the automation should correspond to the human expert’s model of the domain or should be comprehensible to that expert (Smith, et al., 2012). In addition, the brittleness of technology should be considered during the design process to ensure that the expectation for technology performance does not exceed its capabilities (Guerlain, et al., 1996; Smith, McCoy, & Layton, 1997). In the case of departure metering procedure planning, dynamic constraints ensure that plans must be based on incomplete and uncertain information. Therefore, tools should support human planning and decision-making functions rather than assume that the computational models are sufficient for performing such planning functions (Sheridan, 2002).

In this section, we discuss knowledge from the literature regarding the abstract tasks required for managing a departure metering procedure designed according to the prototypical concept outlined above. At its most abstract, departure reservoir management is a distributed adaptive planning and supervisory control task.
Supervisory Control

Departure reservoir management can be conceptualized as a distributed supervisory control task (Sheridan, 2002). While the Departure Reservoir Coordinator (Surface CDM Team, 2011) is not expected to have direct control over the movement of aircraft on the airport surface, the DRC is expected to be responsible for developing and managing a plan for aircraft entry to the active movement area. Supervisory control tasks have been a key part of cognitive systems engineering since its inception. Early researchers recognized that advanced technologies were moving human practitioners from positions of directly controlling the systems for which they were responsible to positions of supervising automated systems as they controlled the physical system (Hollnagel & Woods, 2005; Rasmussen, 1986; Woods & Hollnagel, 2006). Early cognitive systems engineering researchers recognized that this fundamentally changed the work that people were performing, and therefore designers needed to take a new approach to developing technologies to support them.

Recognizing that people were now engaged in supervisory rather than direct control generated new requirements for integrated human-machine system design, whereas previously system designs had often been decomposed into technology components and human components (Hollnagel & Woods, 2005; Rasmussen, 1986; Woods & Hollnagel, 2006). These models made design requirements explicit, such as:

- Designing the human role while designing the physical process (Rasmussen, 1986).
- Incorporating human performance models involving both feedforward and feedback control into joint cognitive systems design (Hollnagel & Woods, 2005).
- Recognizing that in many modern socio-technical systems knowledge is distributed across multiple (human and machine) agents (Smith, Spencer, & Billings, 2007).
• Machines should be designed as effective teammates to humans (Woods & Hollnagel, 2006).

In addition, researchers recognized that human supervisory control, in fact, was a complex role requiring the human to be proficient in multiple generic tasks, including planning, monitoring, diagnosis, and adaptation (Hollnagel & Woods, 2005; Sheridan, 2002). These tasks are discussed in the following sections, including guidelines from the literature for supporting people responsible for performing such tasks.

Planning

The DRC will be responsible for planning at multiple levels and across varying time scales. He or she should be able to develop strategic plans covering the expected departure conditions over the course of the day as well as tactical responses to smaller time-scale events such as reported debris on the departure runway. Effective planning requires the operator to have a good understanding of the system goals as well as of how system parameters and changes in the world impact the system under both normal and irregular operations (Sheridan, 2002).

There are several different models of planning in the literature (Hayes-Roth & Hayes-Roth, 1979; Klein, 1997; Kolodner, 1992; Suchman, 1987). A common theme in these models is the ability to assess a situation by recalling relevant cases and to use key characteristics of those cases to identify an appropriate course of action. Indeed, air traffic managers and flight operator ATC Coordinators have reported that when provided a weather forecast, they mentally develop one or more scenarios indicating how they expect the weather system to impact air traffic in their area of responsibility (Smith, Beatty, Spencer, & Billings, 2003). They use previous experience with similar weather systems to select from a set of high-level strategies for coping with the degree of uncertainty and forecast lead time typical of similar weather systems. The most appropriate high-level strategy is then adapted to fit their expectations for the weather
system currently under consideration. Such contingency planning is performed somewhat independently by different organizations in the system and there are varying levels of support for coordinating these distributed planning activities. Smith, Beatty, et al. (2003) proposed principles for supporting distributed contingency planning in the NAS.

Understanding how experts engage in planning can help identify approaches to supporting their planning tasks. For example, tools can support them in identifying discriminating features of a situation that help them identify the kind of scenario they are encountering and therefore develop appropriate responses. Many of the scenarios such as dynamic weather for which air traffic managers must plan involve a great deal of uncertainty. Therefore, practitioners must be prepared for multiple contingencies (Smith, Beatty, Spencer, & Billings, 2003). Smith, Beatty, et al. (2003) suggested carefully distributing responsibilities according to access to “data, knowledge, processing capacities and characteristics, goals, and priorities.” They illustrated how these parameters can modify what is an appropriate distribution of responsibilities over time as more and better information becomes available to different practitioners.

To support distributed contingency planning, tools should enable practitioners to communicate in terms of the contingencies for which they believe the distributed system should prepare. They also should have tools that support flexibility in implementing a plan and adapting that plan to dynamic conditions. Adapting a plan is necessary if conditions change such that the original plan is no longer suitable (Sheridan, 2002; Smith, Spencer, & Billings, 2007). Detecting that a plan is no longer suitable requires a practitioner to monitor the trajectory of a system relative to the plan.

Such a model of planning also can be used to understand how to design for air and surface traffic management. Tools for personnel in such roles should help them identify relevant stimuli in the environment, develop and communicate a coordinated strategy, anticipate when the strategy may need to be modified, and adapt the strategy accordingly.
It should also support tactical planning, and re-planning, in response to changes in the situation on the ground.

Monitoring

Monitoring is a critical part of adaptive planning and control (Hayes-Roth & Hayes-Roth, 1979; Hollnagel & Woods, 2005; Hutchins, 1995a; Sheridan, 2002; Vicente, Mumaw, & Roth, 2004; Woods & Shattuck, 2000; Zsambok & Klein, 1997; Suchman, 1987). It enables practitioners to detect when a process begins to deviate from “normal” or “controlled” conditions and requires attention to and anticipation of trends in key system variables.

Monitoring may require attending to several variables at once, tracking past trends, projecting those trends into the future, and anticipating when they will indicate an anomalous state (Sheridan, 2002; Woods & Hollnagel, 2006). Vicente, Mumaw, and Roth (2004) proposed that monitoring engages experts in a proactive problem solving process. They identified activities involved in monitoring a nuclear power plant, several of which are relevant to DRC monitoring requirements. In this model, monitoring consists of “initiating events” as well as cognitive, monitoring, and facilitating activities.

Initiating events act as cues that alert the practitioner that he or she may need to modify the plan. Such triggers may include details of a situation that violate expectations generated by the practitioner’s model of the situation (Klein, 1999; Vicente, Mumaw, & Roth, 2004; Woods & Hollnagel, 2006). Alternatively, initiating events may include procedural actions in which the practitioner routinely engages (Vicente, Mumaw, & Roth, 2004) such as hourly traffic counts recorded by traffic managers or routine teleconferences for information sharing and collaborative planning.

These triggers cause the practitioner to compare features of the current situation with a situation model that the practitioner has developed with experience over time (Klein, 1999; Vicente, Mumaw, & Roth, 2004). The situation model may be composed of
a set of cases (Klein, 1999; Kolodner, 1992; Smith, Giffin, Rockwell, & Thomas, 1986) whose features the practitioner can recall quickly and automatically (Klein, 1999). If the practitioner does not directly “perceive” the problem and associated solution (action), then he or she may have to build (or modify) a mental model of the current situation using one (or a composite) of these cases and fill in the details (Shute & Smith, 1993).

Tools to support monitoring should help the practitioner detect violations of the expectations set by his or her situation model (Sheridan, 2002; Vicente, Mumaw, & Roth, 2004). Such tools might, for example, display past and anticipated future trajectories of key system parameters that allow the practitioner to gauge system performance (Sheridan, 2002). Better yet, tools should support the practitioner in integrating these parameters into a coherent understanding of current and anticipated future system performance (Bennett, Toms, & Woods, 1993; Smith, Bennett, & Stone, 2006; Vicente, Mumaw, & Roth, 2004). Such tools should help the practitioner quickly compare system parameter values with values (or ranges of values) that would meet their expectations for the given situation.

When the practitioner detects that his or her expectations are violated by current or anticipated system state, in most cases well-designed tools should support the practitioner in directly perceiving an appropriate response action (Vicente & Rasmussen, 1990). However, even when using well-designed tools agents can encounter situations that were not foreseen by system designers. The practitioner may then need to engage in a diagnosis process to identify the cause for the violation and one or more appropriate actions to adapt the system parameters accordingly.

Diagnosis

Diagnosis is a common (and difficult) task requiring abductive reasoning (Peirce, 1955; Smith, et al., 2012; Woods & Hollnagel, 2006), a process by which hypotheses that
explain observed data are generated and tested, often against additional observations. The diagnosing agent should select the hypothesis that best explains the data.

The process of abductive inference described by Peirce (1955) represents the hypothesis generation portion of diagnosis: “The surprising fact, C, is observed; but if A were true, C would be a matter of course, hence, there is reason to suspect that A is true.” In anomaly detection and response there should be multiple candidate hypotheses to help ensure that the problem space represented by the candidate hypotheses includes the true explanation for the data (Fraser, et al., 1989; Klayman & Ha, 1987; Woods & Hollnagel, 2006). Woods and Hollnagel (2006) suggested supporting diagnosis by aiding practitioners in broadening the candidate set of hypotheses such as through building teams with diverse perspectives (Hong & Page, 2004) and using automation to critique practitioners’ problem solving processes (Guerlain, et al., 1996).

The hypotheses generated as candidate explanations for the data should be tested. One common approach to hypothesis testing is to attempt to confirm the hypothesis by generating test cases that will be true if the hypothesis is true (Klayman & Ha, 1987; Wason, 1960). This has proven to be a problematic strategy in a number of laboratory tasks such as those presented by Wason (1960), but Klayman and Ha (1987) pointed out that there are real-world tasks in which such a positive test strategy is appropriate. Smith, Rockwell and Giffin (1986) showed that experts often know the appropriate tests to discriminate between competing hypotheses that have been generated, thus efficiently avoiding potential pitfalls of a positive test strategy.

Indeed, both confirming and disconfirming evidence is useful in hypothesis testing. Fraser, et al. (1989) noted the importance of using some data to determine whether the hypothesis can explain the available data while using different data to determine whether all other hypotheses can be rejected (converging evidence). Such evidence can be collected through diagnostic interventions which serve both as attempts to resolve the anomaly and to perform further diagnosis (Woods & Hollnagel, 2006).
Collecting disconfirming and converging evidence can help experts avoid issues in diagnostic reasoning such as fixation and vagabonding (Woods & Hollnagel, 2006). Practitioners suffering from hypothesis fixation often fail to revise their leading candidate hypothesis despite disconfirming evidence. On the other hand, some practitioners seem to constantly shift their attention from one insignificant detail to another without developing a coherent set of hypotheses to test (Woods & Hollnagel, 2006).

Some issues that arise in diagnostic reasoning can be attributed to the difficulty of the diagnostic task. For example, in masking cases multiple different anomalies can exhibit similar symptoms that require expert reasoning to differentiate (Fraser, et al., 1989; Guerlain, et al., 1996). Similarly, garden path problems can arise when initially available evidence induces plausible but incorrect hypotheses. The evidence against such hypotheses may only arise later in the diagnostic process and may be available only in weak cues, making it difficult to detect the need to revise (Woods & Hollnagel, 2006).

However, incorporating certain strategies into the diagnostic reasoning process can support expert performance. For example, Fraser, et al. (1989) studied an expert in detecting errors in other practitioners’ diagnoses. They identified several strategies that this super-expert used to detect such errors, including:

- Using base rates to judge the likelihood of a diagnosis.
- Questioning whether probabilistic information was used deterministically.
- Ensuring a sufficient number of candidate hypotheses was entertained.
- Ensuring that the practitioner collected converging evidence.
- Questioning whether the practitioner misinterpreted evidence that would have violated his or her expectations, an example of biased assimilation (Smith, McCoy, & Layton, 1997) or a framing effect (Woods & Hollnagel, 2006).
 Appropriately diagnosing why the departure metering plan is or is anticipated to be inappropriate for the given departure scenario would allow the DRC to develop an appropriate approach to adapting that plan.

Adaptation

The dynamic nature of NAS conditions requires continuous adaptation of traffic management plans to maintain safe and efficient traffic flows (Smith, Beatty, Spencer, & Billings, 2003). These adaptations can be shifts in overall strategy that affect several aircraft or they can be changes impacting one or a few flights. The nature of the necessary adaptations depends on several factors, such as the:

- Degree of uncertainty in conditions, such as uncertainty in how a weather system will develop (Smith, Beatty, Spencer, & Billings, 2003).
- Length of the available planning horizon between the time that the need for adaptation is identified and when the change must be in place in order to have the desired effect.
- Amount of variability that can be tolerated and still maintain acceptable system performance.
- Lag between the time at which a change is implemented by a human manager and the time the change is fully realized in the system (Hutchins, 1995a).

Acknowledging the need for adaptation in system designs is a result of recognizing that planning is a continuous activity (Suchman, 1987; Woods & Shattuck, 2000). Because complex systems such as the NAS reside in a dynamic world, planning and adaptation occur in a continuous nonlinear cycle across time and levels of control and abstraction. Therefore, tools to support continuous, distributed adaptive planning should help people cope with the varying levels of uncertainty encountered in the domain (Woods & Hollnagel, 2006) and develop, monitor, and adapt their plans accordingly.
Adaptation implies not only intervention to modify system parameters, but also a process of learning from the experience (Sheridan, 2002; Woods & Hollnagel, 2006). Learning, of course requires feedback as to the effectiveness of the intervention (Woods & Hollnagel, 2006). For systems exhibiting a time lag between implementing an adaptation and seeing its effects on the system, such (feedforward) feedback should be in forms that allow practitioners to anticipate the effects of changes (Sheridan, 2002).

Such tools should support planning and re-planning across multiple levels of control or abstraction (Gauthereau & Hollnagel, 2005; Smith, Spencer, & Billings, 2009; Woods & Shattuck, 2000). Plans developed within adaptive organizations often are underspecified, recognizing that human agents at the “sharp end” of practice must perform their own situation assessment and adapt the plans of their superiors accordingly (Suchman, 1987; Woods & Shattuck, 2000).

Tools also should support planning over multiple time scales (Woods & Hollnagel, 2006). Adaptation often includes tactical planning in response to specifics of the situation at hand. Tactical re-planning and adaptation should be consistent with the strategic plans and goals of the system in which they are embedded (Woods & Shattuck, 2000). Therefore, tools to support adaptation should allow agents to respond to local conditions, and to track performance relative to system goals.

Tools to support adaptive planning should help people develop accurate models of the state of the system and anticipate how the system will change over the planning horizon (Smith, Bennett, & Stone, 2006; Woods & Hollnagel, 2006). They also should provide appropriate feedback about how well the plan fits the changing situation (Sheridan, 2002; Smith, Stone, & Spencer, 2006; Woods & Hollnagel, 2006).
Chapter Summary

The NAS is a highly distributed complex system. Multiple agents representing organizations that simultaneously compete and cooperate routinely make decisions and take actions that impact departures on the airport surface. When dynamic conditions such as weather introduce airspace constraints, the decreased capacity can strongly impact the ability of aircraft to depart. This is one source of congestion on the airport surface that can exacerbate departure delays.

In the face of such dynamic exogenous constraints, distributed agents must coordinate their activities in order to maintain efficient use of available resources. Traffic managers on the airport surface must develop plans for managing surface congestion and staging departures in ways that allow them to maintain departure throughput. This may include adopting procedures such as departure metering at the spot to manage the flow of traffic from the gates onto the airport active movement area. A conceptual departure metering procedure is outlined in this chapter.

Managing a departure metering procedure is a function that, in the concept outlined in this chapter, falls to a role called the Departure Reservoir Coordinator (Surface CDM Team, 2011). This person (or group of people) must engage in a dynamic process of planning, monitoring, and adaptation of a departure metering plan. However, the DRC does not have direct control over the preparation of aircraft in accordance with the plan (a flight operator function), nor does the DRC have control over the staging and sequencing of aircraft for departure (an ATCT function). Thus, the role can be characterized as one involving distributed adaptive planning and supervisory control.
Chapter 3: Tools Used to Support Concept Exploration and Evaluation Activities

Several tools were used to complement the methods discussed in Chapter 4 below in understanding of traffic management on the airport surface. In fact, the research methods helped in developing the tools, and in turn the tools supported and helped refine the methods. These tools included scenarios and examples gathered from:

- The literature (Atkins, Brinton, & Walton, 2002; Brinton, Lent, & Provan, 2010; Obradovich, et al., 1998; Smith, Beatty, Spencer, & Billings, 2003; Spencer, et al., 2007; Spencer, Smith, & Billings, 2005; Spencer, et al., 2003).
- Observations and interviews with practitioners as described throughout this dissertation and in Fernandes and Smith (2011a; 2011b).
- Scenario generation stimulated by decisions confronted in exploring potential design solutions (Fernandes, et al., 2010).

Several design concepts guided by these scenarios and examples were embedded into an airport surface simulation environment designed and developed in concert with this research (Fernandes, Smith, Spencer, Wiley, & Johnson, 2011; Smith, et al., 2011).

In addition, structured interviews and concept evaluation activities were facilitated by memory aids such as airport diagrams illustrating a facility where a participant had worked. These interviews and concept evaluation activities were conducted remotely using web conferencing software.

This chapter will discuss the tools in general and provide some examples, while discussion of tools in later chapters will focus on specific tools used to discuss or evaluate particular information requirements and/or design solutions.
Scenarios and Examples

Scenarios and use cases are important in human-centered design (Carroll, 2000; Smith, Stone, & Spencer, 2006) and proved useful in this project. Scenarios were derived from several sources, including the literature (Atkins, Brinton, & Walton, 2002; Brinton, Lent, & Provan, 2010; Obradovich, et al., 1998; Smith, Beatty, Spencer, & Billings, 2003; Spencer, et al., 2007; Spencer, Smith, & Billings, 2005; Spencer, et al., 2003), observations and interviews such as those described by Fernandes and Smith (2011a; 2011b), and goals of departure management (Fernandes, et al., 2010). Specific scenarios and examples encountered and developed are discussed throughout this dissertation in the context of the concepts they are used to illustrate.

The scenarios and examples were used to develop and refine a user model of the Departure Reservoir Coordinator responsible for managing a departure metering procedure (Surface CDM Team, 2011). User models are useful in designing features of a procedure and/or software tool by situating the features in the context of a user trying to accomplish one or more goals (Carroll, 2000; Smith, Stone, & Spencer, 2006; Suchman, 1987). Scenarios and use cases highlight the complexities of the domain and the difficulties of the user’s tasks (Carroll, 2000), thereby allowing the designer to ensure that the design facilitates a broad spectrum of user needs.

Hypothetical Major Airport (MJA)

Although the examples observed in situ or related by practitioners were situated at the respective airports and/or airspaces at which they occurred, they were often mapped to a hypothetical airport, Major Airport (MJA). A diagram of MJA is shown in Figure 8 on page 59 above. Mapping scenarios and stories to MJA allowed multiple practitioners

---

4 Major Airport was designed by Philip J. Smith, Ken Durham, Charles Billings, Mark Evans, Eric Wiley, and Amy Spencer.
with experience at different facilities to be presented with the same dilemmas during concept evaluation activities.

To situate the airport and provide further context for problem solving, MJA was located roughly at the site of Dallas-Fort Worth International Airport (DFW). In all scenarios presented to participants in concept evaluation activities, the airport was in a south configuration with departures on runways 18C and 18L and arrivals on 18R. Winds were at 4 knots from the south and did not shift enough during the scenario to warrant runway configuration changes. The parallel runways were designed to have enough distance between them that they could operate independently from each other. Scenarios involving dynamic weather used actual weather from the Dallas area on July 26, 2010.

To provide additional context, participants in structured interviews and concept evaluation activities had access to a diagram of the Standard Instrument Departures (SIDs) for MJA, shown in Figure 10 (although participants in the departure metering concept evaluation had no need for it). The SIDs formed headings off of the runway with 15 degrees of separation (FAA, 2008). They provided aircraft with routes to departure fixes located 60 miles from the airport, which is atypical for today’s NAS (Borgman, et al., 2010a) but consistent with proposals for an expanded TRACON airspace in the future. The TRACON airspace extended across the 60 miles and included flight level 250 (25,000 feet). The separation minimum was assumed to be 3 nautical miles throughout the TRACON airspace (Borgman, et al., 2010a).

While MJA was useful in situating structured interview questions, it also was important to identify important features of existing airports that would provide different constraints than MJA.
Figure 10. Standard Instrument Departures (SIDs) for Major Airport (MJA).

*Airport Surface Diagrams*

To identify airport characteristics that contribute to surface management strategies and constraints, structured interviews also included questions regarding the participant’s
own airport. To support the participant in answering those questions, an airport diagram of the airport where the participant had most recently worked was provided.

However, static diagrams of airport layouts would not support a full spectrum of concept evaluation activities. Therefore, Major Airport and its SIDs were embedded in a lightweight simulation environment built during the course of the research project (Fernandes, et al., 2011; Smith, et al., 2011).

**Simulation Environment**

Major Airport and its SIDs were embedded in a simulation environment called the Collaborative Airport Traffic System (CATS). CATS is a test bed for identifying and exploring human factors requirements for supporting integrated management of airport surface and airspace constraints (Fernandes, et al., 2011). CATS can be used as a fast time simulation, it can be run with humans playing key roles, and it can be used to create structure for interviews and cognitive walkthroughs (Fernandes, et al., 2011). A sample CATS display is shown in Figure 11. This view shows the airport surface display with a snapshot view of the current departure reservoir state, a weather display, and a tool allowing the user to select aircraft according to characteristics such as departure fix.

CATS facilitates direct comparison of airport performance with and without a departure metering procedure. Without the environmental control allowed in a fast time simulation, identifying “similar” days for comparing performance can be difficult (Nakahara, et al., 2011). The hybrid fast time/human in the loop capability sets CATS apart from other fast time airport surface operations simulations (Malik, Gupta, & Jung, 2010; Parasuraman, Hansman, & Bussolari, 2002). Its lightweight nature sets it apart from high fidelity simulations such as Future Flight Central (Dorighi & Sullivan, 2003).

---

5 Several members of the research team, in addition to the author, participated in the design and development of CATS, including Philip J. Smith, Dustin Johnson, Amy Spencer, Garth McMurray, Mark Evans, Roger Beatty, Ken Durham, Eric Wiley, and Kristen Weaver.
allowing faster setup and greater flexibility in the number of human agents involved in a simulation run. CATS facilitates concept evaluations using a variety of approaches, including:

- Running fast time simulation scenarios to demonstrate airport performance differences under different surface management strategies and procedures.
- Static displays (screen captures) to structure interviews (Fernandes, et al., 2011).
- Running the simulation to structure interviews such as those described in Chapter 4.

The concept evaluation activities that used the simulation to structure interviews are discussed in Chapter 4. That discussion includes specific examples of display configurations used in those concept evaluation activities.
The displays used in concept evaluation activities with practitioners represent a series of design decisions, from the selection of color codes to salient yet unobtrusive cues (Baecker, et al., 1995) designed to allow the Departure Reservoir Coordinator to:

- Gauge performance of the departure metering procedure relative to goals.
- Detect changes in airport departure performance and changes in constraints that are likely to impact airport departure performance.
- Anticipate changes in airport departure performance and changes in constraints that are likely to impact airport departure performance.

Particularly challenging was the desire to develop integrated displays to provide the DRC with information about current and future constraints in both time and space. The compromise was to use separate windows for distinct sets of information but to integrate them in function, such as to highlight information in all displays where it appeared when some item was selected for highlighting in one of the displays. For example, selecting a route in the selection tool on the left hand side of Figure 11 would highlight all aircraft on the surface display filed to that route as well as in the list of flights (not shown). Similarly, selecting an aircraft icon on the surface display would also highlight that flight in the list of flights. This represents a kind of functional grouping that highlights relationships among the selected elements (Smith, Stone, & Spencer, 2006) and uses a model for display integration suggested by Spencer, et al. (2007). To the extent possible, the CATS displays were designed to conform to good usability practices (Smith, Stone, & Spencer, 2006; Smith, et al., 2011).

CATS also was useful in concept exploration and development. Developing a computational model of a concept requires the designer to examine that concept in greater detail than might otherwise occur (Newell, 1990). The process of building and testing a computational model exposes weaknesses in the concept as well as conceptual issues indicating that there may be multiple valid design approaches. Several such issues were discovered in the process of building CATS.
For example, multiple algorithms for computing and allocating target spot times to flights and flight operators were instantiated in CATS. One instantiation was a strict ration by schedule assignment in which target spot times were assigned to aircraft solely based on the order of their scheduled push back times. The ration by schedule paradigm has been accepted by the Collaborative Decision Making community as an equitable approach to rationing capacity exceeded by demand (Wambsganss, 2001). A second instantiation represented a “ration by route” approach in which aircraft with earlier scheduled push back times were assigned earlier target spot times except when doing so would create a departure queue with greater demand for a given route than expected capacity on that route. However, the “ration by route” approach requires a new definition of equity that considers the appropriate delay to assign to aircraft currently filed for a constrained route as well as the appropriate change in delay for a flight whose filed route is changed from a constrained route to a less constrained route. This dilemma may not have been discovered if the algorithm had not been programmed into CATS.

A similar question arose when the design team was considering how to adjust the departure metering parameters when the departure reservoir was or was anticipated to be larger or smaller than the target (beyond some threshold distance from the target). There are several possible approaches to compute the necessary adjustment to return the departure reservoir to its target size. For example, the algorithm could attempt to minimize the number of aircraft whose target spot times were adjusted or it could minimize the adjustment made to any given aircraft’s target spot time.

Additionally, developing a computational decision-making model of metering enforcement identified some open questions. If an aircraft arrived to its spot earlier than the start of its target spot time window, the CATS ground controller could simply deny that aircraft entry to the active movement area until the start of its target spot time window. However, if an aircraft that arrived to its spot on time was queued behind the early aircraft, it would not be fair to require it to wait for the flight that arrived early if the non-compliant flight’s target spot time window opened later than the compliant flight’s.
A human ground controller held responsible for enforcing target spot time windows might move the early aircraft to a “penalty box” on the active movement area where it would not be in the way of compliant aircraft. However, without the sophisticated decision-making and adaptation capability of a human ground controller, it is not trivial to identify a suitable secondary location and to move the non-compliant aircraft to that location so it can wait for its target spot time window to arrive.

Similarly, implementing even a simple ground controller proved non-trivial. A ground controller with only one strategy, to prevent having a final departure sequence with back-to-back flights to the same departure fix, has many opportunities to create a suitable departure sequence. Such a ground controller could create a sequence solely by selecting the order in which aircraft are allowed to enter the active movement area. However, such a strategy might require some aircraft whose spots were close to the runway to wait longer than would be realistic while another aircraft taxied from a more distant spot. This hints at how difficult it can be to reliably predict taxi-out times (Balakrishna, Ganesan, & Sherry, 2008; Gong, 2009), even in a simulated environment. As a result, a semi-greedy algorithm was implemented in which aircraft generally were allowed to enter the active movement area in the order in which they arrived to a spot. When more than one aircraft arrived to a taxiway intersection, the aircraft that was earlier in the schedule was selected to proceed first. However, the order of aircraft in the sequence may not be the same as the order in which they entered the active movement area if they arrived to intersections at different times.

CATS was used in the structured interviews and concept evaluation study described in Chapter 4. All of these evaluations were performed with remotely located participants via a web conferencing service.
The GoToMeeting desktop web conferencing software and service – a form of groupware (Baecker, et al., 1995; Olson & Olson, 2000) – were used to facilitate distributed concept evaluation. The way the groupware was used varied by activity.

In the ATCT surface management decision making study (described in Chapter 4), the service was used to present representations of weather-related airspace restrictions to individual surface traffic management experts. The experts then answered structured interview questions, via voice, to explain what airspace and surface management strategies they would use to maintain departure throughput despite the airspace restrictions. Individual air traffic control experts in the departure metering concept evaluation study (also described in Chapter 4) used the desktop sharing feature of GoToMeeting to remotely perform the Departure Reservoir Coordinator role in the CATS simulation environment. In the air traffic management decision making study, the service was used to share current and forecast weather images with two remotely located air traffic management experts. The groupware allowed both experts to view the weather images simultaneously and discuss the airspace restrictions they expected would be required as a result of the weather systems they observed.

Performing concept evaluation activities with remote participants influenced the design of those activities for many of the reasons that groupware and distance often influence distributed activities (Baecker, et al., 1995; Olson & Olson, 2000).

For example, the size of the computer screen that could be used to present information to the participant was limited by the use of groupware and lack of control over the computer used by the participant. The DRC might be expected to have access to multiple monitors for displaying information and controls required to manage a departure metering procedure, but the groupware prevented the use of multiple monitors. The

---

6 www.gotomeeting.com
limited screen size required us to focus on the highest priority displays for supporting the tasks and roles of interest. This led to decisions to scope the activities, such as to task participants in the departure metering concept evaluation study with managing the departure metering procedure for only one runway instead of for the entire airport.

Chapter Summary

The main functions of the tools used in this research were to explore and refine the design concepts and to structure interviews in concept exploration and evaluation activities. Scenarios derived from the literature and from observations and interviews with practitioners formed the basis of design and evaluation activities, focusing the design process and structuring evaluation activities. In particular, they were used to develop a user model of the Departure Reservoir Coordinator and to orient other design activities according to that model (with consideration for other roles in the system).

A hypothetical airport further situated design and evaluation activities, allowing multiple practitioners from different airports to consider the same dilemmas. Practitioners also were given the opportunity to examine concepts in the context of the airport where they had most recently worked, describing strategies they used and noting key characteristics that set their airport apart from others (including the hypothetical airport). Airport diagrams for the airport in question were used to situate these discussions.

The CATS simulation used to present concepts and displays to study participants embodies hypotheses about useful and usable displays to support the DRC (Fernandes, et al., 2011) as well as prototype algorithms for managing a departure metering procedure. The process of designing and developing CATS posed several challenges and design questions that may not have otherwise been identified and that encouraged the design team to push the concept definition further as a result.
In addition, the lightweight nature of CATS allowed it to run on a single computer and be shared with a remote computer via a web conferencing service for concept evaluation activities. Using the web conferencing service for concept evaluation constituted a distributed approach to distributed work research and created constraints that influenced the design of concept evaluation tasks and displays. The various concept evaluation activities are discussed in detail in the next chapter.
Chapter 4: Research Methods and Results

This research has taken a multi-faceted approach to understanding traffic management on the airport surface. Activities have included literature reviews, observations of people at work, unstructured and structured interviews of experts in the domain, as well as a pilot study to explore and assess potential design solutions.

This chapter describes the activities undertaken to perform this research. Each activity helped to identify and explore various strengths and gaps in the current state of knowledge, technology, and processes in traffic management on the airport surface.

Observation of Practitioners in the Air Traffic Management System

A key component of understanding the various complexities in a joint cognitive system is to observe the system in action (Hutchins, Cognition in the Wild, 1995a; Smith, Stone, & Spencer, 2006; Hoffman, et al., 1995; Suchman, 1987; Woods & Hollnagel, 2006). Observations were carried out at various kinds of facilities. The typical facility visit involved a tour of the facility and time spent observing practitioners during a period of time when they were expected to be busy. The observer(s) opportunistically asked questions when the practitioners experienced a lull in operations (in particular, when they were not actively controlling aircraft). These questions typically focused on observed events, displays, and behaviors, particularly related to surface management strategies and interactions with other organizations. Questions also involved recall of incidents when surface management (or air traffic management for TRACON and ARTCC facilities) and/or coordination were difficult, such as during severe weather events.
Personnel in the following kinds of facilities were observed:

- Two ATCTs.
- Two TRACONs.
- Three ARTCCs.
- Two flight operator systems operations centers.
- Four ramp control towers operated by flight operators.
- One Metering Desk operated by an airport operator.

Observing at different kinds of facilities helped the author develop a cross-organizational understanding of air traffic management, including inter-connections between activities on the airport surface and activities elsewhere in the air traffic management system. It also allowed the author to see firsthand some of the challenges faced in air traffic control and management and how practitioners overcome them. While the researcher visited a variety of airport, air traffic control, and flight operator facilities, many practitioners have not had the opportunity to directly observe personnel at work in facilities other than their own.

The observations and interviews contributed to findings that cut across facilities and informed the departure metering procedure concept and support requirements discussed in Chapter 5. Some of the more influential issues are highlighted here.

Gate Availability

Ramp controllers at 2 of the 4 ramp control facilities visited over the course of this work cited gate availability as an issue (Borgman & Smith, 2010). They reported that gate availability often contributed to long departure queues because when the flight operator pushed a departure off of a gate in order to make the gate available to an arrival, the most logical place to “store” the departure was in the runway queue. Gate availability is an issue for many flight operators (Obradovich, et al., 1998) and was observed to
contribute to at least one performance issue in the departure metering procedure at JFK (Borgman & Smith, 2010). Gate availability also was cited as a barrier to implementing a departure metering procedure at other airports both in observations described by Borgman and Smith (2010) and in the departure metering concept evaluation study.

The potential for one or more arrivals’ gates to be unavailable is one source of uncertainty with which personnel must cope. The next section identifies some strategies for coping with uncertainty that were encountered over the course of this project.

Coping with Uncertainty

Surface and air traffic management personnel consistently cope with uncertainty due to a variety of factors (Smith, Beatty, Spencer, & Billings, 2003). Departure schedules are optimized according to a view of the world in which the time a flight spends in the air and on the ground is deterministic (Barnhart, Belobaba, & Odoni, 2003) and aircraft, flight crews, cabin crews, passengers, and cargo all arrive to a departure gate in a timely manner. However, constraints such as weather, traffic volume, aircraft reliability, and crew availability all can cause schedule disruptions to which practitioners must adapt (Smith, Beatty, Spencer, & Billings, 2003).

Ramp controllers in one facility reported that they had to cope with uncertainty not only due to system issues, but also due to behaviors of other agents. They said that distributed personnel had access to several tools that provided information, but that different people might make different decisions based on that information – even if they were in the same role. This phenomenon was observed in the ATCT surface management study discussed later in this chapter, in which participants varied in the surface management strategies they indicated they would use in response to the same departure constraint information. This finding points toward a need for tools that facilitate traffic management personnel communicating their expected strategies to impacted agents.
In addition, personnel at multiple ramp control facilities reported that they attempted to create an efficient sequence of departures leaving the ramp. This was intended to ensure that the departure sequence reflected the flight operator’s priorities. It also might ease ATCT workload. One ramp control facility director said, “We do as much [sequencing] as we can in the ramp… including [sequencing for] miles in trail restrictions… If we don’t do it, [the ATCT will] do it, and they don’t do it the same way” (Borgman & Smith, 2010). Ramp control personnel were explicitly trying to carry out their flight operators’ business priorities in a manner that also allowed ATCT personnel to meet their safety and efficiency priorities. The sequence of departures leaving the ramp area was intended to influence departure sequencing decisions made by the ATCT.

However, ramp controllers at multiple facilities reported that the ATCT often changed the sequences they developed (Borgman & Smith, 2010). This was the only feedback that ramp controllers would receive that their sequence may not correspond to the ATCT sequencing strategy. The ATCT is ultimately responsible for building the departure sequence. There is no one standard procedure by which ATCT personnel share their priorities, constraints, and desirable departure sequence characteristics with ramp control (Spencer & Smith, 2003; Spencer, Smith, & Billings, 2004).

The departure sequence can be viewed as a domain artifact that reflects ramp control priorities when aircraft are leaving the ramp area and may be modified to better reflect ATCT priorities by time aircraft reach the runway threshold. Such artifacts are common in distributed work domains (Nemeth, et al., 2004). The departure sequence may be a more effective artifact for coordination, however, if distributed parties were aware of each other’s priorities in building or modifying the sequence. However, communications were observed between ATCTs and ramp control personnel at two other airports in which the ATCT indicated to the ramp control tower how it wanted to manage the airport surface (Borgman & Smith, 2010). (The issue of communicating surface management strategies is revisited in Chapter 5 in the context of building a departure reservoir that meets ATCT departure needs.) Regardless of whether ATCT surface management
strategies are told to or inferred by ramp control personnel, ramp control personnel develop their own strategies for managing the flow of departures from the gates under their control to the active movement area.

**Use of Airport Surface Surveillance Systems**

Airport surface surveillance systems were observed at several different facilities. They have been credited with supporting ATCT personnel in surface traffic management (Spencer, Smith, & Billings, 2004; Spencer, et al., 2002), with supporting coordination and collaboration between ATCT and airspace air traffic management personnel (Fernandes & Smith, 2011b), and with supporting ramp control personnel (Fernandes, Weaver, & Smith, 2012; Spencer & Smith, 2003; Spencer, Smith, & Billings, 2005). As with many technologies, some people have found surprising ways to use them.

ARTCC traffic managers’ decision-making often is influenced by the status of the airport surface but they typically do not have a direct view of the surface. Instead, they depend on information from ATCT personnel provided via telephone. ARTCC traffic managers with access to a surface surveillance display reported that it enabled them to build a better situation model that helped them to better anticipate future demand for their airspace and to made decisions accordingly (Fernandes & Smith, 2011b).

The surface display allowed traffic managers to make earlier, more precise predictions about when demand for a specific departure route would exceed capacity. They could “ask the guys in the ramp tower to space them out a little bit coming out,” said one ARTCC traffic manager, rather than invoke a traffic management initiative such as a miles in trail restriction that might decrease capacity more than necessary to manage ARTCC sector controller workload. The traffic manager could then monitor traffic flows via the surface display and very quickly evaluate whether the informal restriction was likely to be sufficient (Fernandes & Smith, 2011b). This illustrates one way in which
direct knowledge of surface status can influence air traffic management decision making, which in turn has a direct impact on surface traffic.

Traffic managers at a consolidated TRACON reported using displays showing the active movement areas of the major airports in their airspace for the following:

- To “find airplanes.”
- To “see how busy they are. Are they getting backed up on the departures?”
- “It helps us understand what they’re doing. It helps us understand their lack of flexibility in the lineup.”
- “It helps us see where they’re bunched up [on the surface and whether] we need to re-evaluate our departure restrictions.”
- “It tells us who [which airport] we need to favor, how long it will take to get them out of gridlock.”
- It “is an informational tool that a person can look at and say I can’t forget about [X]” (external memory aid).

Surface surveillance displays also used color-coded aircraft icons and data blocks to draw users’ attention to high-priority aircraft (Smith, Stone, & Spencer, 2006; Fernandes & Smith, 2011b). Such aircraft often had crossed some threshold in the time they had spent active relative to tarmac delay regulations (Department of Transportation, 2009), had a crew in danger of timing out, or were carrying a passenger marked as a Very Important Person (Fernandes & Smith, 2011b). Multiple ramp control managers said that viewing the aircraft’s location on the surface display allowed ramp control personnel to “see if there’s a way to get him [airborne]” or “start working on getting him back to the gate” to ensure that passengers would have the opportunity to deplane before the three hour tarmac delay limit (Fernandes & Smith, 2011b).

One ARTCC and the ramp control facility for the dominant flight operator in that area embedded asynchronous communications in the surface surveillance display to
coordinate pre-departure route amendments (Fernandes & Smith, 2011b). The region often experiences highly dynamic weather events that are characterized by high levels of uncertainty in the availability of departure routes over periods as small as 15-30 minutes. At times, said a ramp control manager, “a departure gate suddenly closes and there are a lot of departures.” An ARTCC traffic manager said that the alerts and data blocks discussed above were the inspiration for customizing the software to speed coordination during such dynamic weather events (Borgman & Smith, 2010).

One reason the surface surveillance display observed to be shared between the ramp control facility and the ARTCC was useful for facilitating coordination was that its content was relevant to all parties. It helped the distributed agents build and maintain a shared traffic situation model under conditions of extreme uncertainty (Fernandes & Smith, 2011b). Personnel credited the display with reducing the workload associated with coordinating pre-departure route amendments. It also helped agents coordinate activities that they could perform relatively independently of others (Fernandes & Smith, 2011b; Smith, 2011). It also allowed a better distribution of knowledge and data relative to roles and responsibilities (Fernandes & Smith, 2011b; Smith, Spencer, & Billings, 2007).

Ramp controllers were observed to use surface surveillance displays in many aspects of their work. They were observed to use the display as an external memory aid (Obradovich, et al., 1998; Spencer, et al., 2003). Some also had graphical ramp control displays that allowed them to track which gates were occupied, which flights were scheduled to depart soon, and which flights were actually ready to push back (Borgman & Smith, 2010; Spencer & Smith, 2003; Spencer, Smith, & Billings, 2005). However, they also consistently relied on a view out the ramp control tower window to verify the information they received from the graphical display.

Surface surveillance displays are not without their issues, as noted by Fernandes and Smith (2011b). However, they represent a technology that can facilitate coordination in a distributed work system. Fernandes and Smith (2011b) suggested further research
Coordination Strategies in Departure Management

Departure management strategies used by organizations at different airports represent adaptations personnel in those organizations have made over time to the constraints they face (Woods & Hollnagel, 2006). These constraints are both general to departure management but also specific to their airports. In some cases, personnel have tools that support coordination among different organizations, such as the surface surveillance displays discussed above. In other cases, local personnel have developed strategies for overcoming constraints that are unique to their location. Coordination between ATCT and ramp control personnel, between ATCT and airspace traffic management personnel (TRACON and/or ARTCC), between TRACON traffic managers and traffic management personnel at other TRACON and/or ARTCC facilities, and between ramp control and airspace traffic management personnel all were observed at various facilities. Some examples are provided in this section. All have potential lessons for departure metering procedure design.

Coordination between ATCT and Ramp Control

Ramp control facilities play a vital role in surface management. Two of the four ramp control facilities visited provided ramp control services for all (or nearly all) aircraft arriving to or departing from their respective airports, regardless of flight operator. While the other two ramp control facilities provided ramp control services for only their own aircraft, one operated the vast majority of traffic operating at the airport at certain times and the other was only one of seven ramp control operations moving aircraft at any given time. The proportion of traffic controlled by a given ramp control facility can impact several facets of the organization, including the relationship with the air traffic control organization (Borgman & Smith, 2010).
At one airport the ground controller in the ATCT and ramp controllers were observed to contact each other on a two-way radio to coordinate locations for handing off aircraft to each other. Similarly, at another airport the ATCT would also contact the ramp control facility to request that ramp controllers handed off certain aircraft at certain spots. During one period of observation, the ATCT requested that ramp control “stick all the West and Northgates in the back,” and later were “sending everything that can get out through the back door” (Borgman & Smith, 2010). This enabled the ramp control facility to deliver aircraft to the ATCT such that the ground controller had the right inventory of aircraft in the right locations on the airport surface. It might be difficult to achieve such coordination at an airport with multiple ramp control facilities, particularly if such coordination would require a telephone call from the ATCT to each ramp control facility.

Providing ramp controllers with information about ATCT surface management strategies enabled them to provide an inventory of departures that better matched the strategy (Borgman & Smith, 2010). This implies that information about intended ATCT surface management strategies might be useful to a DRC (Surface CDM Team, 2011) in developing a departure metering plan that would deliver aircraft to the active movement area in a manner consistent with the ATCT’s plan for staging and sequencing departures.

Coordination among TRACON and ARTCC Traffic Managers

In addition to supporting surface management strategies that may vary according to the contingencies for which the ATCT is planning, departure metering procedures should be able to support strategies ATCT personnel use to coordinate departure management with TRACON and/or ARTCC traffic managers.

One TRACON whose airspace was located between two busy ARTCCs developed unique means of coordinating with other airspace facilities in the region when departures were constrained. A TRACON traffic manager there was credited with developing a procedure based on the notion of Coded Departure Routes (CDRs) as a
means of coordinating the use of Tower Enroute Control (TEC) routes with other TRACONs during severe weather events. TEC routes are low altitude routes that keep aircraft below ARTCC airspace and are sometimes used for short flights when regular departure routes are constrained.

The TRACON worked with neighboring airspace facilities and the ATCSCC to develop a Playbook specific to their region that allowed the ATCSCC to tactically coordinate use of these TEC routes. However, the computer system used to communicate departure clearances digitally from the ARTCC to TRACONs and ATCTs, the Departure Spacing Program (DSP), did not have information about these routes and therefore flagged these aircraft as having no route available. “We scan the strip into DSP to let them [the ARTCC] know he’s coming. Because he has no route available, the Center DSP turns it red. But the Center knows we have the [Playbook] activated” and so the ARTCC Traffic Management Unit can note in DSP that the aircraft is cleared on a TEC route.

DSP is a “vital interface between all the towers, TRACON, and the Center. We use it for flight plan processing, as a communications tool, and to ensure the lineup’s to the TRACON,” said one ATCT traffic management coordinator. Because it is such a vital tool it is recommended in Chapter 5 that a DRC and/or departure metering procedure management software have access to its flight clearance data. However, a DRC and/or departure metering procedure management software also would need information about when the clearance data in DSP is overridden by human intervention.

Designs for tools to support a DRC also should support better aligning traffic management coordination decisions with the time at which a flight can actually depart. For example, one TRACON coordinated with a neighboring TRACON to facilitate departures whose routes were unavailable. A traffic manager there explained that if the “westbounds are shut down, [the neighboring TRACON] might be south of the weather. [Say we have a flight to] Chicago. [Its normal route] is closed and he can’t get to [the
A typical offload departure fix. [The flight can take off to the] south from [our airport] toward [the neighboring airport] and then it’s treated like a [neighboring airport] departure.” To invoke the procedure, the constrained TRACON calls the other to say, “I have a Chicago. Can I get [an offload route for the flight]?” If the neighboring TRACON agrees, then the constrained TRACON calls the local ATCT to notify them that this aircraft can get a clearance to the south. But “by time he gets to the runway” the alternate route may not longer be available. If it takes 15-20 minutes for the aircraft to taxi out to the runway, “15-20 minutes is big. The weather might move” in that amount of time.

The amount of time that the offload route remains available may be limited, and therefore the time at which the TRACON requests the route should be well-aligned with the time that the flight can actually get to the runway for departure. A departure metering procedure that limits the number of aircraft in the departure queue can improve information about when a flight joining the queue will actually be able to depart (Borgman & Smith, 2010). Thus, if the flight operator keeps the departure metering procedure management software updated with information about when a flight will actually be ready to request access to the active movement area, the ATCT and/or TRACON may be better able to estimate the time at which the flight will be ready to take off and therefore better time the request for the alternate route. Similarly, when the alternate route is approved it may be easier to expedite the departure of that aircraft if necessary in order to use the available airspace on the alternate route.

Another tool that was observed to be used for coordination among TRACONs and ARTCCs was the Traffic Management Advisor (TMA). While TMA is used for time-based flow management of arrivals, it often applies delays to flights departing from “Tier 1” airports within neighboring ARTCCs to the ARTCC of the arrival airport. For Tier 1 airports, TMA requires a process very similar to the manual Approval Request (APREQ) process discussed by Doble, et al. (2009) and Spencer, et al. (2007). An issue cited by personnel at several different facilities was that aircraft were not issued TMA departure clearance times until after the aircraft was taxiing out.
A departure metering procedure should take into account the delays to which aircraft are subjected due to TMA in order to maintain a satisfactory departure reservoir. If the departure metering procedure is successful in facilitating information sharing (Surface CDM Team, 2011), particularly the time at which a flight will be ready to enter the active movement area, it should be possible to obtain TMA release times before a flight enters the active movement area.

In order to be most effective, departure metering procedure management software should have access to the data used and generated by software used in other aspects of air and surface traffic management. That would require the departure metering procedure management software to overcome software integration issues that were observed at a number of facilities, as discussed in the next section.

Software Integration

A lack of software integration was observed at several different facilities (Borgman & Smith, 2010). Several instances were observed in which a traffic manager or ramp control supervisor viewed information provided by one system and typed that information into another system for purposes of information sharing and reporting. One traffic manager at a different TRACON said that he was responsible for maintaining the same information in several different systems because none of those systems could share the data with each other.

The lack of software integration also required traffic managers and ramp control personnel to use several different monitor screens in order to view the information they needed when it was relevant and mentally integrate that information. This caused entire screens to be ignored, or even turned off, at times when the information provided by the computers to which those monitors were attached was not relevant to the current operation. At the same time, other monitors presented multiple useful pieces of
information and therefore windows on those monitors had to be toggled or shared among multiple displays (Borgman & Smith, 2010).

Designers should be mindful of the tools that already exist in an environment and design their tools to integrate with existing tools where possible. If one system needs data from another, it should be able to read that information directly and pass it on where necessary.

In addition to observing practitioners at work, three sets of structured interviews provided specific information about air traffic management and surface management decision making during severe weather events, as well as feedback on departure metering procedure and Departure Reservoir Coordinator display concepts. A discussion of each of these series of interviews follows.

Air Traffic Management Decision-Making in Dynamic Weather

Weather-related constraints are widely recognized as key contributors to departure delays and strongly influence airport surface management decision-making. Departure airspace restrictions due to weather constraints were generated for use in a simulation study to examine surface management decision making during dynamic weather events. Two retired traffic managers (1 ARTCC and 1 ATCT/TRACON) were engaged in a structured interview in which they evaluated current and forecast weather images from an actual weather event and generated what they believed to be reasonable departure restrictions to cope with the weather. The interview is summarized here.

Participants

This structured interview involved two participants. One was a retired ARTCC traffic management supervisor who had worked at the Kansas City ARTCC, a Level 11 facility (NATCA-FAA Agreement, 2009), for 38 years including 15 years as a sector
controller and 23 years in the Traffic Management Unit. The second worked as an ATCT air traffic controller for 3 years, a TRACON air traffic controller for 22 years, and a TRACON traffic management coordinator for 7 years, all at the Detroit TRACON and the Detroit Metropolitan Wayne County Airport (DTW), a Level 5 ATCT/TRACON facility (according to the old 5-level scale, prior to the scale described in the 2009 NATCA-FAA Agreement). The ARTCC traffic manager had been retired for 3 years and the TRACON traffic manager had been retired for 7 years.

Method

To develop representative weather constraint data for use in follow-on studies, the researcher walked through a series of weather images with the retired traffic managers. The weather images were actual current and forecast weather from July 26, 2010, in the Dallas, TX area. They were generated by the Corridor Integrated Weather System (CIWS) and provided by Dr. Rich DeLaura of MIT Lincoln Laboratory.

The participants were told that the goals of the exercise were to:

- Generate weather-related restrictions necessary to build a realistic simulation scenario.
- Develop detailed planning information for a dynamic weather situation that would help the research team understand what information could aid planning in surface management.
- Gain insight into air traffic management strategies, including the information traffic managers considered in their planning, when they needed that information, and what strategies they used.

The participants were provided an introduction to Major Airport (MJA) and its surrounding TRACON airspace using the images shown in Figure 8 on page 59 above and Figure 12 below. They were told that the airport was located in roughly the same location as Dallas/Fort Worth International Airport (DFW).
Participants were told to assume that only departures from MJA would be using the Standard Instrument Departures (SIDs) shown in Figure 12 and that no arrivals would deviate into any of the MJA SIDs. In addition, they were to assume that there would be no overflights using the airspace surrounding MJA. These assumptions served to simplify the problem space. However, participants were told that if arrivals’ behavior would influence their thinking they should state that to be the case.
The quantity and magnitude of flight deviations are key indicators to traffic managers that route availability has become constrained. In addition, traffic management personnel reported that sometimes flight crews reported turbulence and other airspace disruptions that were not visible on weather displays (Borgman & Smith, 2010). However, there was insufficient information available about traffic demand for the routes to allow the participants to use actual deviations in their decision making and pilot reports for the airspace in question were unavailable. Therefore, participants were asked to provide their best estimate of when they would expect flights to start deviating around the weather systems and to use that as the time when they would put in restrictions.

Weather data was updated every 5 minutes and forecasts were provided in 15-minute increments. The researcher asked the participants to generate the departure route restrictions they thought they would put in place given the weather data. They also were asked to discuss their expected traffic management strategies and recommendations.

Table 1 shows example traffic management restrictions defined for the participants. All restrictions applied to a departure fix, a set of departure fixes, or a departure direction. The participants were expected to generate start and end times for all restrictions. The start time could be the current time or they could generate a restriction they expected to be required at some future time. For example, if the current time was 1700Z, then the restriction on the Wiley departure fix shown in the first row of data in Table 1 would start immediately. The restriction on Wiley shown in the second row of data in Table 1 would be expected to start in 45 minutes at 1745Z, and the restriction shown in the third row of data would be expected to start 75 minutes from now at 1815Z. Participants were encouraged to generate predictions for a 2-hour planning horizon when possible to facilitate surface and departure management planning activities.

Further, participants were told that a miles in trail restriction applied to two departure fixes, such as 15 miles in trail on Wymon and Phils, meant that the fixes represented two separate streams. Each stream would require 15 miles in trail. However,
Table 1. Examples of departure fix restrictions provided to participants.

<table>
<thead>
<tr>
<th>Departure Fix(es)</th>
<th>Start</th>
<th>End</th>
<th>Restriction</th>
<th>Required / Expected?</th>
<th>Probability of Extension</th>
<th>Reason</th>
<th>SWAP / Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>WILEY</td>
<td>1700z</td>
<td>1745z</td>
<td>15 MIT</td>
<td>Informal</td>
<td>HIGH</td>
<td>WX</td>
<td>Isolated cell moving south</td>
</tr>
<tr>
<td>WILEY</td>
<td>1745z</td>
<td>1815z</td>
<td>15 MIT</td>
<td>EXPECTED</td>
<td>HIGH</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WILEY</td>
<td>1815z</td>
<td>1900z</td>
<td>CLOSED</td>
<td>EXPECTED</td>
<td>MODERATE</td>
<td>WX</td>
<td></td>
</tr>
<tr>
<td>WORTH and WICKR</td>
<td>1700z</td>
<td>1800z</td>
<td>OPEN</td>
<td>EXPECTED</td>
<td>MODERATE</td>
<td>WX</td>
<td></td>
</tr>
<tr>
<td>WORTH and WICKR</td>
<td>1800z</td>
<td>1900z</td>
<td>20 MIT as 1</td>
<td>EXPECTED</td>
<td>MODERATE</td>
<td>WX</td>
<td></td>
</tr>
<tr>
<td>WYMON and PHILS</td>
<td>1700z</td>
<td>1800z</td>
<td>20 MIT as 1</td>
<td>REQUIRED</td>
<td>HIGH</td>
<td>WX</td>
<td></td>
</tr>
<tr>
<td>WYMON and PHILS</td>
<td>1800z</td>
<td>1900z</td>
<td>20 MIT</td>
<td>EXPECTED</td>
<td>LOW</td>
<td>WX</td>
<td></td>
</tr>
<tr>
<td>NORTH</td>
<td>1700z</td>
<td>1800z</td>
<td>CLOSED</td>
<td>REQUIRED</td>
<td>HIGH</td>
<td>WX</td>
<td>NOBLR, HELV expect WILEY, WORTH, or WICKR NIKKY, NEXAR expect BEATY</td>
</tr>
<tr>
<td>NORTH</td>
<td>1800z</td>
<td>1900z</td>
<td>CLOSED</td>
<td>EXPECTED</td>
<td>MODERATE</td>
<td>WX</td>
<td>NOBLR, HELV expect WILEY, WORTH, or WICKR NIKKY, NEXAR expect BEATY</td>
</tr>
</tbody>
</table>

if Wymon and Phils were restricted to 15 miles in trail as 1, then the two fixes would be treated as a single stream of traffic such that any two flights to either Wymon or Phils or a flight to Wymon followed by a flight to Phils would require 15 miles in trail.

Participants also were told that “required” restrictions were typical miles in trail restrictions or fix closures like they would encounter in the NAS today. However, two additional kinds of restrictions were defined. “Informal” restrictions represented instances when the ARTCC might call the TRACON or the TRACON might call the ATCT to request that the facility “slow them down a bit,” but they would not implement a formal miles in trail restriction. In the scenario, these “informal” restrictions would show a number of miles in trail to indicate magnitude, even through the phone requests they were designed to represent typically do not involve discussion of miles in trail. “Expected” restrictions would represent what the participants anticipated happening in the future. However, the researcher stressed that an “expected” restriction represented what the
participants thought would happen, but if conditions changed, then they were free to change the restriction before it came time to implement it. In addition, the participants were asked to estimate the probability of extension for each of their expected restrictions, even though the probability of extension is typically only estimated by the ATCSCC.

In generating departure fix restrictions, the participants were asked to think about several questions regarding what information they would be able to pass to the ATCT and flight operators about what they might do, including:

- What contingencies are you planning for?
- What would you advise ATCT and flight operator personnel to be prepared for?
- What are you likely to tell the TRACON, ATCT, and/or flight operators?
- What are things the FAA currently may not have a vocabulary for, but that could help ATCT and flight operator personnel in their planning?
- If you want to put in a miles in trail restriction, what is the location in the airspace where you expect that amount of separation to be achieved?

The weather images were embedded in the CATS simulation environment (Fernandes, et al., 2011). The researcher stepped through the weather scenario from 1500Z to 0000Z, stopping every 30 minutes to allow the participants to view the 2-hour forecast in 15 minute increments. For example, the researcher paused the simulation at 1800Z (see Figure 13) and asked the participants to consider whether they would modify any of their existing traffic management strategies based on the current weather.

The researcher then showed the participants the forecasts for 1815Z, 1830Z, 1845Z, 1900Z, 1915Z, 1930Z, and 1945Z, and 2000Z (see Figure 14). After viewing the current and forecast weather for that time period, the researcher asked the participants whether they would modify any of their traffic management strategies based on the forecast weather.
Figure 13. Image of current measure of VIL at 1800Z.

Figure 14. Series of weather images representing the 2-hour forecast at 1800Z.
After discussing all of the forecasts and recording the participants’ departure restrictions, the researcher advanced the simulation until 1830Z. The participants could view forecasts as many times as they liked. However, they could not view past weather.

**Apparatus**

In addition to CATS and the weather data discussed above, the interview took place with both participants simultaneously using the GoToMeeting service and a separate telephone conference line provided by FreeConference. Participants were able to view the researcher’s computer desktop. Audio of the meeting was recorded using Audacity software. These tools are discussed in Chapter 3.

**Results**

For each time period, the participants collaborated on an appropriate set of departure constraints for each direction given the weather forecast. The constraints generated for all time periods are provided in a series of tables that are similar to Table 2 below. Results from some of the time periods are discussed here for illustration.

As an example, the restrictions the participants generated at 1800Z are shown in Table 2. The ARTCC traffic manager had closed three eastbound fixes at 1730Z, expecting all flights planning to depart to the Creak, Treat, or Beamr departure fixes to instead depart to Eartz. Upon seeing the weather forecast at 1800Z, he extended that closure to 2000Z with a high probability of extending it even further because of the line of storms to the east of the airport. In addition, the ARTCC traffic manager said he would need 15 miles in trail on Beaty and Eartz (the two northern-most eastbound departure

---

7 www.gotomeeting.com
8 www.freeconference.com
9 audacity.sourceforge.net
Table 2. Departure restrictions participants generated at 1800Z.

<table>
<thead>
<tr>
<th>Departure Fix(es)</th>
<th>Start</th>
<th>End</th>
<th>Restriction</th>
<th>Required/Expected?</th>
<th>Probability of Extension</th>
<th>SWAP / Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eastbound as 1</td>
<td>1800</td>
<td>2000</td>
<td>5 MIT off ground</td>
<td>Required</td>
<td>High</td>
<td></td>
</tr>
<tr>
<td>Creak, Treat, Beamr</td>
<td>1730</td>
<td>2000</td>
<td>SWAP in effect. Closed.</td>
<td>Required</td>
<td>High</td>
<td>Creak, Treat, Beamr move to Eartz</td>
</tr>
<tr>
<td>Beaty and Eartz</td>
<td>1800</td>
<td>2000</td>
<td>15 MIT at handoff.</td>
<td>Required</td>
<td>High</td>
<td></td>
</tr>
<tr>
<td>Phils, SMITH, Evans, Alisa, Chasz</td>
<td>1600</td>
<td>2000</td>
<td>15 MIT at handoff. 10 MIT off ground.</td>
<td>Required</td>
<td>High</td>
<td></td>
</tr>
<tr>
<td>Whalt and Wymon as 1</td>
<td>1800</td>
<td>2000</td>
<td>SWAP in effect. Whalt closed</td>
<td>Required</td>
<td>Moderate</td>
<td>Whalt moved to Wymon</td>
</tr>
<tr>
<td>Wiley, Wickr, and Worth as 1</td>
<td>1800</td>
<td>2000</td>
<td>SWAP in effect. Wickr and Worth Closed</td>
<td>Required</td>
<td>Moderate</td>
<td>Routing all traffic over Wiley</td>
</tr>
</tbody>
</table>

fixes) at the location where the TRACON handed those aircraft off to the ARTCC because of the expected movement of the isolated cell southeast of the airport.

In addition to the ARTCC requirements, the TRACON traffic manager said he would require all eastbound departures to depart on the same heading with 5 miles in trail off the ground, often measured by the spacing between any two aircraft to that heading at the time of the first radar hit of the trailing aircraft. This was because only one departure heading appeared to be unaffected by the storm cell to the southeast of the airport. He said that with this restriction, the ATCT should alternate departure headings off of the runway (e.g., northbound, eastbound, southbound, eastbound and no two eastbound flights in a row). He said, “They can keep launching at 5 miles in trail as long as they alternate departure fixes.”
Since 1600Z, the ARTCC traffic manager had required all of the southbound departure fixes to have 15 miles in trail at the location where the TRACON handed them off to the ARTCC, and he expected that restriction to continue until 2000Z with a high probability of extending it even further. This restriction represented a constraint that he expected the neighboring ARTCC would pass to him (through the ATCSCC) because of weather in their airspace. To achieve 15 miles in trail at the handoff, the TRACON traffic manager said he would need aircraft to have 10 miles in trail off the ground.

Westbound route availability changed frequently and during this time period the ARTCC traffic manager expected Whalt to be closed with all aircraft planning to depart to the Whalt departure fix rerouted to Wymon. Similarly, he expected Wickr and Worth to be closed and all aircraft planning to use one of those routes would be rerouted to Wiley. His plan was to route Wiley traffic to the north of the severe weather and the Wymon traffic to the south of it. He expected both of those restrictions to remain in effect until 2000Z, with a moderate probability of extension beyond that time. Upon observing the forecast for the weather to the west of the airport, he said, “The way that’s moving it could be out of there in a couple of hours.” No restrictions were expected on northbound traffic. One participant said, “North is still good.”

In the process of collaborating on a set of departure restrictions for each time period, the participants discussed their justifications for the restrictions they proposed. This reflects one benefit of an approach to data collection in which participants are required to work together. The dyad influences them to verbalize aspects of their thought processes, including the data they are intentionally attending to and how they justify their actions based on that data (Woods & Hollnagel, 2006).

For example, when the participants viewed the current and forecast weather for 1800Z (Figure 13 and Figure 14), they discussed how they expected the weather west of the airport to impact the departure routes. An excerpt from the interview is shown in Figure 15. It illustrates the flow of the interview, the nature of the conversation between
the two practitioners as they generated route restrictions, and some of the data they attended to in making those decisions. In the figure, “ARTCC” replaces the name of the ARTCC traffic management participant, “TRACON” replaces the name of the TRACON traffic management participant and “OSU” replaces the name of the interviewer.

**ARTCC**: Yeah, based on the forecast even, Wymon… I think I would leave it open and put 15 [miles] in trail on the Wymon but I would close [Whalt and Worth], close both of them, and move their traffic to, uh, some to Wymon and some to Wickr and Wiley. ‘Cause that’s, they’re almost immediately getting into some pretty heavy weather there…

**TRACON**: What would you do? Would you run, like, Whalt over Wymon and Worth and Wickr over Wiley, split it that way?

**ARTCC**: Yeah.

**TRACON**: So we’ll have 2 swaps out to the west now [OSU]. Whalt will be running over Wymon, and Worth and Wickr will run over Wiley, so all the departures will go out Wiley and Wymon. … We’re keeping Wymons open, we’re moving Whalt over Wymon. So Whalt and Wymon are as 1 over Wymon. Whalt’s closed.

**OSU**: Whalt is [closed], okay. Alright, and then the second [restriction] is with Wiley, Wickr, and Worth as 1?

**TRACON**: Correct. Worth is closed, running all the traffic over Wiley.

**OSU**: Okay, so, would you start both of those immediately?

**ARTCC**: Yes.

**OSU**: And how long would you expect them to continue?

**ARTCC**: I think all the way to 2000.

**OSU**: Ok. Um, and then what would you say is the probability of extension?

**TRACON**: What do you think, [ARTCC], maybe moderate on that one the way that that’s moving it could be out of there in a couple hours?

**ARTCC**: Yeah, yeah. We could open, you know, in a couple hours we could open [Wymon, Whalt, and Worth], maybe.

**TRACON**: Yeah. As that system moves north, unless that south one starts building and closing up, we would just be opening fixes as it ran over the fixes behind it, [OSU], as it moves north. I don’t know if that one to the south is going to cause us more trouble.

Figure 15. Excerpt from interview highlighting collaboration between participants.

123
The data that the participants attended to most frequently were the location and intensity of the current and predicted weather and the restrictions that were already in place. However, they said that in practice they would expect a great deal of feedback that was not available to them in this setting. In particular, the participants said that in practice they relied on feedback from sector controllers and made adjustments to their traffic management strategies based on that feedback. The TRACON traffic manager said:

You’re constantly getting feedback from controllers and the towers about whether the pilots are taking the routes and [if there is] anybody balking or turning back and we would be adjusting on that on the fly. But you have a kind of cookbook in the way you’re set up [so] that you never get any feedback about what the planes are actually doing.

This is consistent with what other ARTCC traffic managers reported. They use weather forecasts to anticipate which sectors and routes are most likely to be restricted but they typically wait to impose restrictions until they receive reports of flight crews requesting deviations (Borgman & Smith, 2010). The participants did not have access to views of actual traffic flows showing aircraft deviations or other forms of feedback. As a result, the participants cautioned that they might be providing conservative estimates and over-restricting departures. The TRACON traffic manager said:

There’s no feedback happening here so we’re putting things out there almost in a worst case scenario… We’re being very conservative. Normally, you’d let some stuff fly into that, but we just don’t know what to expect, and what’s going to really happen. Just to be clear that we’re being a little bit different [from how we would be in the real world].

If the departure restrictions generated by the participants reduce capacity more than what would be the case in practice, follow-on studies using these restrictions as a basis for a departure scenario may overestimate departure delays and produce greater demands on a departure metering procedure.
However, the participants made these comments relatively early in the scenario, before the weather drastically deteriorated. As the weather deteriorated their restrictions became less conservative and they began to use a strategy of attempting to keep at least one route open in each direction. For example, the current weather for 1900Z is shown in Figure 16. Intense weather threatened departure routes to the east, south, and west. An excerpt of the practitioners’ conversation when determining how to respond to the weather to the east of the airport is provided in Figure 17.

![Figure 16. Current VIL image from 1900Z.](image)

As uncertainty in the weather increased the practitioners expressed more certainty in the capacity restrictions they generated than in their plans for managing the airspace. For example, by 1930Z they were confident that they would require 15 miles in trail (off the ground) on all eastbound flights (as 1) until 2130Z. The TRACON traffic manager thought aircraft would use the Brews heading until 2030Z, but he noted that they may have to vary the heading as the weather moved:
ARTCC: That weather to the east didn’t move. It actually filled back in behind it.

TRACON: Yeah, it grew. Yeah... we’re probably going to be done with the eastbounds; we probably won’t be able to get around them. Yeah, just internally in the TRACON, I don’t think we’ll be able to get east. ... The Center’s going to be having conflicts with arrivals, and so will we. So, uh, I think we’re going to have to shut off the east bounds internally.

ARTCC: Uh, [TRACON], is there any way that you could get some of the eastbounds to the north?

TRACON: You know I was looking at that. I was debating that. Um, what made me hesitate is the headings they’d have to take to go that way. ... I’m worried about that Level 3 and 4 stuff that’s just, uh, what is that, 20 miles from the airport? They’d have to be able to turn inside it and they’d have to take that heading from us and I can see them balking at that. Yeah, that is an option. We might be able to run to the north and, um, and get them back around onto Beaty/Eartz, or, it’s a possibility. Yeah, let’s go with what [ARTCC] said. I think he’s right. We’ll keep the eastbounds as 1. ... They’ve got to be 10 in trail off the ground no matter what fix... But what they’re probably going to have to do is put them on the Brews heading... and that could easily change as that moves... closer to the airport. Yeah, that’s about our only available heading. All the eastbounds as 1, 10 [miles] in trail, out the Brews heading. Good call, [ARTCC].

OSU: ... Okay, so [ARTCC], would you make any changes to any of these, um, swaps that you put in?

ARTCC: ...You could go from Brews and we could get them back on course to Beaty as the only fix east but... I think I’m going to want 20 [miles] in trail based on this scenario out here because it’s not going to be easy to get through that. I don’t know... You’ve got a pretty good restriction on the tower right now. Would that end up giving me 20 [miles] in trail?

TRACON: Um, keeping both routes open but 20 [miles] in trail?

ARTCC: I want to go to one route, uh, Beaty only. ... Yeah, I don’t think they would want to use Eartz now.

TRACON: ... I don’t know. We’re going to have to change. My internal restriction’s going to change based on that, [OSU]. I’m going to go to 15 [miles] in trail off the ground then...

ARTCC: You know, in real life, there’d be a good chance that we wouldn’t even be taking anything out east, but we’re going to, we’re going to try that. We’re going to try to keep one route open but have good in trail so we can- Uh, [TRACON] can still come off, get up around the north side of this, and I can still put some planes through this. Controllers are going to be screaming, and pilots.

TRACON: Yeah, absolutely. Yeah, companies are going to be calling. That’s the way it is. Yeah, I think that’s good, 20 in trail, one route, and be prepared to shut it off completely at some point.

Figure 17. Excerpt of participants’ deliberation at 1900Z.
The 15 [miles] in trail for at least an hour, but again, the headings are going to be changing. If I’m not able to use any heading other than Brews, or if I can’t turn sooner than Brews, we may just end up shutting them off completely. Or, what we may end up doing is running them down south on the Evans or Alisa heading and possibly come around the back [south] side of that. It’s going to continue but the headings are going to change.

In this case, routing the departures around the south side of the weather might be possible because arrivals were unlikely to be able to approach the airport from the southeast, but it was important to the traffic managers that the airspace they used for departures would not interfere with arrival flows.

In addition more intense weather caused the participants to develop more complex route restrictions. For example, at 2030Z, the participants were concerned about the potential difficulty of trying to vector aircraft through the spaces between the several severe weather cells east of the airport as well as the cell just north of the Hoppy departure heading (see Figure 18). The ARTCC traffic manager expected that all eastbound routes were closed and that all eastbound flights would be swapped to northbound departure fixes Knave and Nexar. As those flights made their way from Knave or Nexar to their eastbound destinations, the ARTCC traffic manager thought he would require 15 miles in trail. In order to meet the 15 miles in trail restriction at the point of handoff to the ARTCC, the TRACON traffic manager required 10 miles in trail on eastbound flights off the ground, as shown in Table 3.

However, the TRACON traffic manager did not expect that the severe weather shown just north of the Hoppy departure heading in Figure 18 would require much additional separation on aircraft that had originally been filed to use that heading (5 miles in trail rather than the typical 3, as shown in Table 3). Therefore, although eastbound and northbound flights would all be using the same departure fixes they would be subject to different restrictions.
Figure 18. Current measure of VIL at 2030Z.

Table 3. Departure route restrictions for 2030Z.

<table>
<thead>
<tr>
<th>Departure Fix(es)</th>
<th>Start</th>
<th>End</th>
<th>Restriction</th>
<th>Required / Expected?</th>
<th>Probability</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eastbound as 1 (TRACON)</td>
<td>1900</td>
<td>2200</td>
<td>10 MIT off ground</td>
<td>Required</td>
<td>High</td>
<td>Move to Knave and Nexar</td>
</tr>
<tr>
<td>East gate (ARTCC)</td>
<td>2030</td>
<td>2230</td>
<td>SWAP. Eastbound closed. 15 MIT on swapped aircraft</td>
<td>Required</td>
<td>High</td>
<td>Move to Knave and Nexar</td>
</tr>
<tr>
<td>Nikky, Knave, Nexar</td>
<td>2030</td>
<td>2130</td>
<td>5 MIT off ground (except swapped Eastbounds)</td>
<td>Required</td>
<td>High</td>
<td>Use Brews heading</td>
</tr>
<tr>
<td>Nikky, Knave, Nexar</td>
<td>2130</td>
<td></td>
<td>5 MIT off ground (except swapped Eastbounds)</td>
<td>Expected</td>
<td></td>
<td>Use WAYNE/ERICK heading</td>
</tr>
</tbody>
</table>
The participants also noted that they would be likely to produce different restrictions if MJA was located in a different airspace because of differences in sector shapes, sizes, and traffic density, as highlighted by the conversation in Figure 19. In the figure, “[ARTCC]” replaces the name of the ARTCC participant.

**Figure 19.** Participants might respond differently if MJA was in a different airspace.

Discussion

The structured interview served its main purpose of generating a representative set of departure route restrictions illustrating an air traffic management response to dynamic weather. In addition, they provided some insights into the decision making process engaged in by traffic managers.

First, the approach to distributing work in the NAS became apparent in the way the dialogue between the ARTCC and TRACON traffic managers naturally played out. Often, the TRACON traffic manager would wait for the ARTCC traffic manager to
decide how he expected to respond to the current and forecast weather before discussing the restrictions he expected to require in the TRACON airspace. This reflects the airspace design, in that capacity restrictions in ARTCC airspace typically generate constraints for the TRACON (Smith, Spencer, & Billings, 2007). TRACON controllers cannot hand off more aircraft to the ARTCC than the ARTCC controllers can accept. This reflects an approach to distributing work that generates nearly independent subtasks that allow organizations to engage in independent work when possible with processes for coordinating and collaborating when necessary (Smith, 2011).

Indeed, the two traffic managers did collaborate in their decision-making. Even when severe weather was expected to impact either ARTCC or TRACON airspace, but not both, it was not unusual for one of the traffic managers to draw the other traffic manager’s attention to a constraint he may not be overtly attending to or a strategy that may solve his problem but that he did not seem to generate. The excerpt from the interview shown in Figure 15 provides an example of this collaboration.

However, some of the assumptions made in conducting this structured interview may limit the ability to generalize to the complexities of air traffic management decision-making in response to a dynamic weather event. For example, as noted above, the participants may have provided more conservative departure restrictions than they would have in the real world. They attributed this to the lack of feedback, as noted above, as well as the lack of traffic demand information. For example, for each time period the participants were asked to generate their expected departure restrictions for all routes and directions. However, the participants acknowledged that they would use a different strategy if they faced this weather system in the real world, as shown by the excerpt from the interview in Figure 20.

In addition, the lack of time pressure may have allowed them to be more deliberate in their decision making than they could have been if they were working in their respective Traffic Management Units when they encountered this weather system.
**ARTCC**: In real life you never have a bank of departures going out on all 4 fixes at the same time. ... The New York airplanes all go about the same time, the L.A. airplanes all go about the same time, and they never go at the same time. So your first thing is, look at where your demand is going to be. Which direction is your bank of departures wanting to go?

**OSU**: Right. That makes sense.

**TRACON**: Yeah, that’s right.

**OSU**: So if you’re looking at a time period when, basically, nobody’s going east, but you have a heavy west bank, for example. ... You look at the bank and the demand is to the west. How much time would you spend actually considering the situation to the east?

**ARTCC**: Probably not a lot, unless in some drastic cases, you’ve got to go east to go west. You may have to use eastbound departure gates to turn the airplanes back to the west. But if your bank was basically a westbound bank and you were able to go north, south, or west, you probably wouldn’t even be looking at the east that much.

**OSU**: Okay.

**TRACON**: An analogy is the hospital situation. You’re always in triage when you have stuff like this [weather] going on. It’s always what do I have to do right now. The westbound departures need my attention NOW. And by the time you get that straight... you’ve got arrival banks coming in that you’re worried about. And then you have to deal with those NOW. Whatever attention is left over for the areas where the demand isn’t significant you do what you can. But it’s always a tradeoff situation. There’s always 18 things you need to do, and you just do them in order, you know.

Figure 20. Difference in participants' approach from the real world.

The restrictions generated by the participants were used to create a scenario for a second series of structured interviews, described in the next section.

*Air Traffic Control Tower Decision-Making in Dynamic Weather*

In order to design a departure metering procedure that provides a good inventory of departures to the ATCT for sequencing, it would be useful to identify how ATCT traffic managers translate airspace restrictions into surface management strategies. To that end, a series of structured interviews was performed with 12 former ground controllers and ATCT traffic management coordinators. There were two main goals of the study: to identify the surface management strategies required to build a realistic
simulation of the airport surface in a dynamic weather scenario and to determine what surface management strategies should be supported in a departure metering procedure.

Participants

Twelve retired ATCT air traffic controllers participated in structured interviews. Their air traffic control experience is summarized in Table 4. They had an average of 23.4 years of experience as ATCT ground controllers at busy facilities, including:

- San Francisco International Airport (SFO, 1 participant).
- Los Angeles International Airport (LAX, 5 participants).
- Detroit Metropolitan Wayne County Airport (DTW, 2 participants).
- Phoenix Sky Harbor International Airport (PHX, 2 participants).
- Dallas/Fort Worth International Airport (DFW, 1 participant).
- Philadelphia International Airport (PHL, 1 participant).
- Chicago O’Hare International Airport (ORD, 1 participant).

In addition, 8 participants had formal experience as an ATCT traffic management coordinator and 2 had unofficial experience as an ATCT traffic management coordinator (such as performing the role while an official traffic management coordinator was on vacation). Four participants had formal experience as an ATCT supervisor and 3 had unofficial experience as an ATCT supervisor. Seven had experience as a TRACON controller, often gained while they were also an ATCT controller in an upstairs/downstairs ATCT/TRACON facility. Two had experience as ARTCC controllers. In addition, one had experience as a flight service specialist and one had worked for 15 years as an ATCSCC traffic management specialist. They all had experience at one or more busy facilities with at least a complexity level of 8 according to the most recent classification (NATCA-FAA Agreement, 2009) or a Level 5 under the previous classification.
Table 4. Summary of participants' air traffic control experience.

<table>
<thead>
<tr>
<th>Position</th>
<th>Number of Participants</th>
<th>Average Years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground Control</td>
<td>12</td>
<td>23.4</td>
</tr>
<tr>
<td>ATCT TMC</td>
<td>8</td>
<td>5.4</td>
</tr>
<tr>
<td>ATCT Supervisor</td>
<td>4</td>
<td>4.1</td>
</tr>
<tr>
<td>ATCT Supervisor (unofficial)</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>ATCT TMC (unofficial)</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>TRACON Controller</td>
<td>7</td>
<td>16.2</td>
</tr>
<tr>
<td>ARTCC Controller</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Flight Service</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>ATCSCC TMS</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

All of the participants had recently retired from their FAA air traffic control positions. They had been retired for an average of approximately 2.6 years. Their average age was approximately 56.7 years.

Method

The researcher verified that the participant could view the remotely shared screen where the airport surface and departure route constraints were to be displayed. The researcher then collected biographical data related to the participant’s air traffic control background and experience. The participants received the same introduction as the air traffic management experts discussed above to MJA and the MJA airspace.

Similarly to the air traffic management decision-making study discussed above, the researcher stepped through the July 26 Dallas weather scenario from 1500Z to 0000Z, stopping every 30 minutes to allow the participants to view the two-hour forecast in 15-minute increments. At each 30-minute increment, the participant was asked about the surface management strategies they thought they would use in response to the weather. Then the participant was shown the current list of departure restrictions generated by the
air traffic management participants in the previously discussed structured interview and asked whether that information would impact their surface management strategy. The participant also would be shown the scheduled demand over the coming 30-60 minutes. For example, at 1800Z the participant would have access to displays similar to those shown in Figure 21, though not simultaneously because they would not all fit on the screen at the same time.

Figure 21. Displays similar to those shown to participants at 1800Z.

Figure 21 shows the departure restrictions that were current as of 1800Z. Those restrictions that had changed since 1730Z are shown in boldface type. The list of departure restrictions is super-imposed over a static map of the MJA airport surface. Participants were shown a static map with no aircraft on it to try to avoid biasing their thinking in determining a surface management strategy. Participants also were able to see the same current and forecast weather as was shown to the air traffic management participants that generated the departure restrictions. In addition, participants were able to see a list of aircraft already taxiing and scheduled to enter the active movement area over the coming 30-45 minutes. In Figure 21, aircraft scheduled to depart to an eastbound departure fix are highlighted, enabling the participant to assess the demand for eastbound
departure fixes in order to support them in developing a strategy for staging those aircraft for departure from runway 18L.

At each 30-minute interval, the researcher updated the simulated weather and departure schedule, as well as the departure restrictions. The researcher asked the participant questions such as:

- How would you want to stage flights for runway 18C?
- How many flights would you want in the lineup for runway 18C? Would you like to limit the number that are in the lineup at any one time?
- How would you want to stage flights for runway 18L?
- How many flights would you want in the lineup for runway 18L? Would you like to limit the number that are in the lineup at any one time?
- Do you see anything in the current or forecast weather that would cause you to change your plan?
- Do you see anything in the updated departure route restrictions that would cause you to change your plan?

Participants discussed the strategy they would use for staging departures given the weather and the departure route restrictions. It was hypothesized that participants would consider the weather forecast and the scheduled departure demand in developing a surface management strategy. Participants also were expected to use the taxiways to segregate aircraft by departure fix and direction when there were departure route restrictions in place. In particular, participants were expected to use taxiways G and H and run-up pads G-7 and G-8 to stage aircraft for runway 18C and run-up pads R-8 and R-9 to stage aircraft for departure from runway 18L (see Figure 8 on page 59 above). Thus, with two taxiways available for staging aircraft for runway 18C and only one taxiway available for runway 18L, participants were expected to use different strategies for staging departures for the two runways.
Apparatus

In addition to the CATS simulation environment in which the weather and departure schedule were embedded (Fernandes, et al., 2011), participants were provided a static image of MJA and updated set of departure restrictions using Microsoft PowerPoint. Interviews took place with individual participants using the GoToMeeting web conferencing service, including desktop sharing, voice, and audio/visual recording. Participants were able to view the researcher’s computer desktop. These tools are discussed in Chapter 3.

Results

The two departure runways (18C and 18L) differed in the number of taxiways that served them. Despite this, participants used similar strategies to stage departures for each runway, although they expressed that they had greater flexibility in staging departures for 18C because it had two taxiways (G and H) as well as an intersection at F from which aircraft could depart if and when it would be advantageous to coordinate an intersection departure. In addition, the general surface management strategies were not so different when there were departure restrictions in place than when there were no departure restrictions.

Results are provided below in terms of differences in departure strategies for each departure runway and for times when there were no departure restrictions (1500Z) and after departure restrictions were put in place.

Runway 18C: No Departure Restrictions

Runway 18C was served by two taxiways, G and H, and two run-up pads, G-7 and G-8. In addition, participants were told that any aircraft in the scenario could depart runway 18C from the intersection at F.
At 1500Z, before there were any departure restrictions in place, participants said they would use the strategies shown in Table 5 and Table 6 to stage departures for runway 18C. Some of the participants used strategies composed of multiple strategies listed in Table 5 and Table 6 and therefore the total across the two tables adds to more than 12.

Six participants said they would stage departures on taxiways G and H, while 4 participants said they would stage all departures on a single taxiway, as shown in Table 5. Some participants stated reasons for their choice and/or provided further refinement for their strategies than others. There may have been strategies they used implicitly but did not state. Those strategies are not captured in Table 5 or Table 6. Of the 4 participants that said they would use only 1 taxiway, 3 said they did so in order to leave the other taxiway open in case one or more aircraft either would block others from departing or needed a clear path to the runway (e.g., if the aircraft had an Estimated Departure Clearance Time). The fourth participant did not explicitly state any reason for using a single taxiway.

Table 5. Strategies for staging departures for runway 18C (no departure restrictions).

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use both taxiways G and H</td>
<td>6</td>
</tr>
<tr>
<td>Assign taxiway by departure fix</td>
<td>3</td>
</tr>
<tr>
<td>Assign taxiway by aircraft type</td>
<td>2</td>
</tr>
<tr>
<td>All departures on same taxiway</td>
<td>4</td>
</tr>
<tr>
<td>Keep one taxiway open for aircraft with an issue</td>
<td>3</td>
</tr>
</tbody>
</table>

On the other hand, most participants who said they would use both taxiways did so in order to segregate aircraft by departure fix (3/6 participants) or by aircraft type (2/6 participants). One of the 6 participants using the dual taxiways did not explicitly state how he or she would decide which aircraft should be assigned to each taxiway.
Table 6 shows additional strategies some participants stated they would use in building a surface management strategy. These were often in addition to the decision to use one or two taxiways. For example, 4 participants explicitly stated that they would ensure the departure queue was sequenced such that SIDs were alternated (i.e., there were no two aircraft to the same departure heading back to back). Such a sequence would allow the local controller to depart aircraft without modifying the departure sequence. In addition, according to one participant, “It’s always easier for the radar controller if you can alternate SIDs. You can really help the radar room by putting everyone out there so there’s no delay” because a sequence that does have two aircraft to the same SID back-to-back requires 3 miles of separation between aircraft leaving the runway. Note that alternating SIDs is likely a strategy that all of the participants would have used but only 4 stated it explicitly in response to the question.

Table 6. Strategies for staging departures for runway 18C (no departure restrictions).

<table>
<thead>
<tr>
<th>Additional Strategies</th>
<th>Number of Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternate SIDs</td>
<td>4</td>
</tr>
<tr>
<td>Hold short of intersection with F</td>
<td>2</td>
</tr>
<tr>
<td>2 separate queues for local controller</td>
<td>2</td>
</tr>
<tr>
<td>Plan for intersection departures from runway 18C</td>
<td>2</td>
</tr>
<tr>
<td>Use intersections to re-sequence</td>
<td>1</td>
</tr>
<tr>
<td>Plan for departures from runway 18R and/or 23</td>
<td>1</td>
</tr>
</tbody>
</table>

Two participants specifically said they would hold departures on one or both taxiways short of the intersection with F to allow them to change the departure sequence if necessary, while another participant listed several intersections that would allow re-sequencing, including H-4. This represents a more general strategy of delaying commitment to a course of action until as much uncertainty as possible has been removed from the solution space (Weld, 1994). This is a form of contingency planning (Smith, Beatty, Spencer, & Billings, 2003).
In addition, two participants also said they would plan for departures that may want to depart runway 18C from the intersection at F, although one of them cautioned that he or she “wouldn’t do that until it gets really bad because it would be hard for the tower [local] controller to keep straight.” In addition, one participant suggested being prepared to coordinate departures from runway 18R (the arrivals runway) or runway 23.

In addition to asking participants which aircraft they would want to stage where, the researcher asked participants how many aircraft they would like to see active for runway 18C. This was to determine a useful target average departure queue length for managing a departure metering procedure. The participants displayed some variance in their responses, as shown in Table 7.

Table 7. Number of aircraft participants wanted active for runway 18C.

<table>
<thead>
<tr>
<th>Response</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 aircraft per runway</td>
<td>1</td>
</tr>
<tr>
<td>10 aircraft per runway</td>
<td>2</td>
</tr>
<tr>
<td>10-12 aircraft per runway</td>
<td>1</td>
</tr>
<tr>
<td>12 aircraft per runway</td>
<td>2</td>
</tr>
<tr>
<td>6 aircraft per taxiway (G and H)</td>
<td>2</td>
</tr>
<tr>
<td>15-20 aircraft per runway</td>
<td>1</td>
</tr>
<tr>
<td>Last aircraft in departure sequence north of Papa</td>
<td>1</td>
</tr>
<tr>
<td>14-15 aircraft per ground controller</td>
<td>1</td>
</tr>
<tr>
<td>Unlimited until getting saturated</td>
<td>1</td>
</tr>
</tbody>
</table>

Five participants said they would prefer 10-12 aircraft actively taxiing to each runway when there were no departure restrictions. Two of those participants specifically said they wanted to keep the number active at 10 per runway, one participant specifically said 10-12 aircraft, and two said they would like to see 6 aircraft on each of taxiways G and H. Meanwhile, 1 participant preferred 5 aircraft actively taxiing to each runway, and one preferred 15-20 aircraft per runway. One participant even said he or she would want
to ensure that the last aircraft in the departure sequence remained north of the intersection between taxiways G and H with taxiway P, which would require more than 20 aircraft in the departure queue, and another participant said he or she would not limit the number of active aircraft until the taxiway was “getting saturated” because aircraft were unable to depart. Only one participant indicated that he or she would put a gate hold in place, wherein flight crews would be given a time at which they were allowed to request permission to enter the active movement area.

One participant was more concerned about radio frequency congestion and the number of aircraft a ground controller was expected to manage at once than about the number of aircraft actively taxiing to a runway. This participant said that if there was only one ground controller managing all taxiing aircraft, then there should be only approximately 7 aircraft actively taxiing to each runway. However, if there were two ground controllers, such as one managing the west side of the airport and another managing the east side of the airport, the participant said each ground controller could manage 14-15 aircraft. Thus, this participant explicitly considered the workload of the ground controller(s) in determining how many aircraft should be allowed to taxi at once.

Runway 18L: No Departure Restrictions

While runway 18C was served by two taxiways, runway 18L was served by only one. It was hypothesized that participants would use the two run-up pads at R-8 and R-9 to create flexibility in building a departure sequence. Instead, they preferred to build a good departure sequence before aircraft taxied north of P on R, leaving one run-up pad open as much as possible to accommodate aircraft that could not depart. Again, this represents another way in which participants explicitly planned for unknown contingencies in developing a departure management strategy.

The staging strategies that participants said they would use before any departure restrictions were in place are shown in Table 8. A given participant may have stated he or
she would take into account more than one of the considerations listed in Table 8, and additional participants may have considered a strategy but did not state it.

Four participants said they would use taxiways Q and R south of J as “dual taxiways,” in effect creating similar opportunities for sequencing as for runway 18C. This was not expected. Three participants explicitly said they would sequence departures before they taxied on R north of P, although using Q as a dual taxiway as the four participants suggested also implies sequencing departures before they taxied north of P. One such participant said, “I’d never want anything to get to the approach end of the runway that couldn’t roll [such as] too many of the same fix [or] too many that are in the same flow, no numbers,” etc. Therefore, this participant would try to avoid allowing aircraft to taxi north of P unless he was reasonably certain the aircraft would be able to depart once it reached the runway.

Table 8. Departure staging strategies for runway 18L with no departure restrictions.

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use “dual taxiway” Q</td>
<td>4</td>
</tr>
<tr>
<td>Sequence before they are north of P</td>
<td>3</td>
</tr>
<tr>
<td>Alternate SIDs</td>
<td>2</td>
</tr>
<tr>
<td>Use run-up pads to re-sequence</td>
<td>2</td>
</tr>
<tr>
<td>Fixes with worst flow on P short of R</td>
<td>1</td>
</tr>
<tr>
<td>Hold aircraft at the spots</td>
<td>1</td>
</tr>
</tbody>
</table>

One participant wanted to hold aircraft to departure fixes with the most restrictive flow restrictions on taxiway P short of R. One participant wanted to hold aircraft at the spots to prevent congestion on taxiway Q. In addition, two participants specifically said they would prevent two 18L departures to the same heading from being back-to-back in the departure lineup although all participants probably would have used that strategy. Two participants specifically said they would use the run-up pads at R-8 and R-9 to re-sequence aircraft when necessary.
When asked how many aircraft they would want in the departure queue for runway 18L, only 3 participants provided a different answer than for runway 18C. These responses are shown in Table 9. In addition to the responses that were the same as for runway 18C, 1 participant preferred to have only 6 or 7 aircraft north of P. A second participant preferred to allow 10 aircraft north of the intersection of R and P. A third said he would not want the departure sequence to back up on R past P.

Table 9. Number of aircraft participants said they would want active for runway 18L.

<table>
<thead>
<tr>
<th>Response</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 aircraft per runway</td>
<td>1</td>
</tr>
<tr>
<td>10 aircraft per runway</td>
<td>2</td>
</tr>
<tr>
<td>10-12 aircraft per runway</td>
<td>1</td>
</tr>
<tr>
<td>12 aircraft per runway</td>
<td>2</td>
</tr>
<tr>
<td>15-20 aircraft per runway</td>
<td>1</td>
</tr>
<tr>
<td>6 or 7 north of P</td>
<td>1</td>
</tr>
<tr>
<td>10 north of P</td>
<td>1</td>
</tr>
<tr>
<td>Not backed up past P</td>
<td>1</td>
</tr>
</tbody>
</table>

Participants were asked to describe what departure staging strategies they might use at 1500Z to gauge their strategies before there were any weather-related departure restrictions. Starting at 1530Z, there were departure restrictions, although they started light and increased in magnitude and complexity over time. The next section describes the strategies participants used when there were departure restrictions.

Departure Restrictions

In the scenario, the weather built over time. When the scenario began at 1500Z there were no departure restrictions. One half hour later, at 1530Z, the TRACON needed 7 miles in trail on each of three southbound departure fixes (Evans, Alisa, and Chasz). Ten participants said this restriction was not severe enough to cause them to change their plan for staging departures. In fact, several participants said they did not expect a miles in
trail restriction to impact their surface management strategy until 10 or more miles of spacing were required. One participant explained it thusly:

When it exceeds 10 miles in trail, that’s when I start having an issue… 10 miles in trail is equivalent to approximately 2 minutes… When you start getting 8 or 10 aircraft and they’re 2 minutes in trail, that’s 16 to 20 minutes between the first and the last. That’s a long time out there. That translates into a potential reportable delay, with 15 minutes being the magic number [when delay must be reported to the ATCSCC].

At 1530Z the ARTCC also issued a warning that at 1630Z two eastbound departure fixes, Treat and Creak, would be closed and all flights to those fixes would be rerouted to the Beamr departure fix (see Figure 12). Participants were asked what they would do now to prepare for that route closure. Only two participants said they would start planning now to ensure all flights had the appropriate departure clearances.

Most participants said too much could change in the coming hour to act now. (“If I start making my plan an hour before, I may have made too many adjustments to make plan B work when I didn’t need to do plan B in the first place.”) Some said they would wait until 30 minutes (1 participant), 15-20 minutes (1 participant), or 15 minutes (1 participant) before the closure was expected to commence to start planning for it. They said that at that time they would verify that the closure was still expected to occur and begin planning to ensure all flights had appropriate departure clearances. This is another example of delaying action until information was more certain.

Two participants said they would encourage flight operators to prepare flights to depart before their routes closed if possible. Four said they would try to change runway assignments to reduce the number of flights that may be delayed because they were in the departure lineup with flights expecting to use one of the impacted departure fixes.

Most participants indicated that the departure restrictions presented at 1530Z would not induce a change in their surface management strategies. The times at which
participants indicated they would modify their surface management strategies are shown in Table 10. Six participants indicated they would change their plan at 1600Z, 4 said they would change their plan at 1630Z, and one would wait until 1700Z. The restrictions introduced at each of those times are shown in Figure 22. At each of these times, one or more 10 miles in trail restrictions was introduced (restrictions that were introduced during each time period are shown in boldface type).

Table 10. Time participants would modify strategies.

<table>
<thead>
<tr>
<th>Time</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>1600Z</td>
<td>6</td>
</tr>
<tr>
<td>1630Z</td>
<td>4</td>
</tr>
<tr>
<td>1700Z</td>
<td>1</td>
</tr>
</tbody>
</table>

As noted earlier, the weather deteriorated over time. Before seeing the departure restrictions for a time period, each participant was presented with the current and forecast weather for that time period. The researcher asked whether the participant saw anything in the current or forecast weather that caused him or her to expect to change his or her surface management plan.

Figure 22. Departure route restrictions at 1600Z, 1630Z, and 1700Z.
When presented the current and forecast weather for 1800Z, shown in Figure 13 and Figure 14 (on page 119), two participants said they did not expect to change their plan based on the weather. Six participants said they expected the eastbound weather to deteriorate (although 1 other participant expected more eastbound routes to open).

The departure restrictions presented to participants at 1800Z are shown in Figure 23. These were derived from the departure restrictions generated by the TRACON and ARTCC traffic management participants in the previous exercise, shown in Table 2. Each of the southbound departure fixes had had a 10 miles in trail restriction in place since 1700Z, while the TRACON had just introduced a requirement that all eastbound routes would be treated as one route with 5 miles in trail. The ARTCC had closed eastbound routes Creak, Treat, and Beamr at 1730Z and rerouted all of those flights to Eartz. In addition, eastbound routes Eartz and Beaty each had a 10 miles in trail restriction.

Westbound routes Whalt and Wymon would be treated as one route and westbound routes Wiley, Wickr, and Worth would also be treated as one route until 2000Z. All northbound routes were open with no restrictions.

<table>
<thead>
<tr>
<th>Current Time: <strong>1800Z</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Required:</strong></td>
</tr>
<tr>
<td>SOUTH [5 x 10 MIT]</td>
</tr>
<tr>
<td>Start: 1700Z</td>
</tr>
<tr>
<td>Extension: HIGH</td>
</tr>
<tr>
<td>EAST as 1 [1x5 MIT]</td>
</tr>
<tr>
<td>Start: 1800Z</td>
</tr>
<tr>
<td>Extension: HIGH</td>
</tr>
<tr>
<td>CREAK, TREAT, and BEAMR</td>
</tr>
<tr>
<td>Start: 1730Z</td>
</tr>
<tr>
<td>Extension: HIGH</td>
</tr>
<tr>
<td>BEATY and EARTZ [2 x 10 MIT] 10 MIT</td>
</tr>
<tr>
<td>Start: 1800Z</td>
</tr>
<tr>
<td>Extension: HIGH</td>
</tr>
<tr>
<td>WHALT and WYMON as 1</td>
</tr>
<tr>
<td>Start: 1800Z</td>
</tr>
<tr>
<td>Extension: MODERATE</td>
</tr>
<tr>
<td>WILEY, WICKR and WORTH</td>
</tr>
<tr>
<td>as 1</td>
</tr>
<tr>
<td>End: <strong>2000Z</strong></td>
</tr>
<tr>
<td>Extension: MODERATE</td>
</tr>
</tbody>
</table>

Figure 23. Departure route restrictions in effect at 1800Z.
The strategies that participants said they would use to stage departures for runway 18C are shown in Table 11. Again, these represent those issues participants explicitly stated that they would consider in staging departures. Some participants said they would combine multiple strategies, such as staging flights to Wiley, Worth, and Wickr on one taxiway with flights to Whalt and Wymon on the other.

Whereas at 1500Z (with no departure restrictions) only 3 participants specifically said they would assign flights to taxiways according to their departure fix, at 1800Z six participants said they would assign flights to taxiways according to departure fix. Two participants said they would put flights to the most constrained departure fixes on one taxiway and splitters on the other taxiway. In addition, 1 participant would sequence all aircraft on one taxiway at 1800Z, whereas at 1500Z four participants said they would sequence all aircraft on one taxiway. Five participants specifically said they would alternate flights to westbound SIDs.

Table 11. Strategies participants would use to stage 18C departures at 1800Z.

<table>
<thead>
<tr>
<th>Departure Management Strategy</th>
<th>Frequency</th>
<th>Departure Management Strategy</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assign taxiways for 18C by departure fix</td>
<td>6</td>
<td>Single lineup for 18C</td>
<td>1</td>
</tr>
<tr>
<td>Wiley, Worth and Wickr on one taxiway</td>
<td>2</td>
<td>Create second lineup if queue backs up to P</td>
<td>1</td>
</tr>
<tr>
<td>Whalt and Wymon on one taxiway</td>
<td>3</td>
<td>Alternate Westbound SIDs</td>
<td>5</td>
</tr>
<tr>
<td>All westbounds on one taxiway</td>
<td>3</td>
<td>2 Westbounds between any 2 Southbounds</td>
<td>1</td>
</tr>
<tr>
<td>Splitters on separate taxiway</td>
<td>2</td>
<td>Meter aircraft for 18C</td>
<td>4</td>
</tr>
<tr>
<td>Use northbounds as splitters</td>
<td>1</td>
<td>6 max per taxiway</td>
<td>1</td>
</tr>
<tr>
<td>Use Phils and Smith as splitters</td>
<td>1</td>
<td>If 10-12 and building</td>
<td>1</td>
</tr>
<tr>
<td>Use intersection at F to add splitters</td>
<td>1</td>
<td>15 minutes of departures at a time</td>
<td>1</td>
</tr>
<tr>
<td>Move southbound flights from 18C to 18L</td>
<td>1</td>
<td>45-60 minutes of departures at a time</td>
<td>1</td>
</tr>
</tbody>
</table>
In addition, 4 participants said they would meter aircraft to runway 18C, but each had a different metering strategy. One would limit the queue to 6 aircraft per taxiway, while another would start metering departures if the queue grew to 10-12 and was continuing to grow. A third participant did not want more than 45-60 minutes’ worth of departures taxiing out at once, which would be a variable number of aircraft depending on departure conditions. A fourth participant identified groups of approximately 15 minutes’ worth of departures that he would allow to taxi one after the other.

Participants said they would use similar strategies to stage departures for runway 18L, as shown in Table 12. Seven participants said they would prevent any back-to-back departures to a given SID. In particular, only 2 participants said they would use the run-up pads R-8 and R-9 to re-sequence eastbound SIDs, as hypothesized. Four participants said they would use the intersection of taxiways P and R to create a sequence with no back-to-back SIDs. Two participants specifically said they would use northbound flights as splitters for the eastbound flights, whereas one participant said he would use southbounds as splitters. One participant suggested moving northbound flights to Nikky, Knave, and Nexar from runway 18L to runway 18C so that the unconstrained northbound flights would not risk being delayed by eastbound flights. Similarly, one participant suggested rerouting some eastbound flights to the south in order to reduce delays on eastbound departures.

In addition, 6 participants said they would meter departures to runway 18L. One would allow 4-5 aircraft on taxiway R north of P, one would allow 6, and two participants said they would limit the number of aircraft on R to 10. One more participant would require aircraft to hold at their gates until flights caught in the latest route closures reached the runway, while another would institute a gate hold and assign 2 minutes between push back times.

Several participants considered ground controller and local controller workload in deciding which strategy they preferred. For example, at 1800Z one participant said he
Table 12. Strategies participants would use to stage 18L departures at 1800Z.

<table>
<thead>
<tr>
<th>Response to Restrictions</th>
<th>Frequency</th>
<th>Response to Restrictions</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>No change to plan for Eastbounds</td>
<td>1</td>
<td>Meter eastbounds</td>
<td>6</td>
</tr>
<tr>
<td>Split SIDs for Eastbounds</td>
<td>7</td>
<td>No more than 4-5 at a time</td>
<td>1</td>
</tr>
<tr>
<td>Use R-8 and R-9 to split Eastbound SIDs</td>
<td>2</td>
<td>No more than 6 at a time</td>
<td>1</td>
</tr>
<tr>
<td>Use P and R to split SIDs</td>
<td>4</td>
<td>No more than 10 at a time</td>
<td>2</td>
</tr>
<tr>
<td>Use Northbounds as splitters</td>
<td>2</td>
<td>2 minutes between push back times</td>
<td>1</td>
</tr>
<tr>
<td>Use Southbounds as splitters</td>
<td>1</td>
<td>Gate hold 18L departures until taxing flights with changed fixes get to runway</td>
<td>1</td>
</tr>
<tr>
<td>Suggest swapping some Eastbounds to South</td>
<td>1</td>
<td>Move Hoppy flights (Nikky, Knave, and Nexar) to runway 18C</td>
<td>1</td>
</tr>
</tbody>
</table>

could make a case for using either one or two taxiways for sequencing departures for runway 18C. The ground controller sequencing all of the departures together on one taxiway would minimize workload for the local controller:

You want to reduce the work that Local has to do. If you give him 2 lines with different fixes, he has to put more heads down time in the tower control [local control position] even with an assist person. Who’s the number 1 on Golf? Oh, that’s them. Verify number 1 on Golf. Yeah, that’s me. Okay, I want you to go around this guy… That’s a lot more heads down, compromise to efficiency moving airplanes as opposed to just position up, line up and wait, line up and wait, line up and wait.

On the other hand, he said that using one taxiway increases the risk that a ground stop or other restriction creates delays for several flights. “If I put everybody in the line, [OSU], sequenced, and all of a sudden I have an unanticipated, no-notice ground stop or hold, if the TRACON says hold everybody going west, boom, now that entire line is stopped.” Further:
Right now it’s 1800 and I’m showing… 2 westbound flows [streams], no flow [restrictions] and south I’ve got 5 by 10 [10 miles in trail on each of 5 southbound departure fixes]. So the line going south is theoretically slower. Then I have to do the math and mix it with my lineup there. …2 lines would probably make more sense because I have the option for 2 lines here. ... As long as I’ve got the concrete let’s use it... That way there’s continued pressure if there’s a mechanical breakdown of one aircraft, then everybody in line’s got to hold. ... But, it does involve doing a lot more talking, it does involve the tower [local] controller doing a lot more heads down, doing a lot more sequencing at the runway. If [local control] assist is staffed and he can help them then I would probably do that [use two taxiways]. If he’s by himself I probably wouldn’t do that.

Other participants considered whether there was one ground controller or two in determining how they would want to stage departures or whether they would want to limit the number of active aircraft. One said he would try to “keep it as routine as possible” to manage complexity for the controllers. This represents an example of using standard procedures when possible to cope with complexity. It also represents the participants’ views on how the task of staging, sequencing, and clearing aircraft for departure should be distributed. For at least one participant, the local controller should be responsible only for clearing aircraft for departure in a safe and efficient manner (“lock and load and clear for takeoff”), while the ground controller should deliver a “perfect all the ducks in a row sequence” that enabled the local controller to do just that. Other participants, however, wanted to provide the local controller with options to ensure there was always an aircraft at the front of the departure queue that could depart, delaying ATCT commitment to a final departure sequence as long as possible.

Although the number of participants selecting a given strategy differed between the time periods with and without departure route restrictions discussed here, the basic building blocks of their strategies were consistent. In fact, participants used similar strategies to those discussed here for all of the time periods.
In addition to the departure management strategies they would use in response to dynamic weather, participants were asked about the rules of thumb they used to determine how many splitters to use in order to meet a miles in trail restriction.

Number of Splitters used to meet a Miles in Trail Restriction

As noted in the earlier discussion of air traffic management decision making, TRACON and ARTCC traffic managers prevent too many aircraft from entering a sector of airspace impacted by weather via spacing restrictions such as increasing the required miles in trail. In order to build a model of departure sequencing, it is important to understand how ATCT personnel interpret these miles in trial restrictions. In addition, when not all departures are subject to the restriction in question, it also is important to understand how the ATCT maintains efficient use of the runway while also meeting the miles in trail restriction.

The ATCT maintains efficient use of the departure runway through a variety of means, including by mixing unrestricted aircraft into the departure lineup with restricted aircraft. They select a number of unrestricted aircraft to act as splitters between restricted aircraft. In order to understand how many unrestricted aircraft should split restricted aircraft in the departure lineup, participants were asked how many aircraft they would put between two aircraft that were subject to a 10, 15, or 20 miles in trail restriction.

When there are 10 miles in trail off the ground, how many flights need to be between?

The most frequent response was to separate two flights subject to a 10 miles in trail restriction by 2 aircraft, as shown in Table 13, although several participants said they would separate them by 1 aircraft.
Table 13. Strategies for separating two aircraft subject to a 10 MIT restriction.

<table>
<thead>
<tr>
<th>Response</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 aircraft</td>
<td>3</td>
</tr>
<tr>
<td>2 aircraft</td>
<td>4</td>
</tr>
<tr>
<td>1 or 2 aircraft</td>
<td>2</td>
</tr>
<tr>
<td>2 minutes</td>
<td>1</td>
</tr>
<tr>
<td>Launch 2\textsuperscript{nd} when 1\textsuperscript{st} is 5 miles off the field. 1 minute, maybe 1 aircraft.</td>
<td>1</td>
</tr>
</tbody>
</table>

However, participants did not present these as hard and fast rules. Some of the considerations they mentioned included:

- “Depends on the type. If they’re both jets and one’s not a Citation then you put 1 airplane in between them.”
- “It has to do with wake turbulence and accommodating crossing traffic down field, and so forth… You also don’t want to provide any more than that number because if you provide more than that number then you’re probably self-imposed restrictions and it’s not a good thing. So you want to be right on the dot with that…”
- “If they’re rolling at 6,000 feet, uh, and, you know, turning, then you can put, uh, two airplanes in between them… If you do immediate divergence, and I need 10 miles in trail I should be able to get two airplanes in between… 6,000 feet will get you 2 ½ to 3 miles, you’ve got 3, 6, 9 miles.”
- “Our rule of thumb, when they wanted 10 miles in trail we would launch, or clear for takeoff the 2\textsuperscript{nd} aircraft when the 1\textsuperscript{st} one was 5 miles from the airport. That would normally give us 10 miles by the time the 2\textsuperscript{nd} guy is airborne.”
- “Two. As a radar controller that would definitely give me more than 10 [miles in trail]. If they could run them 3 miles apart every time they could give me more than 10 [miles in trail].”
- “Say like I have 10 of them that are 10 miles apart and then I have… only 5 of them that aren’t [subject to that restriction] then I wouldn’t want to put 2 of
those between- you know, I don’t want to use up the ones I could split them with by putting 2 in between… and then all of a sudden have a whole row of them with no splits.”

Although the responses did vary, sequencing one or two aircraft between any two aircraft that are subject to a 10 miles in trail restriction seems like a reasonable approach.

When there are 15 miles in trail off the ground, how many flights need to be between?

Participants were asked how they would sequence departures that were subject to a 15 miles in trail restriction. Their responses are shown in Table 14. Their reasoning was quite similar to that provided for sequencing for a 10 miles in trail restriction, although one participant mentioned that “if they’re stuck on the ground, say, 30 seconds longer you’re gaining another 3-4 miles that you’re basically wasting as flying miles… It’s better to have 2 [flights off within] 15 [miles] than 1 [flight off] in 10 [miles].”

Table 14. Strategies for separating aircraft subject to a 15 MIT restriction.

<table>
<thead>
<tr>
<th>Response</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 aircraft</td>
<td>3</td>
</tr>
<tr>
<td>2-3 aircraft</td>
<td>2</td>
</tr>
<tr>
<td>3 aircraft</td>
<td>3</td>
</tr>
<tr>
<td>4-5 aircraft</td>
<td>1</td>
</tr>
<tr>
<td>Alternate SIDs</td>
<td>1</td>
</tr>
</tbody>
</table>

Another participant would vary the strategy by aircraft type. If the two aircraft subject to the 15 miles in trail restriction were a “heavy [followed by a] heavy… I would stick a small, a 737, that would be 2 aircraft in between for your 15 miles. If I had just a heavy… I would stick three 737s” in between.

A third participant also said it “depends on the mix” because “a turboprop is not as fast” as a larger aircraft. He also said, “It’s always easier trying to alternate SIDs because you can get more airplanes off.”
Again, although the responses varied, it seems reasonable to sequence 2-3 aircraft between any two aircraft subject to a 15 miles in trail restriction.

When there are 20 miles in trail off the ground, how many flights need to be between?

Participants’ responses varied more widely when asked how they would sequence for a 20 miles in trail restriction, as shown in Table 15.

Table 15. Strategies for separating aircraft subject to a 20 MIT restriction.

<table>
<thead>
<tr>
<th>Response</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>At least 2 or 3 aircraft</td>
<td>1</td>
</tr>
<tr>
<td>3-4 aircraft</td>
<td>2</td>
</tr>
<tr>
<td>4 aircraft</td>
<td>3</td>
</tr>
<tr>
<td>8 aircraft</td>
<td>1</td>
</tr>
</tbody>
</table>

The participant who said he or she would use 8 aircraft to separate aircraft subject to a 20 miles in trail restriction expected that to be variable, saying, “I would try to go with 8… You also have headings you could use to spread them out… The tower would talk to radar [to see] how is this working, do you need more space, how does this look… If you give them 2 less one time the next time you might give them a few more.”

As a result of these responses, sequencing 3-4 aircraft between any two aircraft subject to a 20 miles in trail restriction seems like a reasonable approach.

Discussion

As hypothesized, the key departure management strategies involved using strategic locations on the active movement area to segregate aircraft according to their characteristics such as the two parallel taxiways serving runway 18C. What was surprising was the extensive use of taxiway intersections such as the intersections of G and H with F and the intersections of Q with J and P to build in opportunities for adaptation when departure route availability became more uncertain. Creating such
opportunities is an example of contingency planning (Smith, Beatty, Spencer, & Billings, 2003) as a strategy for coping with uncertainty. The explicit consideration of decomposing the sequencing task across the local controller and ground controller, and the workload of people in each position, was a surprise as well. It also was interesting to note that several participants were concerned about accommodating different aircraft types when there were no departure restrictions, but that as departure route availability became more dynamic, departure fix became the dominant aircraft characteristic.

It was not expected that participants would vary as much as they did in their approaches to metering. Some participants did not want to meter aircraft at all, whereas others were quick to implement metering when departure route availability was impacted by the weather. Those who chose to meter varied quite a bit in the number of aircraft they wanted in a given departure reservoir, ranging from as small as 4-6 to as large as 12.

These surface management strategies are important for understanding how a departure metering procedure should work as part of a coordinated airport surface departure management system. Since so many surface management strategies are built from just a few general components, it should be possible to design tools for managing a departure metering procedure that allow the Departure Reservoir Coordinator to feed queues built using such strategies. If the DRC has access to the strategies that ATCT controllers want to use in building an efficient departure sequence, he or she can build an appropriate inventory of aircraft for them to use those strategies. Furthermore, understanding the way ATCT controllers interpret and describe those strategies facilitates building departure metering procedure management tools that support the ATCT in communicating those strategies to the DRC. As noted above, if the departure reservoir is viewed as an artifact of the domain that facilitates coordination across organizations, agents may be able to more effectively coordinate their activities if they have information about, for example, ATCT targets for the departure reservoir.
While the design of tools to support ATCT participation in a departure metering procedure is beyond the scope of this dissertation, strategies used by ATCT controllers to manage departures have been used to develop some concepts for tools to support the DRC. These are discussed in Chapter 5. The tools discussed in Chapter 5 also were informed by a departure metering concept evaluation exercise, described next.

*Departure Metering Concept Evaluation*

The insights gained from the observations and interviews described above were used to develop information requirements and design solutions for meeting those requirements within the air traffic management environment. Those information requirements were explored further through a third series of structured interviews with additional practitioners who had air traffic management expertise. Participants performed the Departure Reservoir Coordinator (Surface CDM Team, 2011) role in a simulated environment and provided feedback on the metering concept as well as concepts for displays to support the DRC.

*Participants*

Seven retired and one current ATCT air traffic controllers participated. The participants’ air traffic control experience is summarized in Table 16. They had an average of 24.1 years of experience as ATCT air traffic controllers at facilities including:

- Los Angeles International Airport (LAX, 2 participants).
- Phoenix Sky Harbor International Airport (PHX, 1 participant).
- Chicago O’Hare International Airport (ORD, 1 participant).
- Dallas/Fort Worth International Airport (DFW, 2 participants).
- San Francisco International Airport (SFO, 1 participant).
- Minneapolis-St. Paul International Airport (MSP, 1 participant).
In addition, 3 participants had formal experience as an ATCT traffic management coordinator and 3 had unofficial experience as an ATCT traffic management coordinator (such as performing the role while an official traffic management coordinator was on vacation). Two participants had formal experience as an ATCT supervisor and 1 had unofficial experience as an ATCT supervisor. Five had experience as a TRACON controller, often gained while they were also an ATCT controller in an upstairs/downstairs ATCT/TRACON facility. Four had brief experiences as ARTCC controllers (average of less than 3 months). One had worked approximately 1 year as a TRACON traffic management coordinator and for approximately 1.5 years as an ARTCC traffic management coordinator. All participants had experience at one or more busy facilities with at least a complexity level of 9 according to the most recent classification (NATCA-FAA Agreement, 2009) or a Level 5 under the previous classification.

Table 16. Summary of participants' air traffic control experience.

<table>
<thead>
<tr>
<th>Position</th>
<th>Number of Participants</th>
<th>Average Years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground Control</td>
<td>8</td>
<td>24.1</td>
</tr>
<tr>
<td>ATCT TMC</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>ATCT Supervisor</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>ATCT Supervisor (unofficial)</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>ATCT TMC (unofficial)</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>TRACON Controller</td>
<td>5</td>
<td>11</td>
</tr>
<tr>
<td>TRACON TMC</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>ARTCC Controller</td>
<td>4</td>
<td>0.22</td>
</tr>
<tr>
<td>ARTCC TMC</td>
<td>1</td>
<td>1.5</td>
</tr>
</tbody>
</table>

All but one of the participants had recently retired from their FAA air traffic control positions, while one was still active. Those that were retired had been retired for an average of approximately 2.7 years. Their average age was approximately 56.1 years.
Apparatus

Participants were given the task of managing the departure metering procedure for one side of Major Airport (MJA), discussed in Chapter 3, which was located approximately at the site of Dallas/Fort Worth International Airport (DFW). In both study scenarios the airport was in a south configuration with departures on runways 18C and 18L and arrivals on 18R. Winds were at 4 knots from the south. For the study, participants were to manage the departure metering procedure for runway 18L. The task was limited to a single runway because there was not sufficient screen space available to display the departure metering controls for both departure runways.

The airport, DRC display concepts, and study scenarios were embedded in CATS (Fernandes, et al., 2011), which the participant was able to control remotely through the GoToMeeting web conferencing service which also facilitated visual and audio communication and also generated video recordings of the sessions. Participants performed the Departure Reservoir Coordinator task, as discussed in the next section.

Method

The exercise involved two different displays. One display was similar to that shown in Figure 24. This view included an airport surface display, flight list, message window, and departure metering procedure management window.

The departure metering procedure management window, shown in the lower left corner of Figure 24, provided controls for adjusting the departure metering procedure parameters. Each control allowed the participant to type the desired number in the text box or use the up or down arrows to modify the parameter. The participant had to click on the Apply button for the changes to take effect. Controls for adjusting the metering procedure parameters consisted of functions allowing the participant to modify the:

---

11 www.gotomeeting.com
Figure 24. Surface Display Only interface.

- Expected departure capacity for the current and all future time periods.
- Expected departure capacity for individual time periods.
- Target number active for the current and all future time intervals.
- Target number active for individual time periods.

Alternatively, the participant could choose to direct the computer to make a one-time adjustment of the schedule using the current settings for expected departure capacity and target number active. This could be accomplished by clicking on the Adjust button and then clicking Apply.

Changes the participant made to departure metering procedure parameters using the departure metering procedure management window caused the computer to modify the target spot times for some number of flights to reflect the changes in the parameters and to keep the number active as close as possible to the target over time. The only flights whose target spot times were changed had current target spot times later than the time
indicated by the static time horizon (Surface CDM Team, 2011). For this study, the static time horizon was 30 minutes to reflect the time required to load passengers and otherwise prepare many aircraft for departure.

The second display is shown in Figure 25. This display included the same airport surface display, flight list, message window, and set of departure metering procedure controls as the first display. The difference between the two displays was the addition of current and recent past performance information for the airport and the metering procedure designed to provide the user an external memory aid to help him or her detect trends in departure conditions and/or departure metering procedure performance. This information was in the form of a chart showing the number of active flights over time. Yellow squares were printed on the chart to indicate that more than 90 seconds had passed since the last flight departed to alert the user to a large gap in departures.

![Interface including the Control Chart.](image)
The second display also included a table showing the actual number of departures from the runway during each 15-minute interval as well as summary statistics showing the average, minimum, and maximum number active for the runway during each 15-minute interval. Participants were able to view two hours’ worth of performance data at a time and had the option of scrolling to view data for different time periods.

If managing a departure metering procedure is viewed as a process control task, one would expect a graphical display of information about process performance to improve the operator's ability to manage the process (Hollnagel & Woods, 2005; Sheridan, 2002). The intent of the study was to determine whether providing a graphical display of the departure queue size relative to the target over time would improve the participant's ability to effectively manage the airport departure metering procedure. It was hypothesized that the graphical “control chart” display shown in Figure 25 would influence the participants’ strategy for managing the departure metering procedure.

The researcher confirmed that the participant’s computer and internet connection satisfied the study requirements by confirming that the participant could read the text on the display, requesting the participant to assess whether the animation in the simulation view was smooth enough for them to monitor aircraft movement. The participant also was requested to confirm that they could see all parts of the researcher’s screen.

The researcher introduced the departure metering concept, the DRC role, MJA, and the MJA airspace. The researcher also provided training on the tools in the simulated environment that the participant would be able to use to monitor and manage the departure metering procedure. Participants then performed the departure reservoir coordinator task in one or two simplified scenarios. All participants performed the task for two simulated hours of a scenario in which a few aircraft experienced small (random) delays at the runway (played at 1.8x real time). Five participants performed the task in an additional scenario in which the departure rate decreased slightly to simulate an event.
such as a more conservative local controller (such as a trainee) taking over the local control position.

After the participant completed the task, he or she was engaged in a structured interview to explore the feasibility of the metering procedure as described and experienced in general and at the participant’s airport in particular. The structured interview also provided feedback on display concepts for supporting the Departure Reservoir Coordinator (Surface CDM Team, 2011). The task the participant performed, scenarios during which they performed the task, and the structured interview questions are discussed in the following sections.

Task

The study task required the participant to act as the Departure Reservoir Coordinator and manage one side of the airport for one or two simulated hours, depending on the scenario. Participants were told that as a DRC their job was to manage the number of departures on the active movement area for one side of a busy airport. Specifically, they were to use the controls they were given to minimize the queue length but to ensure that the departure queue never went dry.

In addition, participants were to monitor flight operator conformance with target spot times. A non-conforming flight was defined as one that arrived to its spot more than five minutes before or after its target spot time. If a flight was observed to be non-conforming, the participant was to report it as such.

Participants also were to act as a liaison between air traffic control organizations, ramp controls and airlines, and the airport authority. As such, the flight operators would periodically make requests of the DRC that would help to manage their operations. Specifically, the study participant would be asked to perform flight swaps and to cancel flights in the system on behalf of the flight operators. Participants were asked to perform the flight swap or cancellation and then acknowledge that the request had been received.
and acted upon. This was a secondary task intended to reflect the likely reality that the DRC would be responsible for facilitating coordination between the ATCT and ramp control operators in ways other than manipulating the departure metering procedure parameters. In addition, such tasks were included in the responsibilities ascribed to Metering Desk personnel at JFK, as described in Chapter 2.

Adapting the Departure Metering Procedure

Participants were told that although their task was comprised of three components, their highest priority was to monitor and manage the departure metering procedure. They were told that they would periodically need to make adjustments to the expected departure rate or the target number active. This might be due to a change in the underlying departure rate compared with what was expected, such as in the case of a TRACON radar failure (Fernandes, et al., 2010). On the other hand, participants were told that an adjustment might be required because some small number of aircraft had required additional time than expected to depart. Perhaps there had been a short period of time when the lineup contained multiple heavy jets (which require greater wake turbulence separation than smaller aircraft and therefore greater time to depart and clear the runway for the next departure). In such a case, these departures would take longer than the average and cause the departure lineup to be a little longer than desired although the underlying departure rate had not changed.

Participants were free to choose the target number active that best fit their comfort level, although both scenarios in which participants engaged used the same default values for target average number of aircraft active (10) and expected departure rate (55 per hour, displayed as 13.8 per 15 minutes). Participants were allowed to change their target number active because of the variance among the number of aircraft participants in the ATCT surface management decision-making exercise wanted in the departure lineup.
Participants were encouraged to adjust the departure metering procedure parameters (expected departure rate and target average departure reservoir size) when they felt it necessary to do so. However, they were cautioned that every time they made an adjustment they were modifying the spot times for a number of flights and therefore impacting the operations of flight operator personnel – gate agents, ramp agents, and ramp control personnel. Participants were cautioned to be mindful of this tradeoff between adjusting the procedure frequently to meet their goals as a departure reservoir coordinator and making it hard for the airlines to plan their operations. Coordinated work often requires agents to sacrifice short term performance on their own goals for the benefit of the system (Woods & Hollnagel, 2006). In addition, Brinton, et al. (2010) found that unstable target spot times were difficult for flight operators to cope with in their report of Collaborative Departure Queue Management trials.

The nature of the departure metering parameter adaptation required differed in the two scenarios in which the participants performed the DRC role. These scenarios are discussed in the next section.

Scenarios

Participants interacted with one or two separate scenarios during the course of their study participation. Both scenarios included a “silent” increase in the number of active aircraft over time, but with different underlying causes. They were designed to require different reasoning processes to detect that the departure process had changed and to diagnose the reason for the change and the most appropriate corrective action to take.

The two scenarios exhibited “silent” increases in the number of aircraft active because they were considered to be caused by events that the DRC may not be able to detect other than by monitoring airport departure performance. The first scenario involved a number of flights that experienced random departure delays at the runway
threshold. The second scenario assumed a decreased departure rate such as may be caused by a local controller in training on the position.

Other causes for a change in departure metering procedure performance would likely be accompanied by cues that the DRC could perceive through tools other than the displays shown in Figure 24 and Figure 25. For example, if the DRC had access to the ATCT radio frequencies, he or she would likely hear about events such as a TRACON radar failure (Fernandes, et al., 2010) before their impact could be detected on the displays.

Scenario DRC A: Random Delays

In scenario DRC A, 17 flights were subjected to a random delay at the runway (average of 73.5 seconds). Therefore, if the participant did not adjust the departure metering parameters, the number of flights actively taxiing to the runway would increase from 9 aircraft at 1600Z to 17 at 1800Z (the target average was 10 aircraft). The departure metering procedure monitoring and management window showing the growth in the number of aircraft active if no action is taken is shown in Figure 26. Participants in the Control Chart condition would have seen such a display if they took no action.

It was hypothesized that participants might have difficulty diagnosing the cause for the increase in the average number of active flights because, as is visible in Figure 26, the departure rate (number of flights off) did not show a clear trend. It was expected that once the number of flights active reached some threshold, participants would use the “Adjust” button (shown in Figure 26) to initiate a software-controlled adjustment to the target spot times. It was hypothesized that all participants would not have the same threshold that would initiate action.
While participants using the second display that included the control chart could have observed the increasing trend in the number of active aircraft on the graphical display shown in Figure 26, participants using the first display did not have access to the graphical display (see the display shown in Figure 24). Their information reflected only snapshot information of current airport status such as the text box of summary information on the surface display, the locations of aircraft on the surface display, and/or from their memory of how many aircraft had been active at points in the past.

Scenario DRC B: Local Controller in Training

One participant in the ATCT surface management decision-making exercise discussed in the previous section described how training a controller on the local control position could impact the departure rate. An excerpt from the interview is provided in Figure 27. This was used as the basis for the second scenario, DRC B.

In scenario DRC B, the departure rate decreased from the default value of 55 aircraft per hour to 49 aircraft per hour for a period of 25 minutes (2202Z until 2327Z) to simulate a period during which a local control trainee might be on position. If the participant did not adjust the departure metering parameters, the number of flights
actively taxiing to the runway would increase from 13 aircraft at 2200Z to 19 at 2300Z (the target average was 10 aircraft). The departure metering procedure monitoring and management window showing the growth in the number of aircraft active if no action is taken is shown in Figure 28. Participants using the control chart display would have seen such a display if they took no action.

ATCT: “A lot of times the restrictions are multi-causal. I mean, in this case weather being the predominant reason, but there also could be other issues, for example volume, maybe, but not related to weather; a disabled aircraft, a closed taxiway, equipment outage, training in progress in the control tower. All these things lend to that point of 15 minutes or more [reportable delay]…”

OSU: “They, um, actually will slow down because of training in the tower?”

ATCT: “Um, theoretically, uh, yes. I mean, obviously, the trainer should not let it go to that point, safety is first, but sometimes when you train you have to let the trainee go and march and learn. So if there’s a little bit of inefficiency for the moment because the trainee is trying to learn how to do it, so be it. A lot of that data isn’t captured. But when you get to the point where you got a lineup and delays are 10, 12, approaching 15 minutes, what does the instructor do? Put the trainee aside and say Oh, let me take the frequency, otherwise we’re going to have delays, clean it up if you will, and then give the trainee back the frequency? Well, that all sounds good and dandy … but in practice the trainee has to work and figure it out on his own…”

OSU: “Okay. …When you have a controller trainee, is anybody discussing on the frequency the fact that this guy is new? Or is it just sort of, things are just moving more slowly because the person has to spend more time thinking about what they’re doing?”

ATCT: “Well, a lot of times… the trainee, even a new one, may sound really good. … But, in fact he is less efficient because he’s not maximizing the use of his knowledge and his future knowledge.”

Figure 27. How a local control trainee could slow the departure rate.

It was expected that once the number of flights active reached some threshold, participants would decrease the expected number of flights off by one or two flights per 15 minutes using one of the controls shown in Figure 28 to initiate a software-controlled adjustment to the target spot times. It was hypothesized that all participants would not have the same threshold that would initiate action.
While participants using the control chart display could have observed the increasing trend in the number of active aircraft on the graphical display shown in Figure 28, participants using the first display without the control chart did not have access to the external memory aid provided by the graphical display (see Figure 24). Instead, they had only a snapshot view of current airport performance from the text box of summary information on the surface display that included the number of flights off during the previous 15 minutes and the current locations of aircraft on the surface display to supplement their memory of how many aircraft had been active at points in the past.

After the participant had completed one or two “shifts” as a Departure Reservoir Coordinator he or she was engaged in a structured interview, described next.

**Structured Interview**

After the participant had acted as the DRC in one or two different scenarios, he or she was engaged in a structured interview to gain feedback on the display concepts and tools for adjusting the departure metering parameters. Interview questions included:

- How often did you look at the departure lineup?
• How often did you look at the numbers in the text box on the surface display?
• How difficult [or easy] was it to determine how well you were doing at managing the metering procedure?
• Did you have enough information to manage the metering procedure?
• What additional information / displays might help manage the metering procedure? Where would you expect to get this information?
• Do you think that the expected number off and target number active are sufficient controls to manage the procedure? What other controls might be appropriate?
• Were you at all concerned about what was going on with the center runway?

The researcher also opportunistically asked questions that were specific to a participant’s actions while performing the DRC task. Some of these questions, which were not asked of all participants, included:

• I noticed that after you made a change you seemed to pause. What was going through your mind? What were you looking at? What were you looking for?
• I noticed that you increased the expected rate at around 2130Z when the actual number active was spot on the target. What was going through your mind?
• Despite your changes, the number active did creep down to 7 and then 8. What was going through your mind when you saw that? Why did you wait as long as you did to make a change?
• At some point you seemed to decide that you had caught up on the ramp control/airline requests and you quit processing them for a while. What was the rule you were using?

Additional questions were intended to provide feedback on the displays that the participant had used to perform the DRC task. These questions requested the participant to provide a rating on a 5-point scale, where 1 meant “not at all useful” and 5 meant “extremely useful” for each of the following display elements:
• Data in the text boxes on the airport surface display.
• Control allowing the user to modify the expected departure rate.
• Control allowing the user to modify the expected departure rate for specific time intervals.
• Control allowing the user to modify the target number active.
• Control allowing the user to modify the target number active for specific time intervals.
• “Adjust” button.

The last portion of the interview was less structured and encouraged the participant to consider the applicability of the departure metering concept to an airport where they had reported to the research team that they had worked. The participant was shown a current diagram of the airport in question. The interviewer asked about ways in which they believed the departure metering concept would need to be modified to be successful at an airport with characteristics of the airport where they had worked such as:

• Multiple ramp control operators.
• No ramp control operator such that the ATCT controlled aircraft pushing back from the gate.
• Limited ramp area and/or holding areas on the active movement area.

The scenarios were presented using the Collaborative Airport Traffic System (CATS) simulation environment (Fernandes, et al., 2011) and the displays used by the participant were used to structure the interviews. The participants’ feedback on the tools and displays they were provided is discussed in the next section.

Results

Participants gave varied feedback based on their experience with the prototype tools to support the DRC. As part of the follow-up interview, they were asked the
questions outlined above. In particular, they were asked to provide ratings of the usefulness of the tools and displays they had used to perform the departure metering procedure management exercise. They were also asked to provide feedback on the departure metering concept in general.

In performing the DRC task, participants tended to select one control of those shown in Figure 24 and Figure 25 that they would modify. For example, one participant modified the departure capacity for the current and all future time periods multiple times, but no other participants modified that parameter at all. Similarly, 3 participants modified the expected number of departures for specific time periods, but the remainder did not. Three participants modified the target average number active for the current and all future time periods, while only 2 participants modified the target number active for individual time periods. No participants used the Adjust button.

The strategies participants seemed to use (based on observation of their mouse movements on the display) varied as well. The main source of information seemed to be the physical departure lineup. Six participants appeared to look at the departures in the lineup. Three were directly observed counting aircraft icons in the lineup, despite the presence of the summary text box right next to the lineup, and two were observed clicking on one or more aircraft icons. Four participants said they looked at the departure lineup as shown on the surface display, as shown in Table 17.

Table 17. Displays participants said they used to monitor the metering procedure.

<table>
<thead>
<tr>
<th>Display Element</th>
<th># Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Departure lineup</td>
<td>4</td>
</tr>
<tr>
<td>Text box on surface display</td>
<td>2</td>
</tr>
<tr>
<td>Control chart</td>
<td>1</td>
</tr>
</tbody>
</table>

One participant said, “Looking at the queue was useful. [I saw it was a] little long [which] directed me down to the numbers [where I could] look to see how many were
starting taxiing, how many weren’t taxiing. [The] departure queue out there was my first clue that something was amiss and needed to change.”

When asked about the text box on the surface display (shown in Figure 25), two participants said that they preferred counting the aircraft in the lineup because the text box did not distinguish between aircraft in the departure lineup and aircraft anywhere else in the active movement area. One participant said, “I was more often counting the lineup because this active number reflects the active aircraft moving on the surface, it doesn’t take into account just the aircraft in the lineup. I was using the visual of the number in the lineup and then using the active number to gauge the aircraft I had moving.” Indeed, two other participants were observed searching the surface for aircraft that were active but not yet in the lineup.

In addition to the number of aircraft in the departure lineup, three participants were observed looking at flights moving in the ramp area. One participant said he used the number in the ramp shown in the text box “because that gave me an inclination of how many were moving, that weren’t active. … [I was] adding those into… the number active, so if I saw the number active high but nothing in the ramp, I thought okay, we’re going to end up whittling the line down. If I saw an active of… 20… I didn’t have many, if any, in the ramp so I knew that yes there’s a lot moving on the taxiway but there’s nobody else pushing back is the way I was looking at it. That was what I was looking at it for the active number and where the line was.”

Usefulness of Conceptual Displays and Prototype Tools

As part of the follow-up interview, participants were asked to provide ratings of the usefulness of the tools and displays they had used to perform the departure metering procedure management exercise. These questions covered the text boxes on the airport surface display providing summary information (shown in Figure 24 and Figure 25), the controls allowing them to modify the expected departure capacity and target average
number active, and the “Adjust” button in the departure metering procedure management window. In addition, participants using the control chart display shown in Figure 25 were asked about the usefulness of the control chart and the yellow squares indicating a gap between departures.

Text Boxes

To obtain feedback on the usefulness of the text boxes on the airport surface display (visible in Figure 24 and Figure 25), participants were asked to rate the usefulness of the information provided in the text boxes. They were asked, “On a scale of 1 to 5, where 1 means ‘Not at all useful’ and 5 means ‘Extremely useful,’ please rate the usefulness of the information in the text boxes on the airport surface map.” While asking the question, the researcher used the cursor to outline the text boxes on the shared display to draw the participant’s attention to them. The distribution of participants’ responses is shown in Table 18.

Table 18. Usefulness ratings of text boxes on airport surface display.

<table>
<thead>
<tr>
<th>Response</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>3.5</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

Six participants provided an average response of 3.75, with a variance of 0.48. The participants made comments such as the following:

- “I was using the visual of the number in the lineup and then using the active number to gauge the aircraft I had moving…”
- “I like the way it’s separated out – blue and purple (or pink?) – I can focus on those pink airplanes and I know that those are mine. Anything that’s blue I can disregard except [as an] advisory.”
- “On a weather not a factor day, with no restrictions, no anything, it’s not really needed. If there’s no restrictions, no weather, nothing holding us back… I don’t think it’s needed. However, on a weather day where weather is
definitely a concern and a restriction to our ability to move airplanes I could see where it would be helpful… There were certain things we used to do at San Francisco to determine if we had enough at the runway. This might have helped knowing what we had.”

- “Those were the numbers that you were ultimately trying to keep right and it shows how your judgment translated” from the departure metering procedure management window to the departure lineup.

As a follow-up question, the researcher asked, “What additional information would you provide in the text boxes?” One participant suggested adding arrival information and the departure SID each aircraft expected to use. A second participant pointed out that flight status was not labeled consistently between the text boxes and the flight list. For example, the text boxes provided a count of the number of active aircraft whereas the flight list would label an active flight as “Taxiing.”

After the one participant suggested providing departure fix information in the text boxes, the researcher asked later participants whether they thought that information should be added. Three of those participants agreed that departure fix information should be included while a fourth said that it should not be included. Participants provided comments such as:

- If the ground controller sees that information “they will be able to separate the SIDs.”
- “Instead of Treat, Creak and Knave [60-mile departure fixes] have the inner fix [heading, e.g., Diver, Coper, and Altes, shown in Figure 12 and Figure 21] and go with that.”

**Departure Capacity Input**

As noted above, participants could modify the expected departure capacity in two ways: they could make one entry that would modify the expected number of departures
during the current and all future time periods, or they could modify the expected number of departures for one or more individual time periods. One participant used the single entry to modify the expected departure capacity for the current and all future time periods and three participants modified the expected number of departures during individual time periods.

Participants also were asked to rate the usefulness of the ability to modify the expected departure capacity (number of flights off per 15 minutes) by making a single entry that would impact the current and all future time periods. The researcher asked, “On a scale of 1 to 5, where 1 means ‘Not at all useful’ and 5 means ‘Extremely useful,’ please rate the usefulness of allowing input of a modified departure rate.” While asking the question, the researcher used the cursor to highlight the control in question. The distribution of participant responses is shown in Table 19.

Table 19. Usefulness ratings of control to modify default expected departure rate.

<table>
<thead>
<tr>
<th>Response</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

Four participants provided an average response of 3.5 with a variance of 9. They provided comments such as the following:

- The expected departure rate is useful as a way to predict what is expected to happen, and to communicate that expectation to the flight operators. However, the expected departure rate should not be used as a performance target for the local controller. “I don’t think that it’s something that you would say, okay, uh, tower man, here’s what we expect, we want 14 out of here in the next 15 minutes. Either that or you’re back on the bench, okay? … As for trying to dictate policy I would not say it is a useful tool. But as for a possible prediction of what we’re expecting to be doing I would say it would be a good
tool. A very good tool.” Also, “I could see it as a gauge of… this is what we normally run, this is what we did run.”

- “[I would] rather make the changes every 15 minutes… rather than watch a whole hour.”
- “That’s based on weather. If it’s a weather day, [I give it a rating of 4].”
- "If the main goal is to keep whatever target number active- If you’re trying to accomplish what you said are the goals [of a departure metering procedure] then how else are you going to do it?"

The researcher also asked the participants to rate the usefulness of being able to modify the expected departure rate for individual time intervals. The researcher asked, “On a scale of 1 to 5, where 1 means ‘Not at all useful’ and 5 means ‘Extremely useful,’ please rate the usefulness of allowing input of a modified departure rate for specific time intervals.” While asking the question, the researcher used the cursor to highlight the control in question. The distribution of participants’ responses is shown in Table 20.

Table 20. Usefulness ratings of control to modify single expected departure rate.

<table>
<thead>
<tr>
<th>Response</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

Three participants provided a rating with an average of 4.33 and a variance of 0.67. One participant commented, “Usefulness would definitely be a 5. [It] would give you the opportunity to slow it down or speed it up depending on the type of aircraft.”

Target Active Input

Similarly to the expected departure capacity, participants had two options for modifying the target average number of active aircraft. They could make a single entry that would impact the current and all future time periods, or they could modify the target number active for individual time periods. Three participants used the single entry that
impacted the current and all future time periods and two participants modified the target number active for specific time periods.

Participants also were asked to rate the usefulness of being able to modify the target average of number of active aircraft by making a single entry that would impact all future time periods. The researcher asked, “On a scale of 1 to 5, where 1 means ‘Not at all useful’ and 5 means ‘Extremely useful,’ please rate the usefulness of allowing input of a modified target number active for the current and all future time periods.” While asking the question, the researcher used the cursor to highlight the control in question. The distribution of participants’ responses is shown in Table 21.

Table 21. Usefulness ratings of control to modify target average number active.

<table>
<thead>
<tr>
<th>Response</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>3.5</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Four participants provided an average rating of 3.38 with a variance of 8.69. A fifth participant did not provide a rating because “I was going to ask you about that… I didn’t grasp that one. I just figured the capacity number works with the target number… [I] wasn’t sure what kind of effect that would have on the whole situation.”

In addition, participants were asked to rate the usefulness of being able to modify the target average number of active aircraft for individual time periods. The researcher asked, “On a scale of 1 to 5, where 1 means ‘Not at all useful’ and 5 means ‘Extremely useful,’ please rate the usefulness of allowing input of a modified target number active for specific time intervals.” The distribution of participants’ responses is shown in Table 22.

Table 22. Usefulness ratings of control to modify single target average number active.

<table>
<thead>
<tr>
<th>Response</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
Three participants provided an average rating of 3.33, with a variance of 8.67. One participant commented, “I like the flexibility it all gives you.”

**Adjust Button**

Participants also were asked to rate the usefulness of the “Adjust” button that signaled to the software that it should recalculate the target spot times, although no participants used the button during the exercise. The researcher asked, “On a scale of 1 to 5, where 1 means ‘Not at all useful’ and 5 means ‘Extremely useful,’ please rate the usefulness of the ‘Adjust’ button.” The distribution of participants’ responses is shown in Table 23.

Table 23. Usefulness ratings of "Adjust" button.

<table>
<thead>
<tr>
<th>Response</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

Four participants gave the Adjust button an average rating of 3.33 with variance of 7.78. They provided comments such as:

- “I wouldn’t want to take this away, I’m sure there’s some people that would, you know, do the one-time adjustment, some people may find that easier to do than [modify the expected number off for specific time periods]. I mean, again, you’re coming back to technique. The more buttons there are to push everybody’s going to pick the one they like best.”
- “I really didn’t understand what the adjust button meant… I’m sorry I didn’t take advantage of that.”

**Control Chart**

Participants using the control chart display gave positive feedback on their perceived usefulness of the control chart, but few seemed to actually use it. Two participants were observed looking at the control chart while performing the task (based
on their mouse movements). When asked about the usefulness of the control chart, one participant said that the chart provided “good information, [but] if I didn’t have it I wouldn’t miss it … as long as I could look up here [at the departure lineup] and see what the queue was doing.” A second participant felt the control chart would be useful for personnel not located in the ATCT that wanted to monitor airport departure performance:

The little graphic [is] kind of nice… You can see how we’re doing for the day. … [If the] target’s 11 and we’re getting 7 off at a time and you can go, okay, well, why did that happen. Well, you can use that to point to different things such as, well, was it weather, was there a mechanical at the runway and we had to stop for a minute, or who’s working the position… The TMC’s up there [in the ATCT] and you don’t really need a graph to see what’s going on [as a traffic management coordinator]… [But the] manager in the TRACON [or the] tower manager [not located in the ATCT cab], he can pull this up and see what’s going on.

Yellow Squares

Only one participant seemed to become aware of yellow squares that appeared while he was performing the departure metering procedure management task. When asked about the usefulness of the yellow squares on the chart, another participant responded that:

It’s going to make me wonder why a minute and a half went by and nobody took off… If I saw 3 or 4 of these little yellow squares grouped together I would start to wonder… [I would] look at the departure queue to see what it looks like… something’s going on somewhere.

Further, this participant suggested that a 2 minute gap in departures would be a more appropriate trigger for a yellow square to appear than the 90 seconds used in the scenarios “because it could be a heavy jet, could be 2 or 3 heavy jets in a row would not be uncommon.”
Location of Departure Reservoir Coordinator

During the introduction to the departure metering procedure concept, participants were told that it was not yet clear whether the departure reservoir coordinator would be located in the ATCT or elsewhere. While the question of where the DRC should be located was not posed to the participants, five of them volunteered their opinion and all said that the DRC should be located in the ATCT. Their primary reason was so that the DRC could have a live view of the airport surface and proximity to the air traffic controllers. The reasons they gave are shown in Table 24.

Table 24. Reasons participants said the DRC should be located in the ATCT.

<table>
<thead>
<tr>
<th>Reason</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Live view of airport surface</td>
<td>2</td>
</tr>
<tr>
<td>Proximity to ATCT controllers</td>
<td>3</td>
</tr>
<tr>
<td>Communication</td>
<td>1</td>
</tr>
<tr>
<td>Information availability</td>
<td>1</td>
</tr>
<tr>
<td>Rapport with ATCT controllers</td>
<td>1</td>
</tr>
</tbody>
</table>

One participant believed that proximity to the controllers was important so that the DRC could communicate with them. A second said that the DRC should have access to the information that is communicated among practitioners in the ATCT but not broadcast on the radio frequency:

[You said you had] not determined if this person would be in the tower… [If the DRC is not in the tower] you’d lose a lot of information just sitting in the room and watching this stuff… even if you had the frequency. … You’d lose the chatter. … Instead of you trying to figure out what’s going on and making a phone call… all that information would be available to you. … When you make that phone call you’re not guaranteed to get the same quality of information.

A third participant said the DRC would be able to build a better rapport with the controllers if he or she was located in the ATCT:
Having some guy in a distant room saying we need American 123 off of such and such a gate, you're going to get a ground controller turning around and look at you and saying yeah, right. Not only no, but heck no.

Still another participant said that not only should the DRC be located in the ATCT, but he or she should have an air traffic control background. He said that if the DRC did not have an air traffic control background:

That’s going to be a really hard sell to an air traffic controller… Controllers are real focused on the way they do things and to have a 3rd person come in with no background… [They] can have all the screens in front of them but… as far as a coordinator is concerned you need to have somebody with a strong air traffic control background. … [The] DRC needs to have a good, solid, high level tower background. … [If the DRC is located] in the TRACON [he or she] needs a radar background rather than taking somebody out of a small VFR tower and promoting him into a position like that.

Other Comments about Departure Metering

Participants often made comments about the departure metering concept throughout the study session. Some of these comments included reasons that participants were skeptical of the idea that the DRC would be a role affiliated with air traffic control. Rather, these participants thought it should be a flight operator function. One participant said, “In a way this seems like a position that would be not an FAA position.” Another said that managing aircraft that had not yet requested entry to the active movement area is “really not an FAA function. Once they come out we take the ball then. [We] coordinate with them if someone gets a delay time” but not for flights that are not otherwise subject to a delay.

Other participants expressed doubt that the flight operators would accept the departure metering procedure. One participant said, “I don’t think the airlines are going to like having this person tell them what to do. … Airlines expect [to] go to the runway and depart.” A second participant said:
I don’t see the point of dictating whether they get off the gate or don’t get off the gate. … [The flight operators] want that aircraft in the air. They’re losing money when it’s sitting on the ground. … [They want to] get it back out to the runway and on to its next destination.

Some participants saw the information display concepts as useful means for distant personnel to gauge airport surface performance. For example:

I don’t really see the purpose of FAA per se dictating policy to the airlines how to do their job… [But] this is no doubt a useful tool to see what’s going on and getting an idea” of airport departure performance. But “our whole job as controllers [is to] taxi to the runway [and the] tower [local] controller safely and expeditiously get him off the ground. That’s the whole job.

In addition, some participants were skeptical that departure metering would be particularly useful during normal operations because “on a clear day it’s just let them run but on a weather day it would be kind of nice to know how we’re coming up with it.” They suggested that departure metering might be useful during severe weather events:

With weather definitely [departure metering would be useful]. If west gates all are stopped, if they could keep the west departures on the ramp and not move them out onto the taxiways and runways that would certainly help the ground controller because they don’t have to find a place to put them out of the way. … I think what we have here would be helpful and also verbal communication between the [traffic management coordinator] and the ramp tower. … [There] definitely would be a lot of coordination between the traffic manager and this departure position and coordination between this departure position and the ramp tower. The departure position here is really … in the middle of a lot of that. … Typically traffic managers- I’m thinking of TMUs in the [airspace] – what’s important is the arrivals and you have to get the arrivals in. … At the same time [during my career] I saw… [it was] more and more important to get departures out. That’s where this departure position kind of gets put in the middle… as a supervisor in the middle between the radar rooms and the tower itself.
Some of those that remained skeptical of departure metering believed that the prototype tools could support improved coordination and flight operator decision-making during weather events. For example:

If the airline had that and they could see how many planes are taxiing out, planes at the runway [and the] interval between departures [they could make decisions like] I want this flight out so don’t push back this other flight. … He could say I need this gate. … [There are] things that they [flight operators] could do to help themselves. … [It] feels like you’re doing a lot of work here that if they had the info to look at they [flight operators] could do better decisions. … If they had ways to make adjustments to their own operation… this kind of a system would be not necessary.

Some participants suggested that the departure metering concept duplicated the efforts of flow programs managed through the ATCSCC. One participant, however, noted a departure metering procedure that had been in place at an airport where he had worked:

We used to do this in L.A. but we used to call it real time flow. [We were] looking at 15 minutes ahead all the time… how airplanes were going to be on the runways. We hardly ever went into gate holds. … [We] informed the airlines of the control windows that certain flights had and they would improvise… reposition the airplanes to delay somewhere else. I think that we’ve been doing this, what you’re trying to do... we’ve been doing it without the software.

Acting as a Liaison for Flight Operators

The subtask requiring participants to cancel flights and swap target spot times was a secondary task designed to increase their workload beyond that required of monitoring the departures. It was expected that giving the participants a secondary task would create a workload more closely mimicking that of the DRC. Note that such administrative tasks are required of Metering Desk personnel at JFK, as discussed in Chapter 2.

Messages requesting action by the participant were scheduled to arrive at a rate of 2-3 per simulated minute. Participants were asked to perform the action indicated in the
request and then type an acknowledgement in the same text window where the requests appeared. Participants were told that their first priority was to manage the departure metering procedure, their second priority was to monitor aircraft compliance with their target spot times, and their third priority was to perform the administrative tasks.

The administrative tasks turned out to consume more of the participants’ time than expected. Some participants were better than others at managing the priorities laid out for them in the tasks. Some decided that the aircraft for which flight operators were requesting action were scheduled far enough in the future that they could stop processing the flight operator requests long enough to monitor the departure reservoir for some time. Others, on the other hand, became fixated on processing the requests and seemed to pay little or no attention to the departure metering procedure performance.

In particular, the secondary task proved too engaging to allow the participants to think aloud while they worked. Therefore, the accounts related here are retrospective and based on the follow-up interview portion of the study session. After the participant completed the task, the researcher asked interview questions based on observed behaviors.

In addition, several participants expressed frustration at the tedious nature of the task. They considered it unrealistic both because of the workload and because the aircraft involved in the swaps and cancelations were more than one or two hours in the future. (This was to prevent aircraft times from changing during the portion of the scenario that the participant was working. Otherwise, the ability of the participant to manage the secondary task would impact the scenario that the participant saw.)

Discussion

In short, the results of the study were mixed. On one hand, participants had difficulty predicting what impact their actions would have, which implies that they needed better training on the tools, the airport, and the departure metering concept.
Between this and the small sample size it is difficult to derive definitive statistical results regarding their experience.

On the other hand, their experiences and comments provided a great deal of information about the usefulness of the concepts for the departure metering procedure and for the tools and displays. For example, the airport surface display was a key source of information. This is likely because it is a direct representation of a system with which they were familiar, even if abstract representations may be more effective in supporting process control tasks (Bennett, Toms, & Woods, 1993; Smith, Bennett, & Stone, 2006; Vicente, 2002). As noted above, airport surface surveillance displays are useful for a variety of roles and tasks in the NAS and a surface surveillance display is among the recommendations in Chapter 5 for supporting the Departure Reservoir Coordinator.

The text boxes on the airport surface display provided a snapshot view of current airport departure performance that some participants found useful. However, some participants wanted to see an additional category showing how many aircraft were in the departure lineup as well as the number of aircraft taxiing to the departure lineup and the number taxiing in the ramp area. This begs the question of how many separate categories of aircraft for which the system should provide a count, how those categories should be defined, and how the statistics should be displayed.

In particular, if the departure reservoir is defined as a complex parameter composed of multiple departure reservoirs of aircraft with different characteristics staged in different locations, such a snapshot view of departure reservoir statistics may not be feasible in the current format. In addition, if the departure reservoir includes aircraft staged, for example, on taxiway G holding short of the intersection with F – as recommended by some participants in the ATCT decision making study discussed above – it may be difficult to define the time at which an aircraft enters the departure lineup. In observations of facilities in which the Departure Spacing Program (DSP) was installed, a departure was considered to be in the lineup when its flight progress strip was scanned
and handed off from the ground controller to the local controller (Borgman & Smith, 2010). If the surface surveillance system had access to information from such software, then it could include a similar definition of “in the lineup.” However, all ATCTs do not have systems like DSP and it may be more difficult for the surface surveillance system to determine when an aircraft enters the departure lineup.

Participants did not unequivocally embrace the departure metering procedure concept. Some seemed to view it as potentially punitive to ATCT controllers and/or flight operators and counter to their goals. Some participants expressed concern that the expected departure rate would be used as a performance metric for local controllers, such as the participant quoted above who said, “I don’t think that it’s something that you would say, okay, uh, tower man, here’s what we expect, we want 14 out of here in the next 15 minutes. Either that or you’re back on the bench, okay?”

Other participants expressed a view that flight operators would not want to hold their departures on the gate and that there would be insufficient space in the ramp area to hold departures on a regular basis. For example, one participant said:

Sometimes you have to get departures off the ramp to make room for the arrivals to get into the [gates]. That can change where you’re holding your queue. Sometimes you can’t hold them in the gate. … DFW [is] not designed to hold departures in the ramp. [The] idea was departures get out and then arrivals get in.

The participants did seem confident that the Departure Reservoir Coordinator should be located in the ATCT, which is contrary to the example set at JFK (Borgman & Smith, 2010) or by the Surface CDM Concept of Operations (Surface CDM Team, 2011).

One difficulty of conducting the study remotely was in administering the usefulness questionnaire. Administering such a questionnaire on paper may have made it easier to encourage participants to provide a numerical rating. Most participants were happy to discuss the tools but did not readily provide a numerical rating. In addition, some participants spent a lot of time talking about the tools in other portions of the
conversation and the flow of the interview would have been disrupted by asking them to repeat the information in this format. Therefore, not all participants provided numerical rating responses to the usability questions, and the number of participants answering each question varied.

**Chapter Summary**

All of the research activities described here have contributed to an understanding of airport surface management in general and departure metering procedures in particular. Observing practitioners in situ helped develop an understanding of their environment and some of the challenges they face. It also helped understand the relationships among the roles and organizations in the highly distributed NAS. Understanding these relationships is important in designing procedures and tools to improve coordination and collaboration in the distributed work system.

Performing structured interviews with practitioners helped develop an understanding of their decision-making processes and the constraints of their domain. The interviews contributed to a model of practitioner performance sufficient to design concepts – what Woods and Hollnagel (2006) might call “design seeds” – for tools to support work in the domain. Specifically, the model of ATCT practitioner performance can be used to design tools to support the DRC in building a departure inventory that is compatible with the surface management strategies employed by ATCT controllers and traffic managers.

A number of general findings that emerged over the course of the research are summarized in Chapter 6. For example, practitioners performing different roles in the NAS sometimes use very different problem representations in their work which may have consequences for supporting a departure metering procedure. In particular, previous departure metering concepts described airspace constraints in terms
of departure route restrictions such as miles in trail (Borgman, et al., 2010b; Surface CDM Team, 2011), when in fact ATCT personnel transform these restrictions into surface management strategies involving departure staging locations, aircraft characteristics, and splitters. Such differences in problem representations have consequences not only for the design of tools to support the DRC, but also in supporting inter-facility coordination and collaboration throughout the NAS.

In addition, the research activities described in this chapter identified a number of strategies that practitioners use to cope with complexity and uncertainty. In many ways, these strategies reflect common themes that cross domains (Woods & Hollnagel, 2006). For example, ATCT traffic managers and ground controllers often used strategies that allowed distributed personnel to tactically respond to changes in the system in a coordinated way. To some extent, this reflects a complex system in which procedures are routinely used to aid coordinated contingency planning and constraint propagation (Smith, Beatty, Spencer, & Billings, 2003; Smith, Spencer, & Billings, 2007). But it also reflects a system in which practitioners explicitly consider complexity and uncertainty in developing and refining plans. In particular, several participants in the ATCT decision making study explicitly considered the level and division of workload across local and ground controllers in determining how they would stage aircraft for departure.

However, the main purpose for the research activities described in this chapter was to derive information requirements and design concepts for supporting the Departure Reservoir Coordinator. These findings are described in Chapter 5 with a focus on how the information requirements support the process control task that the DRC is expected to perform.
Chapter 5: Departure Reservoir Coordinator Information Requirements

This chapter focuses on the Departure Reservoir Coordinator (DRC) role (Surface CDM Team, 2011) as applied to MJA and described in Chapter 2. It defines requirements for supporting one or more humans in that role. Note that because there are some differences between the departure metering concept described in this dissertation for MJA and the one introduced by the Surface CDM Team (2011), there may be some differences between the envisioned DRC roles.

The chapter presents an overview of the envisioned DRC role. It is not clear whether this role should be assigned to a traffic management coordinator in an ATCT or to a third party outside of the ATCT such as is done at JFK (Borgman & Smith, 2010), although participants in the departure metering concept evaluation exercise indicated that the DRC should be located in the ATCT. The most appropriate distribution of the DRC role may vary according to airport. Regardless of the location of the DRC, this chapter aims to define DRC responsibilities and the information requirements for supporting a person (or team of people) in that role. It puts forth a characterization of the role as one involving distributed adaptive planning, monitoring, coordination and collaboration. It uses information from the literature as well as from the research activities described in Chapter 4 as a basis for providing relevant information requirements. It also includes display concepts for supporting the DRC, most of which are implemented in the Collaborative Airport Traffic System (CATS) simulation (Fernandes, et al., 2011). Where available, feedback on those concepts from the concept evaluation activities discussed in Chapter 4 is described.
Departure Reservoir Coordinator Role

The DRC role may be performed by an individual or a team. They are likely to consult with others, and this chapter does not distinguish between information received from other people via telephone, chat, or other communication device versus information provided via computer displays. It is possible that some of the functions ascribed here to the DRC should be distributed among traffic management personnel in the ATCT, TRACON, and/or ARTCC. Who should be responsible for performing the DRC role, where the DRC responsibilities should be located physically, and how the DRC should interact with others are important open questions. Such questions can best be answered after a functional analysis of the requirements of the DRC role has been completed and the expertise required of personnel taking on the role is well understood. The findings of the functional analysis presented in this chapter and observations of Metering Desk personnel at JFK (Borgman & Smith, 2010) indicate that the expertise required for the DRC is similar to that of traffic managers in the ATCT and TRACON.

The departure reservoir for which the DRC is responsible acts as a buffer against a variety of contingencies, including weather impacting the availability of one or more departure routes and equipment failures (Fernandes, et al., 2010). For example, if westbound flights are restricted such as due to weather, the target departure reservoir may be described according to the number of westbound flights that should be active and where those westbound flights should be staged, along with the number of other (non-westbound) flights that should be active and where they should be staged. This is similar to the “metering categories” described by the Surface CDM Team (2011). Note that in this document, the departure reservoir is discussed as if it is a single entity unless it is important to emphasize the compound (and dynamic) composition of the departure reservoir.

A desirable departure reservoir is as small as possible to limit the time aircraft must spend in the queue (Borgman, et al., 2010b). Note that this priority sets the DRC
role apart from other traffic management roles. However, the departure queue should
never go dry unless there is not demand that could have used the available capacity; there
should always be a flight ready to depart that can use available airspace. “You have to be
somewhat seamless in your ability to continue departing aircraft,” said one former
ARTCC traffic manager, even when airspace availability is uncertain. In some places,
“you have airspace that goes unused and departures that still don’t get out.”

ATCT controllers should have sufficient aircraft available to avoid wasted
capacity. The departure reservoir also should have a suitable mix of aircraft to build an
efficient departure sequence that enables ATCT controllers to maximize departure
throughput (Borgman, et al., 2010b). In addition, access to the departure reservoir should
be equitable to flight operators.

As a distributed adaptive planning task, departure reservoir management requires
planning, monitoring, diagnosis, adaptation, coordination, and communication. Each of
these sub-tasks requires appropriate support, but they are not independent of each other
and the system design needs to support all of the sub-tasks together. The following
sections outline the information requirements associated with each of these functions.

### Planning Functions

In order to appropriately allocate departure capacity to aircraft, the DRC must
anticipate the departure rate given dynamic and uncertain departure conditions and set the
departure metering procedure parameters accordingly, keeping in mind that different
departures may be impacted differentially by uncertainty in departure conditions.
Anticipating trajectories of system parameters is a critical part of planning (Hollnagel &
Woods, 2005; Sheridan, 2002), particularly in the face of uncertainty (Smith, Beatty,
Spencer, & Billings, 2003), and the ability to do so is a hallmark of expertise in a domain
(Woods & Hollnagel, 2006).
Anticipate Departure Rate

Departure conditions are strongly impacted by surface and airspace constraints. They are uncertain and dynamic in both time and space and may impact different departures differentially over time. Therefore, the DRC should be able to anticipate departure rates for different classes of departures to most effectively characterize the expected airport departure capacity. Another key factor in the anticipated departure rate is the mix of aircraft available for departure in a given time period. Note that these three main considerations – surface constraints, airspace constraints, and departure demand all are dynamic, are subject to uncertainty, and interact with each other in space and time. Supporting the DRC in planning requires making salient surface and airspace constraints that are likely to interact with departure demand.

Surface Constraints

Surface constraints most likely to impact the runway departure rate are those associated with runways and taxiways. Runway availability, condition, and configuration determine which runways are in use for departures. They contribute to the runway occupancy time of each departure and the time required between departures. Runways can be unavailable for a variety of durations and reasons ranging from a long-term closure due to construction to a short-term closure due to a disabled aircraft or snow removal (Billings, Spencer, & Smith, 2001; Borgman & Smith, 2010; Fernandes, et al., 2010). Even when runways are open weather conditions such as visibility, precipitation and winds can require aircraft to take longer to depart than usual, and runway surfaces can be contaminated by precipitation or foreign objects (Billings, Spencer, & Smith, 2001).

Runway configurations introduce procedural constraints on the departure rate. Under normal conditions, aircraft can depart from a runway approximately 1 minute apart if there is no interaction between runways, leading to a departure rate of approximately
60 per hour. However, the departure rate decreases if the runway is shared between arrivals and departures, intersects another active runway, or is too close to a second parallel runway (Billings, Spencer, & Smith, 2001). In addition, some aircraft are unable to use some runways (or are only able to use them under suitable flight conditions). Typically, each airport has local standard operating procedures indicating the maximum departure rate for a given runway configuration (Federal Aviation Administration, n.d.). Such rules of thumb are simple to calculate and allow ATCT personnel to quickly make capacity and delay estimates. They can be included in software-computed default values for maximum expected departure rate in a given runway configuration.

Certain weather conditions, particularly those impacting wind, visibility, and runway contamination, can contribute to uncertainty in runway availability for some or all aircraft.

Taxiway availability and condition can impact the ability for aircraft to get to the runway for departure. The availability and condition of various taxiways can be impacted by many of the same constraints as those impacting runways such as unavailability due to construction or a disabled aircraft, or unsuitability for use by certain aircraft. Taxiway congestion and gridlock also can impede aircraft flow to the departure runway.

Note that some of these constraints are moderately predictable, such as construction or snow removal, while others are unpredictable such as an aircraft experiencing a mechanical issue. Their net result is an impact on the ability for aircraft to reach the departure runway.

Table 25 summarizes some surface constraints and the information that can indicate to the DRC the likely impact of those constraints on the ability for aircraft to reach the runway and depart. Those constraints that are often subject to considerable uncertainty are indicated.
Table 25. Surface constraints that can impact departure rate.

<table>
<thead>
<tr>
<th>Data</th>
<th>Surface Management Consideration</th>
<th>Subject to Uncertainty?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Runway configuration</td>
<td>Procedural constraints on departure rate</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Aircraft that can use each runway</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Which runways are in use for departures</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Which aircraft are assigned to each runway</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Typical staging areas for departures</td>
<td></td>
</tr>
<tr>
<td>Runway condition</td>
<td>Runway occupancy times</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Surface contamination</td>
<td></td>
</tr>
<tr>
<td>Runway availability</td>
<td>Long-term closure</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Short-term closure</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Suitability for certain aircraft</td>
<td></td>
</tr>
<tr>
<td>Weather conditions</td>
<td>Visibility</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Precipitation</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Winds</td>
<td>X</td>
</tr>
<tr>
<td>Taxiway availability</td>
<td>Long-term closure</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Short-term closure</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Suitability for specific aircraft</td>
<td></td>
</tr>
<tr>
<td>Taxiway condition</td>
<td>Contamination</td>
<td>X</td>
</tr>
</tbody>
</table>

Figure 8 on page 59 above shows an example surface surveillance display that can be used to provide the DRC information about surface constraints. The display is embedded in CATS (Fernandes, et al., 2011) and formed the baseline display for the concept evaluation activities described in Chapter 4. Aircraft icons are color coded to indicate the runway they are expected to use. Color coded aircraft icons have been observed on surface displays installed in a number of different facilities (Fernandes & Smith, 2011b). Often, icons are color coded to discriminate between arrivals and departures or to indicate that an aircraft has been active longer than 60 minutes. Color coding by assigned runway, as shown in Figure 8, would be particularly helpful if departure reservoirs are separated by assigned runway as they were in the departure metering concept evaluation exercise discussed in Chapter 4.
Indications of additional surface constraints can be added to the surface display. These can range from indicating current runway configuration to an alert that a runway or taxiway has been closed. Airspace constraints, on the other hand, can more easily be represented on a different display.

Airspace Constraints

Airspace constraints most likely to impact the departure rate are those associated with weather and traffic volume. Weather conditions, particularly convective weather, are routinely cited by practitioners as a chief cause of delays in the NAS. Not only can the weather directly cause delays for departures, but also it can delay arrivals, which in turn impacts the ability for flight operators to prepare departures in a timely manner.

Convective weather can be very dynamic in time and space, creating conditions in which, according to one retired ATCT traffic manager, “It’s terrible to be working in a tower when one of these things happens. It’s ‘stop these, stop these, how long?’, and you don’t know.” Under such dynamic conditions, said one ramp control director, “you do the best you can” (Borgman & Smith, 2010). Planning during such conditions may require adaptation on a short time horizon.

Weather Forecast

Weather forecasts represent a commonly observed class of information available to and used by traffic managers and ramp control operators alike (Borgman & Smith, 2010). The Corridor Integrated Weather Service (CIWS) and the Integrated Terminal Weather System (ITWS) are commonly observed weather tracking and forecasting tools that are expected to be among NextGen tools (FAA, 2010a).

CIWS images from the Dallas, TX, area from July 26, 2010\(^{12}\), were used in the ATCT surface management decision making study described in Chapter 4. Example

---

\(^{12}\) The weather images were provided by Dr. Rich DeLaura of the MIT Lincoln Laboratory.
images are shown in Figure 13, Figure 14, Figure 16, and Figure 18. The user is able to view current weather radar images as well as forecasts for the coming 2 hours. Results from these interviews also verified that departure reservoir characteristics should include location on the airport surface, departure fix, and departure direction because these were consistently used by ATCT personnel to define their surface management strategies.

The CATS weather displays shown in Figure 13, Figure 14, Figure 16, and Figure 18 include a diagram of departure routes and departure fixes. This allows the user to view weather constraints relative to departure routes. Note that CIWS installations also provide access to such a departure route diagram but that most traffic managers do not use them because they know where the routes are. However, the concept evaluation activities described in Chapter 4 for which these displays were used involved notional departure routes for a notional airport with which participants were not familiar.

According to one former ARTCC traffic manager, weather systems extending to altitudes of “30 [thousand feet] and above, within 120 miles of the airport, they’re not going to fly through that…” DeLaura, Robinson, Todd, and MacKenzie (2008) reported that precipitation intensity of level 3 represents a threshold for when pilots start trying to avoid a weather system. In the weather displays shown in Figure 13, Figure 14, Figure 16, and Figure 18, level 3 intensity weather is shown in yellow. Orange and red portions of the images are more intense than level 3 while green portions are less intense.

When presented with images representing precipitation that had decreased in intensity to level 3, the ARTCC traffic manager said, “[I would] start to consider opening up [that route] at this point while there’s still a little yellow [Level 3 activity]. I’d probably try to send a pathfinder out that route if I could work that to see how a flight managed with an eye toward hoping it would open in 15-20 minutes.”
Route Availability Planning Tool (RAPT)

Weather forecasts can help the DRC anticipate when the ARTCC is likely to seek a pathfinder for a route that has been impacted by weather and can help the ATCT and flight operators identify an appropriate flight. However, airspace constraints such as those due to weather are only relevant if they are likely to impact departures. The Route Availability Planning Tool (RAPT) forecasts the impact a weather system is likely to have on departure routes in the New York area (DeLaura, et al., 2008). It has been observed in ATC and flight operator facilities in the region, and personnel have stated that it is useful for planning (Borgman & Smith, 2010).

RAPT is displayed as a table integrated with the CIWS display indicating the expected impact of weather systems on specific departure routes over time (DeLaura, et al., 2008). Figure 29 shows a table similar to the RAPT display that was adapted to the notional airspace used in this work (Borgman, et al., 2010a). Green cells indicate that the route is expected to be available at the indicated time, red indicates that the route is expected to be closed at the indicated time, and yellow indicates that the route may be impacted by weather.

<table>
<thead>
<tr>
<th>Status</th>
<th>Departure Fix</th>
<th>2200</th>
<th>2205</th>
<th>2210</th>
<th>2215</th>
<th>2220</th>
<th>2225</th>
<th>2230</th>
<th>2235</th>
<th>2240</th>
</tr>
</thead>
<tbody>
<tr>
<td>KMJA</td>
<td>Current Time 2100Z</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Off Time</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NOLJA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NELYN</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KNAVE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NEXAR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AKUNA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BANDY</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BEATY</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EARTZ</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BEAMBR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 29. Display similar to RAPT. Adapted from DeLaura, et al. (2008).

---

13 Image created by Eric Wiley.
Departure Route Restrictions

A display providing quick access to current airspace restrictions also would be useful for determining the likely departure rate. Figure 30 illustrates one potential interface for representing such restrictions in CATS. Restrictions are represented by their start and stop times, the restriction in place in terms of Miles in Trail (MIT), and the departure fixes impacted by the given restriction. To date, this display has not been included in any concept evaluation activities. Figure 21, Figure 22, and Figure 23 illustrate how such restrictions were presented to participants in the ATCT surface management decision making study described in Chapter 4.

![Figure 30. List of current airspace restrictions.](image)

Information Display and Dissemination System (IDS-4)

The information provided by the display in Figure 30 is similar to that provided by one page in the Information Display and Dissemination System (IDS-4) that has been observed in various ATC facilities (as well as one flight operator facility). IDS-4 provides a great deal of information about airport status and conditions. The following were observed, although the system contains much more information:

---

14 Display by Garth McMurray.
- Automatic Terminal Information Service, including weather conditions and other updated information about conditions intended for flight crews.
- Current restrictions with expected expiration times when available. These are often displayed prominently on overhead displays in an ATCT such that controllers have easy access to them.
- Wind speed and direction.
- Approaches in use and their status.
- Airport conditions and any equipment outages (e.g., beacons, taxiway lights).
- Page allowing traffic management personnel to enter airspace restrictions, Approval Request (APREQ) requirements, etc., as they are reported through the National Traffic Management Log (NTM) and/or telephone. This is the restriction information that is displayed for controllers.
- Radio frequency being used by each control position.
- Summary page showing winds, conditions (e.g., VMC or IMC), visibility and ceilings, secondary arrivals (i.e., which aircraft types can land on a secondary runway).
- Position relief briefings.

Each ATC facility has access to IDS-4 or a similar tool to help controllers and traffic management personnel remain up to date on airport status information. IDS-4 also was observed at one ramp control facility. Personnel there credited it with providing them key information that otherwise they would need to obtain from ATCT personnel via telephone. Thus, their access to IDS-4 reduced the time required to coordinate because it “cuts down on the phone calls. We used to call them [the ATCT] saying, ‘I see we have 4 Whites just sitting out there. What’s going on?’” It would be useful for the DRC to have access to IDS-4 or a similar system that contains the same information that the ATCT uses to develop their surface management strategies. Ideally, the display provided to the DRC would automatically be updated when the ATCT display was updated.
Automated Terminal Information System (ATIS)

The Automated Terminal Information System, accessible through IDS-4 (as well as a radio frequency dedicated to airport information), provides information about runway conditions that can help the DRC determine whether aircraft are likely to occupy the runway longer than under normal conditions. Such information also is available through pilot reports to the local controller.

Operational Information System (OIS) Page

Information about programs published by the ATCSCC is available from the Operational Information System, or OIS (FAA, n.d.). In fact, this web page has been observed in most of the facilities visited during the course of this research, including ATCT, TRACON, ARTCC, ramp control, and flight operations center facilities. The Metering Desk at JFK was observed to have devoted an entire monitor to it. One Metering Desk controller said, “We absolutely live with this” to remain aware of programs that might impact the JFK operation. For example, if there is a Ground Delay Program in effect for a destination airport, the Metering Desk personnel know to look for Expected Departure Clearance Times (EDCTs) for flights to that destination.

Flight Schedule Monitor (FSM) and Traffic Management Advisor (TMA)

The Flight Schedule Monitor (FSM) and Traffic Management Advisor, although used for different purposes, both provide estimated arrival demand. Metering Desk personnel at JFK use FSM to anticipate arrival demand for each 15-minute period and from that determine the likely number of departures. Personnel at several facilities said that TMA has more accurate arrival predictions and therefore could enable the DRC to more accurately predict when there would be time for departures to use the shared arrival/departure runway. This information could help the DRC more precisely allocate target spot times and more precisely maintain the target departure reservoir characteristics.
Personnel at one ATCT reported using TMA to identify potential gaps in the overhead stream for their departures that were subject to Approval Requests (APREQs). Note that this way of using TMA to support departure activities seems similar to the concept for Departure Flow Management (DFM) presented by Spencer, et al. (2007).

**Arrival Rate Calculator**

Traffic managers typically do not try to estimate the departure rate directly but do consider the arrival rate. The departure rate can be inferred by subtraction if the airport has a maximum number of hourly operations. A historical average arrival rate is available for many airports from the OIS (FAA, n.d.), and tools such as FSM and TMA provide expected arrival demand.

In addition to tools available from the ATCSCC, personnel sometimes develop tools locally to support their needs. For example, a traffic management coordinator at EWR developed a spreadsheet for computing the expected arrival rate that considers the number of heavy aircraft expected over each arrival fix as well as the runway configuration, the expected presence of weather conditions “such that we’ll have to increase the miles in trail on the approach,” the maximum tailwind that different kinds of “airplanes can handle,” and the possibility that a secondary arrival runway will be “catching props only.” Computing the expected arrival rate requires similar variables to those required for computing the expected departure rate. Therefore, such information can support the DRC in estimating the expected departure capacity, particularly if the DRC has traffic management experience and a tool similar to the arrival rate calculator.

**ATCT Radio Frequencies**

Metering Desk personnel at JFK listen to the local control frequency “to see how fast they’re getting off.” They also listen to the ground control frequency, as do ramp control tower personnel at every facility visited during the course of this research (at least during severe weather events). The radio chatter provides a number of clues as to the
departure conditions, from pilot reports of braking action on arrival to indications of runway changes. One Metering Desk controller said that if they hear on the ground control frequency during a certain time of the day that the airport operator will be sweeping runways 22R and 22L, “that tells me they’re about to change runways to go to two departure runways.” That allows the Metering Desk to plan for a departure rate increase after the runway configuration change is complete.

**Impact of Airspace Constraints on Surface Traffic**

Weather can decrease the capacity of impacted airspace or even cause airspace to be closed, decreasing the rate at which aircraft can depart to that airspace. This can decrease the rate of departures to that airspace, and aircraft in the departure queue that are planning to use that airspace can impact the ability of other aircraft to depart to available airspace. These aircraft then effectively become a surface constraint.

Sometimes airspace constraints can have a direct impact on surface traffic, such as lightning strikes in the vicinity of an airport, which disrupt the activities of ground operations personnel that are required to prepare aircraft for departure. Such disruptions in the preparation of aircraft for departure necessarily decrease the flow of traffic to the runway for some period of time and then, according to one flight operator operations manager, “every terminal has 15 aircraft coming out at the same time,” creating a potential for surface congestion.

Constraints on the departure rate due to traffic volume work similarly to those due to weather except that they can be more predictable. Multiple visits to ATCTs have included observations of a telephone call from the TRACON indicating that a route is stopped. The ATCT supervisor or traffic management coordinator taking the call often asks how long the route will be stopped, and the response will typically be either:

- The stop is due to weather and it is not clear how long it will last.
The stop is due to volume and it will reopen in a few minutes (typically 5-15 minutes).

The result is a decrease in departure rate to the impacted airspace and any aircraft planning to use that airspace may be in the way of aircraft planning to use other, available, airspace.

Airspace constraints also take the form of procedural aircraft separation standards that maintain safety (Federal Aviation Administration, 2012). ATCT personnel consider these constraints and have strategies to sequence departures so as to maximize the departure rate. For example, they might sequence aircraft such that there are no two aircraft to the same heading back to back, as noted by several participants in the studies discussed in Chapter 4. ATCT controllers build sequences accordingly. This has direct influence on the nature of the ideal departure reservoir(s) and different ATCT ground controllers can have different preferences for how to build an efficient sequence.

Table 26 summarizes some airspace constraints and the information that can indicate to the DRC the likely impact of those constraints on the ability for aircraft to depart. Those constraints that are often subject to considerable uncertainty are indicated.

<table>
<thead>
<tr>
<th>Data</th>
<th>Surface Management Consideration</th>
<th>Subject to Uncertainty?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weather forecast</td>
<td>Impact on departure rate</td>
<td>X</td>
</tr>
<tr>
<td>Traffic volume</td>
<td>ATCT surface management strategies</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Desirable departure reservoir characteristics</td>
<td>X</td>
</tr>
<tr>
<td>Arrival delays</td>
<td>Resulting departure delays due to delays in arriving aircraft, crew, passengers, gates, etc.</td>
<td>X</td>
</tr>
<tr>
<td>Lightning strike</td>
<td>Resulting departure delays due to possible ramp closures, etc.</td>
<td>X</td>
</tr>
<tr>
<td>Procedural aircraft separation standards</td>
<td>Procedural constraints on departure rate</td>
<td>X</td>
</tr>
</tbody>
</table>
Departure Demand

Air traffic control personnel classify departures according to departure route and aircraft type, as observed in different facilities and noted by participants in the studies discussed in Chapter 4. As mentioned above, ATCT ground controllers try to build a departure sequence in which there are no departures to the same departure heading back to back. When airspace constraints cause route availability to be uncertain, they may include more than one splitter between any two aircraft to the same departure fix or heading. They also may develop a departure sequence that considers the performance of different aircraft types.

In addition to sequencing according to departure fix and aircraft performance, different classes of aircraft require different separation to prevent the trailing aircraft from entering the wake vortex of the leading aircraft (FAA, 2012). As such, the number of heavy, B757, or “super-heavy” aircraft in the departure sequence is an important factor in the maximum departure rate. Brinton, et al. (2010) incorporated the number of heavy aircraft in the schedule into their computation of the departure capacity.

However, the effect of heavy aircraft on the departure rate is not straightforward to calculate because ATCT controllers use strategies for accommodating heavy aircraft efficiently. Heavy aircraft are often grouped together so they depart sequentially, and the extra time required between heavy and non-heavy departures is often used for runway crossings (Idris & Hansman, 2000). Therefore, the DRC should be able to consider the aircraft mix in determining the likely departure rate, particularly because ATCT strategies for accommodating heavy, B757, and super-heavy aircraft may make it difficult for an automated system to reliably predict their impact on the departure rate.

In the departure metering concept assumed for this chapter, the DRC is responsible for creating a departure reservoir that allows the ground controller to build an
efficient departure sequence. Therefore, it is important for the DRC to understand the elements of an efficient departure sequence and have access to relevant information about aircraft and their characteristics. It also is important for the DRC to have access to information about the departure staging and sequencing strategies ATCT personnel will use. Table 27 summarizes the information discussed here that can help the DRC develop a model of the expected effects of departure demand on the departure metering plan. Those constraints that are often subject to considerable uncertainty are indicated.

Table 27. Surface management impacts of departure demand.

<table>
<thead>
<tr>
<th>Data</th>
<th>Surface Management Consideration</th>
<th>Subject to Uncertainty?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combinations of aircraft type</td>
<td>Wake vortex separation</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Aircraft performance</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ATCT staging and sequencing strategies</td>
<td></td>
</tr>
<tr>
<td>Aircraft destination, route, departure fix, and/or departure heading, controlled departure times</td>
<td>ATCT staging and sequencing strategies</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Number of splitters</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Target departure reservoir characteristics</td>
<td>X</td>
</tr>
</tbody>
</table>

Thus, the DRC should have access to the departure schedule. Basic schedule data includes flight data such as aircraft call sign, equipment type (aircraft type or aircraft weight class), and departure fix. Certain departure management tasks require access to expected departure times as well (Brinton, Lent, & Provan, 2010; Fernandes & Smith, 2011a). In truth, if a digital surface traffic management tool has access to any of the flight data in the FAA’s Traffic Flow Management System or Host Computer it should have access to all the data about a given flight. The challenge is in choosing which of the data to display to the DRC, how, and when.

Figure 31 shows a list of flights scheduled to depart from one runway over an approximately 40-minute period. The list can be configured to show any flight characteristics available to the departure metering procedure management software.
Figure 31. List of Runway 18C departures with flights to Wiley highlighted.

For the DRC concept evaluation interviews described in Chapter 4, the flight list provided the following characteristics:

- **Aircraft call sign**: A unique identifier for the aircraft consisting of a three-letter flight operator identifier and a four-digit number.

- **Equipment type**: A four-character identifier for the aircraft type, such as E145 (Embraer-145) or B737 (Boeing 737).
- Aircraft status: Indication of whether the aircraft is at the gate, starting its engines, taxiing in the ramp, at the spot waiting for permission to taxi, taxiing to the runway, or off.
- Target spot time: Time at which the aircraft is expected to be at a spot, ready to taxi to the departure runway.
- Actual spot time: Time at which the aircraft arrived to a spot, ready to taxi to the departure runway.
- Departure fix: Departure fix identifying the SID this aircraft intends to use.
- Gate: Terminal gate the aircraft is expected to use. The gate is used to determine which spot the aircraft is likely to use as well as the estimated unimpeded taxi time for that aircraft.
- Target out time: Time at which aircraft is expected to push back from the gate in order to meet its target spot time. In the departure metering concept flight operators are free to push back their flights according to their own gate use policies. The target out time is simply a guide.
- Actual out time: Time at which the aircraft actually pushed back.
- Target off time: Time at which aircraft is expected to take off from the runway so as to use the expected departure capacity to the extent possible. In the departure metering concept the ground controllers select aircraft to taxi in the manner that allows them to build their own departure sequence. They are not required to adhere to the order in which departures’ target off times are listed. The target off time is simply a guide.
- Actual off time: Time at which the aircraft actually departed the runway.

Participants in the ATCT surface management decision making and departure metering concept evaluation studies described in Chapter 4 wanted to see the departure headings of aircraft in the runway departure queue (as well as the departure fixes) to ensure that they had built an efficient departure sequence (i.e., a departure sequence in which no two flights to the same departure heading were back to back). Some
participants indicated that weight class information for aircraft in the departure queue was particularly important. (“We have such a fleet mix of wake turbulence at our airport, that’s a huge factor in our departure queues.”) This is consistent with observations that surface displays used in the field are configured to include weight class and departure fix in aircraft data tags (Fernandes & Smith, 2011b).

When presented with weather-related constraints, participants in the ATCT surface management decision-making study were most interested in aggregate demand for constrained departure routes as well as demand for the constrained direction. In planning for dynamic weather, individual flight information did not seem as important. This implies that context determines which aspect(s) of a flight are most important to decision makers, a finding that is consistent with the literature (Smith, Stone, & Spencer, 2006; Woods & Hollnagel, 2006).

Determining Which Flights to Display

In addition to which flight characteristics to display and how to display them, designers must determine which flights should have their information displayed at any one time. Context seems to determine which flights are most important, but the flights of interest do depend on the time horizon under consideration. For example, flights are likely of little interest to surface planning after they have departed.

Participants in the departure metering concept evaluation exercise described in Chapter 4 agreed that flights should be removed from the flight list after they are off. An important open question is the amount of time that should lapse between the time the flight takes off and when it is removed from the list. Alternatively, the list could scroll automatically so that the current time, the next 30 minutes, and the previous 15 minutes were shown at all times (one participant suggested keeping flights in the list for 15 minutes after they took off). However, a window that scrolled automatically may be frustrating to the user if he or she was trying to view a specific point in time not included in the default view. One participant, for example, scrolled the flight list so that the current
target spot times were always in the middle of the window regardless of whether flights that were currently taxiing were visible.

Determining Order of Flights in the List

While participants were performing the DRC task in the departure metering concept evaluation exercise, by default the departure list was sorted according to target spot times. However, it is possible for the ATCT ground controller to modify the order of flights as they taxi from the spots to the runway (even in CATS). Two participants expressed a desire for the flight list to reflect the lineup order of flights. “I’d want to know the order [in the lineup] so that I can tell if they’re like fixes” to determine whether the departure sequence will make efficient use of the runway.

The departure list window allows the user to sort the list by any available flight characteristic. It may be desirable for some users to sort the table according to expected off time, which could be updated periodically as the flights taxi out. Alternatively, data tags on the surface display can be used to indicate flight characteristics directly affecting the efficiency of the departure sequence (e.g., departure fix, aircraft type). Most observed installations of the Aerobahn surface surveillance display included both departure fix and aircraft type in the data tag (Borgman & Smith, 2010) and ASDE-X surface surveillance displays in ATCTs displayed different icons for heavy aircraft.

Flights with Control Times

An important departure demand consideration is the presence of departures assigned a control time such as an Expected Departure Clearance Time (EDCT) associated with a Ground Delay Program. One would expect an EDCT to be used as the target off time from which the departure metering procedure management software computes a target spot time for the flight. However, the experience of the JFK Metering Desk suggests that the ATCT might be able to get the flight an earlier departure time if the aircraft arrives to the runway early. At the Metering Desk they “never delay someone
because of an EDCT” because “sometimes there is a guy with an EDCT but he gets to the runway [early]. They [the ATCT] can call and may be able to get him out sooner.” One strategy the Metering Desk uses in prioritizing departures is that for an “airplane that’s been delayed already, we don’t contribute to that delay.”

A common ATCT strategy for managing flights with an EDCT is to estimate the number of aircraft that will need to depart before that flight can depart and create a sequence that has the right number of aircraft before the flight with the EDCT. If a flight with an EDCT 20 minutes from now starts to taxi, and the departure rate is 1 per minute, then there should be 19 flights before this one in the queue. Only if the EDCT gives the flight a long delay will the ground controller put the aircraft into a holding pad. In that case, the ground controller estimates the time the aircraft needs to leave the holding pad to get to the runway on time.

Selection Tool

Route restrictions are of most concern when there are multiple departures planning to use the impacted routes. The window on the left side of Figure 32 shows a concept for allowing the DRC to highlight departures according to departure fix. Such a feature might help the DRC predict which departures are likely to be impacted by weather constraints, the number of departures likely to be impacted, and their location and status. Flights can be highlighted according to runway, departure fix, direction, or status. Using this Selection Tool highlights aircraft icons on the surface display and in the list of flights in the departure schedule (shown in Figure 31). Spencer, et al. (2003) noted the usefulness of such integrated displays in the Surface Management System.

Highlighting aircraft by departure fix might also be useful to determine whether the departure reservoir for flights to that fix should be limited in size. Fernandes and Smith (2011b) described a situation in which ARTCC traffic management requested that a ramp control operator slow down departures to a departure fix with particularly heavy
Figure 32. Surface display with flights to Wiley highlighted in Selection Tool.

demand. The DRC could anticipate the ARTCC need to reduce the flow of traffic to a departure fix and build a departure reservoir accordingly.

Viewing aircraft by departure fix also allows the DRC to gauge the likely efficiency of the departure sequence. A key ground control heuristic for departure sequencing is to make sure there are not two flights in a row to the same departure heading. If two flights in a row are filed to the same departure heading, the ground controller is likely to look for an opportunity to put another flight between them as they taxi toward the runway. The DRC can use knowledge of this ground control heuristic to estimate the expected departure rate and therefore the expected time in queue of flights in the departure sequence.
All of the participants in the ATCT surface management decision making study found the ability to highlight departures to a given departure fix to be useful. When shown new departure restrictions, they asked to see how many flights to the restricted fix(es) were taxiing, how many would start taxiing soon, and when those were expected to request permission to enter the active movement area (target spot times).

During a visit to one ATCT a traffic management coordinator was presented with a figure similar to Figure 31 and Figure 32 combined. He said, “That is awesome.” He could see the usefulness of being able to highlight “all south flights. Where are they?” He suggested adding the following features to the selection and highlighting capability:

- Search for a flight by call sign.
- Sort the flight list by the “delay leader” or keeping the delay leader highlighted and showing its call sign and the amount of delay it has experienced. He said, “[Identify the] delay leader. Where is he?” The traffic management coordinator also wanted to know the status of the delay leader, which alternative routes might be appropriate for it, and demand for those alternate routes.
- User-customizable alert related to delay that would cause the aircraft icon (and maybe the flight in the list) to “start flashing” and “changing colors.” (Note that at least one commercially available surface surveillance display includes this feature.)
- Flight plan information, including the number of times that the flight plan has been revised.
- When receiving a message such as “White is stopped, [I want to know] where are my Whites? [I want to] take a look at them and the destination. [If I] click again, [show me] available routes” appropriate for flights to that destination. Include information about those routes such as “extra flight time.” He suggested incorporating information from CIWS as to whether the route is
open and Integrated Departure Route Planning (IDRP) tool data indicating demand for those routes. He said, “IDRP does a lot of that but it doesn’t have surface” views or information about where aircraft are on the airport surface.

In addition to the above, the Selection Tool shown in Figure 32 could be used to highlight aircraft subject to a given airspace restriction that may impact a departure fix, a given route, or a destination (or may exclude some aircraft).

The Selection Tool allows the user to filter aircraft by status when highlighting flights, as shown in the bottom left corner of Figure 32. Specifically, the user can choose whether flights should be highlighted if they are at the gate, taxiing in the ramp area, taxiing in the active movement area, and/or departed. When the traffic management coordinator’s attention was directed to that capability, he said that flights at the gate are “not in the game. I’m worried about guys taxiing,” indicating that by default these aircraft should not be included in selections made by ATCT personnel. However, a DRC is more likely to be interested in flights not yet taxiing when performing planning tasks.

A traffic management coordinator at a different airport, however, was less enthusiastic about the Selection Tool integrated with the airport surface display. Traffic management coordinators at this airport are typically located in the radar room of the TRACON (it is an upstairs/downstairs facility), meaning that they rely less on viewing the aircraft surface out the window to perform their duties than a traffic management coordinator in an ATCT might. The traffic management coordinator indicated that the Departure Spacing Program (DSP) tools allow him to carry out a search for flights by departure fix, destination, or direction, and that IDRP provided the same demand information as the Selection Tool shown in Figure 32. However, he did indicate that the capability provided by the displays shown in Figure 31 and Figure 32 was important and he was glad to have the capability through DSP and IDRP.
Setting Target Departure Reservoir Characteristics

Given the anticipated level of uncertainty in departure capacity, the DRC must determine how to build one or more departure reservoirs that will provide a sufficient buffer in case the actual departure rate is different than expected (or if the rate at which flights join the departure queue differs from the schedule). Departure reservoir parameters can include any or all of the factors listed above that impact the departure rate, such as departure destination, route, fix, and/or heading; location on the airport surface; assigned departure runway; and aircraft type. In addition, the makeup of the departure reservoir must be equitable to all flight operators.

Information requirement:
Anticipated level of uncertainty in departure constraints and departure capacity

Most published examples of departure reservoir management have assumed a single departure reservoir (Borgman, et al., 2010b; Brinton, Lent, & Provan, 2010; Burgain, Feron, & Clarke, 2009; Fernandes & Smith, 2011a; Fernandes, et al., 2010). The Surface CDM Team Concept of Operations (2011) is a notable exception. Of these examples, only Brinton, Lent, and Provan (2010) and the Surface CDM Team (2011) described departure metering schemes that explicitly considered the aircraft type for each flight in the schedule when determining the departure capacity.

In addition to aircraft characteristics, departure reservoirs can be defined according to relevant surface and airspace constraints, and departures for a single runway can be divided into multiple reservoirs. (Note that a single aircraft may belong to multiple departure reservoirs.) Results of the ATCT surface management decision making study described in Chapter 4 indicated that departure fix, direction, destination, and aircraft type were the flight characteristics most important in staging departures on the airport.
surface. Strategies that ATCT personnel expect to use to stage and sequence departures should be a key factor in defining target departure reservoir characteristics.

For example, JFK often uses two departure runways, say, 22R and 31L. The representation provided to Metering Desk personnel was observed to assume a single departure reservoir. However, they reported building departure queue size targets according to the principle of multiple departure reservoirs (one reservoir per departure runway). “In my mind I’m dividing [departures that will use Runway] 22-Right from 31-Left. In my mind I have 9 [aircraft] for each runway but I have only 6 available for 31-Left” because Runway 31L only serves certain departure fixes and demand for those departure fixes was less than for the departure fixes served by runway 22R.

These strategies used by the Metering Desk should be compatible with the surface management strategies used by the ATCT. One former ATCT and TRACON traffic manager from a different airport provided an example of runway use over the course of a departure push:

If you’re selecting a single runway to use for departures, it’s often at the beginning of a departure push… If many flights at the beginning of the departure push are at gates on one side of the terminal or the other you might start the departure push on the runway closest to their gates [to minimize taxi distance] and then switch to the other runway if later flights are at gates on the other side of the terminal. If you have arrivals as well, it’s easier to have them use the outer runways, the right or left runways, because it’s easier to line them up for arrival.

If the ATCT employs such a shifting strategy, departure reservoir targets may need to shift along with it. If the ATCT plans to change departure runway use, the departure metering plan should change such that the departure reservoir supports the transition from the first strategy to the second. Table 28 summarizes information about ATCT surface management strategies that can help the DRC to develop a departure metering plan. Those constraints that are often subject to considerable uncertainty are indicated.
Table 28. ATCT strategies that influence departure metering plan.

<table>
<thead>
<tr>
<th>ATCT Surface Management Strategies For:</th>
<th>Subject to Uncertainty?</th>
<th>Departure Metering Consideration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal operations</td>
<td>X</td>
<td>Location(s) of staging areas (departure reservoirs) for:</td>
</tr>
<tr>
<td>Irregular operations</td>
<td>X</td>
<td>- Aircraft type and weight class</td>
</tr>
<tr>
<td>Airspace constraints</td>
<td>X</td>
<td>- Departure heading/fix/route/destination</td>
</tr>
<tr>
<td>Surface constraints</td>
<td>X</td>
<td>- Location(s) and characteristics of splitters</td>
</tr>
</tbody>
</table>

Conceptually, there can be many ways to define the target characteristics for each departure reservoir. Useful descriptions are likely to be centered on the local taxiway structure and current and expected airspace and surface constraints. For example, if two westbound departure fixes are expected to have miles in trail restrictions, a ground controller at Major Airport may want to stage departures to those fixes on taxiway G short of F with all other flights assigned to runway 18C staged on taxiway H short of F (see Figure 4 on page 21). The DRC may limit the number of flights on each taxiway to 6. In addition, the local controller may want a sequence of 6 aircraft north of F on taxiway G and G-7, at the runway threshold. The DRC then could set these as departure reservoir targets for runway 18C. The expected departure rate for the two constrained westbound departure fixes would influence the number of flights to those fixes that the ground and/or local controller would want north of F. That number may change as constraints over those westbound fixes change over time. In practice it is likely that each airport will have a few standard reservoir descriptions and the DRC at each airport will need to set the target average size of each of the reservoirs in use at a given time.

The departure metering concept evaluation exercise described in Chapter 4 assumed a single departure reservoir for each departure runway, and the key parameter was target average number of active aircraft planning to use each runway. Figure 33 shows the prototype interface for entering departure capacity and target number active that was used in the departure metering concept evaluation exercise. The departure
capacity, defined as the expected number of flights off during a given 15-minute period, can be entered in one of two ways. The user can enter one value to be used for all future time periods or the user can modify the expected number of departures for one or a few time periods. Similarly, the user can enter a single value for target average number active that is applied to all future time periods, or the user can modify the target number active for one or a few time periods.

While Figure 33 assumes a single departure reservoir for each runway that can be fully described by departure rate and target average queue length, multiple departure reservoirs might be more compatible with ATCT surface management strategies. A common strategy used by participants in the ATCT surface management decision making study was to build 2 to 4 queues for runway 18C (see Figure 32). Most departures would be staged on taxiways G and H short of the intersection with taxiway F. Some participants said they would queue aircraft on both run-up pads G-7 and G-8, while other participants would queue aircraft on only one run-up pad and keep the other clear.

Participants decided which aircraft to stage on taxiway G and which on taxiway H by departure fix relative to airspace constraints. One representative response to the question of which aircraft the participant would stage where follows:

Restricted aircraft might be sequenced on one taxiway, say Golf, and then those that are free to flow in could come up Hotel and at Foxtrot you could still meet your restriction or you can keep that Hotel going straight and use that access to the runway because you still have to meet the restriction on the westbounds. Hotel
could flow without restriction. Golf could be used [for westbounds that are subject to a miles in trail restriction].

An additional feature that may enhance usability of the departure metering procedure management window is a useful set of default departure metering parameter values. This was suggested by a participant in the departure metering concept evaluation study: “Does the system have a default number for a facility that you can just go to and it will come- bring everything back to the facility numbers?”

This implies that an interface allowing ATCT traffic management personnel to enter this information directly may be a valuable companion to the display shown in Figure 33. Figure 34 shows one example of an interface that could allow the ATCT supervisor or traffic management coordinator to enter expected surface management strategies. The display concept was created by Amy Spencer.

Figure 34. Notional interface allowing ATCT to communicate surface strategy.

Once the DRC and/or ATCT define the target departure reservoir characteristics, the departure metering procedure management software can use these parameters to generate and allocate target spot times equitably to flight operators through a ration by schedule approach (Brinton, Atkins, et al., 2010; Wambsganss, 2001). The departure
metering procedure management software makes an initial allocation of flights to target spot times and flight operators are free to use their target spot times for any aircraft that meet the departure reservoir characteristics.

Planning Information Requirements

Table 29 outlines information required to support the DRC in estimating departure capacity. The table is organized according to the kind of information the requirement represents, the information requirement, and details exemplifying the information requirement.

Table 29. DRC information requirements to support estimating departure capacity.

<table>
<thead>
<tr>
<th>Information Category</th>
<th>Information Requirement</th>
<th>Details/Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface constraint</td>
<td>Runway availability</td>
<td>Departure runway(s) in use</td>
</tr>
<tr>
<td></td>
<td>Runway condition</td>
<td>Runway occupancy times</td>
</tr>
<tr>
<td></td>
<td>Runway configuration</td>
<td>Time required between departures</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Procedural constraints on departure rate</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Suitability of each runway for given aircraft type</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Independent operations</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mixed arrivals/departures</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Arrivals crossing runway</td>
</tr>
<tr>
<td>Airspace constraint</td>
<td>Equipment status</td>
<td>Terminal radar</td>
</tr>
</tbody>
</table>

Table 30 outlines information required to support the DRC in estimating the departure rate. The table is organized according to the kind of information the requirement represents, the information requirement, and details exemplifying the information requirement.
Table 30. DRC information requirements to support estimating the departure rate.

<table>
<thead>
<tr>
<th>Information Category</th>
<th>Information Requirement</th>
<th>Details/Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface constraint</td>
<td>Taxiway availability</td>
<td>Ability for aircraft to get to the runway</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Availability to certain aircraft type</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Congestion or gridlock</td>
</tr>
<tr>
<td></td>
<td>Taxiway structure and condition</td>
<td>Ability for aircraft to get to the runway</td>
</tr>
<tr>
<td></td>
<td>Ramp area status</td>
<td>Ability for aircraft to push back and taxi to active</td>
</tr>
<tr>
<td></td>
<td></td>
<td>movement area</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Blocked alleyway</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gate availability</td>
</tr>
<tr>
<td>Airspace constraint</td>
<td>Weather constraints</td>
<td>Availability and capacity of departure route(s)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number and location of aircraft planning to use restricted routes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lightning strikes near airport</td>
</tr>
<tr>
<td></td>
<td>Traffic volume constraints</td>
<td>Availability and capacity of departure route(s)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Duration of constraint</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number and location of aircraft planning to use restricted routes</td>
</tr>
<tr>
<td></td>
<td>Required separation standards</td>
<td>Aircraft to the same heading</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Aircraft whose headings diverge at least 15 degrees</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mix of aircraft for wake vortex separation</td>
</tr>
<tr>
<td></td>
<td>TRACON and/or ATCT staffing</td>
<td>Individual controller workload and skill</td>
</tr>
</tbody>
</table>

Table 31 outlines information required to support the DRC in setting appropriate departure reservoir size and composition. The table is organized according to the kind of information the requirement represents, the information requirement, and details exemplifying the information requirement.
Table 31. Information requirements for setting departure reservoir characteristics.

<table>
<thead>
<tr>
<th>Information Category</th>
<th>Information Requirement</th>
<th>Details/Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airspace constraint</td>
<td>Weather constraints</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Traffic volume constraints</td>
<td></td>
</tr>
<tr>
<td>Departure demand</td>
<td>Aircraft characteristics</td>
<td>Mix of aircraft for wake vortex separation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Departure fix</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Departure route</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Destination</td>
</tr>
<tr>
<td>Organizational</td>
<td>ATCT surface management (staging and sequencing) strategies</td>
<td>Segregating groups of aircraft</td>
</tr>
<tr>
<td>constraint</td>
<td></td>
<td>Splitters</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number of each type of aircraft</td>
</tr>
</tbody>
</table>

Table 32 outlines information required to support the DRC in setting appropriate departure reservoir locations. The table is organized according to the kind of information the requirement represents, the information requirement, and details exemplifying the information requirement.

Table 32. Information requirements to support setting departure reservoir locations.

<table>
<thead>
<tr>
<th>Information Category</th>
<th>Information Requirement</th>
<th>Details/Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface constraint</td>
<td>Runway configuration</td>
<td>Key taxiways and intersections</td>
</tr>
<tr>
<td></td>
<td>Taxiway availability</td>
<td></td>
</tr>
<tr>
<td>Organizational</td>
<td>ATCT departure staging strategies</td>
<td>Departure staging/queuing locations</td>
</tr>
<tr>
<td>constraint</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Capacity over time, coupled with the target average departure reservoir size and flight list, provide the departure metering procedure management software with sufficient data to compute and allocate target spot times to flight operators. An initial allocation of target spot times represents an initial plan for the metering period. Once the target spot times are allocated, the DRC role shifts from a planning role to a monitoring role in
which the DRC must monitor departure metering procedure performance and be willing to adapt the departure metering parameters as necessary.

*Monitoring Functions*

The DRC and/or supporting software must continually monitor departure metering procedure performance and adjust the metering parameters accordingly. In particular, the DRC must monitor the size and characteristics of the departure reservoir relative to the targets in order to detect (or anticipate) conditions that violate the expectations of the situation model the DRC develops with experience over time (Vicente, Mumaw, & Roth, 2004).

Monitoring is a process of observation with the goal of detecting “significant” changes in system parameters (Hollnagel & Woods, 2005; Sheridan, 2002; Vicente, Mumaw, & Roth, 2004). A key element of monitoring is situation assessment relative to a situation model that a practitioner develops over time (Hollnagel & Woods, 2005; Vicente, Mumaw, & Roth, 2004). The situation model allows the practitioner to identify variables that do not meet their expectations for the current operation and to select an appropriate response action, which may involve creating conditions for additional monitoring (Vicente, Mumaw, & Roth, 2004).

In order for software to perform the monitoring and adaptation functions, the software should have an appropriate model of the world that it can compare current departure metering procedure performance against. The information requirements identified in this section to support monitoring should be consistent whether the monitoring and adaptation functions are performed by software or the DRC (or a team of the two agents). However, automated monitoring tools may exhibit brittle behavior when their model of the world is violated. They should be designed appropriately to take
redirection from an experienced human that can detect that the software has reached its boundary of competence (Guerlain, et al., 1996; Smith, McCoy, & Layton, 1997).

Situation assessment for the DRC includes evaluating the constraints considered in developing the initial plan, anticipating how those constraints will change over time, and anticipating the effects of those changes on the departure reservoirs. Such changes might be due to ongoing trajectories in surface or airspace constraints, such as movement of a weather system through the area. Alternatively, such changes in constraints might be due to unexpected events such as an aircraft breakdown on a taxiway. According to the operator monitoring model of Vicente, Mumaw, and Roth (2004), situation assessment should add to the DRC’s situation model and help the DRC determine what information to seek out in order to continue the situation assessment process and prioritize further monitoring activities.

Supporting monitoring requires supporting the DRC in detecting changes in the departure reservoir relative to the target characteristics, changes in departure conditions, and unexpected events that impact either the departure reservoir or departure conditions. There are several indicators of departure metering procedure performance that are both data- and event-driven, including the state of the departure reservoir and the occurrence of unexpected events that, when compared to the situation model held by the DRC and/or the software tool, would violate the expectations of the situation model and cause the DRC to engage in a diagnosis process. Table 33 summarizes some information that can help the DRC to detect changes in departure conditions and the departure reservoir relative to the departure metering plan. Those constraints that are often subject to considerable uncertainty are indicated.
Table 33. Information to help DRC detect need to adapt departure metering plan.

<table>
<thead>
<tr>
<th>Information</th>
<th>Data</th>
<th>Kind of Information</th>
<th>Subject to Uncertainty?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size and characteristics of reservoir relative to targets</td>
<td>Relationship</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Trajectories in surface and airspace constraints</td>
<td>Recent past, current, and expected future trajectories, Actual movement of weather relative to expectation/plan</td>
<td>Relative to expectation</td>
<td>X</td>
</tr>
<tr>
<td>Unexpected events</td>
<td>Expected ATCT/ARTCC/TRACON response</td>
<td>Expected impact</td>
<td>X</td>
</tr>
</tbody>
</table>

**Departure Reservoir State**

Departure reservoir state is a key indicator of departure metering procedure performance. This includes the characteristics of aircraft currently in each departure reservoir such as aircraft type, expected departure runway, departure fix or destination, readiness status, scheduled departure time (relative to the current time), and the amount of time aircraft have spent in the departure reservoir. In particular, aircraft characteristics are important relative to departure conditions such as available airspace and the ability to get aircraft to the runway when they can depart.

Departure reservoir location can be an important consideration in whether the ground controller is effectively able to re-sequence flights as necessary to ensure that the local controller always has flights at the runway that can depart to available airspace. Locating departure reservoirs at strategic taxiway intersections is a common ATCT strategy to provide such flexibility, as shown by participants in the ATCT decision-making study discussed in Chapter 4. Departure reservoir location also can be an important consideration in whether aircraft can get to the departure runway at a time...
when their departure route is available (e.g., it may be too far for flights to taxi from a holding area to the runway before a departure window closes).

Trends in reservoir state also are important indicators of departure metering procedure performance. If the number of aircraft in the departure reservoir is increasing or decreasing relative to the target, the departure metering parameters may not be appropriate for maintaining the desired reservoir. Alternatively, such a trend can be an indicator of some unexpected event. It is likely that the DRC and/or software tool would detect such trends if the departure reservoir size exceeded (or fell below) some threshold. It is an open question whether such thresholds should be standard parameters for all personnel working as a DRC at a given airport or what such thresholds should be. Table 34 summarizes some information that can help the DRC to detect changes in departure conditions and the departure reservoir relative to the departure metering plan. Those constraints that are often subject to considerable uncertainty are indicated.

Tools that support the DRC in monitoring the departure reservoir state relative to the target reservoir characteristics allow the DRC to quickly determine the current reservoir size and composition relative to the target. They also support the DRC in anticipating the future reservoir size and composition relative to the target.

The text boxes on the surface display shown in Figure 25 (on page 159 above) are designed to provide the DRC with a snapshot indication of current departure metering procedure status. Participants in the departure metering concept evaluation study described in Chapter 4 indicated that the traffic counts were useful both to determine the number of aircraft active and the number in the ramp area. “That gave me an inclination of how many were moving… If I saw the number active high but nothing in the ramp I thought okay, we’re going to end up whittling the line down…” However, such on-screen summaries were not observed to be used in ramp control facilities even when they were available (Borgman & Smith, 2010).
Table 34. Information to help DRC detect need to adapt departure metering plan.

<table>
<thead>
<tr>
<th>Information</th>
<th>Data/Implications</th>
<th>Subject to Uncertainty?</th>
<th>Kind of Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Characteristics of aircraft currently in departure reservoir and expected to join reservoir within static time horizon</td>
<td>Aircraft type</td>
<td>X</td>
<td>Relative to target reservoir characteristics</td>
</tr>
<tr>
<td></td>
<td>Departure runway</td>
<td></td>
<td>Relative to available airspace</td>
</tr>
<tr>
<td></td>
<td>Departure heading/fix/route/destination</td>
<td>X</td>
<td>Trends relative to targets</td>
</tr>
<tr>
<td></td>
<td>When will aircraft be ready to enter active movement area?</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>How long have aircraft been in departure reservoir?</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Departure reservoir locations</td>
<td>Re-sequencing opportunities</td>
<td>X</td>
<td>Relationship with aircraft characteristics: Which aircraft are staged at which locations?</td>
</tr>
<tr>
<td></td>
<td>Get flights to runway for short departure window</td>
<td></td>
<td>Expectation over planning horizon</td>
</tr>
<tr>
<td>Unexpected events</td>
<td>Delayed aircraft</td>
<td>X</td>
<td>Expectations of situation model violated</td>
</tr>
<tr>
<td></td>
<td>Unexpected restrictions (e.g., pop-up weather)</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Unexpected surface constraints (e.g., aircraft mechanical issue)</td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>

In addition to snapshot traffic counts relative to the target departure reservoir size, the graph shown in Figure 25 allows the DRC to track trends in the departure reservoir size relative to the target. In the figure, the departure reservoir is slightly below the target average size of 10 (depicted by the solid white line). In the departure metering concept evaluation study, participants reported that the chart tracking the number of active aircraft over time was moderately useful, but none reported actually using it to perform the departure metering procedure management task. It provided “good information. If I didn’t have it I wouldn’t miss it… as long as I could look up here and see what the queue was doing…”

225
Flight Readiness

A key contributor to departure reservoir state is the ability for ramp control operators to deliver departures in a timely fashion. One reason for skepticism of departure metering is the unreliability of scheduled departure times. ATC personnel do not trust that aircraft will be pushed back and ready to taxi at the scheduled time. One former ATCT traffic manager said, “The tower does not do sequencing/decision making based on the schedule” because until a flight is pushed back from the gate, the ATCT “doesn’t have sufficient evidence that the aircraft will be ready to go” at the scheduled time.

Indeed, personnel at JFK said flights that are non-compliant with departure metering are more likely to be late than early. Late aircraft can cause the queue to go dry. The Metering Desk has a tool allowing ramp control operators to inform the Metering Desk of aircraft status relative to its target spot time. If the aircraft is not going to be ready the ramp control operator is expected to update its planned taxi time. If the planned taxi time is delayed by more than 15 minutes, the color of the flight changes to indicate that the Metering Desk can swap it with a later flight.

Ramp controllers at one facility reported that it can be hard to know when a flight will actually be ready to push back because there are so many variables, each with variance. Some of the uncertainty in actual out time decreases as tasks in preparing a flight for departure are completed (Beatty, n.d.), but even when it is available ramp control operators may not always share this information with the DRC. For example, the spreadsheet-like display the Metering Desk at JFK uses has a moving vertical green line indicating the current time. “Any flight left of that green line isn’t ready yet,” said one Metering Desk controller. When they see that, Metering Desk personnel use the chat window to ask the ramp control operator if the flight is ready. One cell to the left of the vertical green line, representing the previous 15-minute window, is a vertical blue line. For aircraft between the blue and green lines, “we need to reconcile” the reason that aircraft has not yet contacted the ATCT to request permission to taxi. One Metering Desk
controller said, “Sometimes the airlines are 45 minutes late and don’t update their times.”
But “if everyone’s on time and the queue goes dry, we don’t have enough planes” to
maintain consistent runway demand.

Updating Expected Spot Times

Ramp control operators may not reliably update these expected spot times if they
do not have adequate tools for managing their part of the departure metering procedure.
One manager for a ramp control operator at JFK indicated that it was not possible for him
to impact the way the list of flights was sorted in the tool for the ramp control operator to
manage his or her target spot times. For example, if an aircraft scheduled to depart at
1300 was delayed until 1900, he said that its position in the list of scheduled flights
would not move. The window showing the list of scheduled flights scrolled automatically
– a reasonable design choice – but the delayed flight would be higher in the list than what
the ramp control operator may be able to see with the current scroll location. The ramp
control operator is encouraged to request a later slot for the flight to reflect its delay
status. But the person responsible for managing the ramp control operator’s metering
participation must be aware of the aircraft’s delay status and request the later slot. It may
be difficult for them to remain aware of the delay status if it is not automatically grouped
near aircraft scheduled to operate very soon.

It seems reasonable to allow the flight and/or ramp control operator to update a
flight’s expected spot time to reflect its current delay status. In response, the according to
the JFK ramp control manager, the schedule “needs to be re-sorted” because “the airline
needs to know that the aircraft are still here” and needs to be assigned to a target spot
time. Re-sorting the schedule also should notify the departure metering procedure
management software of the updated expected spot time. The departure metering
procedure management software then could:

• Offer the flight and/or ramp control operator an earlier target spot time for the
  flight if the new expected spot time is earlier and capacity is available.
• Suggest a swap to the flight and/or ramp control operator if the new expected spot time is later and the operator has a later flight that could use the earlier target spot time.
• Notify the DRC that the flight has a new expected spot time, allowing the DRC to determine the best course of action.

The departure metering procedure management software should respond similarly if a flight operator cancels a flight. In addition, delayed flights that have not become active or been canceled could “float” to the top of the currently displayed portion of the list or generate an alert to the flight and/or ramp control operator (and possibly the DRC).

At the very least, it seems necessary for each user to be able to view the portion of the departure schedule relevant to them in whatever way they want.

**Unexpected Events**

There are a number of unexpected events that can impact departure performance and the departure reservoir. Aircraft can be delayed and miss their target spot times, which is actually a key metering performance issue cited by personnel at JFK. Highly dynamic weather can cause constraints that are difficult to predict. And runways, taxiways, and holding areas can become unavailable for any of a number of reasons, including aircraft mechanical issues (Billings, Spencer, & Smith, 2001; Borgman & Smith, 2010). An important part of the monitoring task is to detect such events.

 Appropriately designed alerts to certain kinds of events have been previously recommended to support surface management (Smith, Pear, et al., 2001; Spencer & Smith, 2003; Spencer, Smith, & Billings, 2004; 2005; Spencer, et al., 2003). In the case of departure metering, the DRC may need to be alerted to events such as an aircraft that the flight operator determines will not be ready to depart in time to use its target spot time window or to congestion in the ramp area that may impact the ability of several other aircraft to meet their target spot time windows.
The chart shown in Figure 25 also can help the DRC detect unexpected events. Yellow squares are printed on the chart to indicate that more than 90 seconds have passed since the last flight departed. These indicators were considered useful by participants in the departure metering concept evaluation study described in Chapter 4 “because it’s going to make me wonder why a minute and a half went by and nobody took off…” Another participant said, “This tells me if something happens… If I saw 3 or 4 of these little yellow squares grouped together I would start to wonder.”

**Monitoring Information Requirements**

Table 35 outlines DRC information requirements for performing the monitoring function. Providing the DRC this information alone may not be adequate support unless it is presented in a way that helps the DRC identify relationships among these information items and between the information and the target departure reservoir characteristics (and between the target departure reservoir characteristics and expected departure conditions over the planning horizon). It is known that representing relationships between data elements provides better support than the data elements alone (Smith, Bennett, & Stone, 2006; Woods & Hollnagel, 2006).
Table 35. Information requirements to support the DRC monitoring function.

<table>
<thead>
<tr>
<th>Function Supported</th>
<th>Information Category</th>
<th>Information Requirement</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monitor departure reservoir state</td>
<td>Departure reservoir state</td>
<td>Size</td>
<td>Relative to current and expected future targets</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Aircraft characteristics</td>
<td></td>
</tr>
<tr>
<td>Departure demand relative to constraints</td>
<td>Current and expected mix of aircraft in each reservoir</td>
<td>Aircraft type</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Expected departure runway</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Departure heading, fix, route, destination relative to constraints</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Aircraft readiness status</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Scheduled departure time for aircraft already out and aircraft with target spot time within static time horizon</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Time spent in reservoir</td>
<td></td>
</tr>
<tr>
<td>Surface constraint</td>
<td>Location(s) of reservoir(s)</td>
<td>Ability to get aircraft to departure reservoir and/or runway</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>ATCT ability to build efficient sequence</td>
<td></td>
</tr>
<tr>
<td>Airspace constraint</td>
<td>Availability of departure route(s)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Detect trends in departure reservoir state</td>
<td>Departure reservoir trends relative to targets</td>
<td>Size</td>
<td>Increasing or decreasing</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Aircraft mix</td>
<td>Changing relative to target(s)</td>
</tr>
<tr>
<td>Detect unexpected events</td>
<td></td>
<td>Delayed aircraft</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Unexpected restrictions (e.g., weather, equipment failure)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Unexpected surface constraints (e.g., aircraft mechanical issue)</td>
<td></td>
</tr>
</tbody>
</table>
Diagnosis is a difficult task that requires abductive reasoning (Peirce, 1955; Smith, et al., 2012; Woods & Hollnagel, 2006), a process by which hypotheses that explain observed data are generated and tested, often against additional observations. The diagnosing agent should select the hypothesis that best explains the data.

When the DRC detects that the departure reservoir is off the target, he or she can engage in a diagnosis process in order to identify the cause and build and/or update a situation model (Vicente, Mumaw, & Roth, 2004) that can help him or her anticipate its impact on the departure reservoir. This process may be deliberate or automatic, depending on the information available to the DRC. Either way, it is necessary in order to determine how best to adapt the metering plan.

For many departure disruptions likely to impact the departure reservoir, the DRC is likely to have access to information that will automatically and directly identify the cause. For example, the Metering Desk personnel at JFK were observed to listen to the ATCT ground control and local control frequencies, as were personnel at several different ramp control facilities (Borgman & Smith, 2010). Certain disrupting events are likely to be discussed on the radio frequency, such as an emergency landing or a flight crew report of debris on the runway. Similarly, if the DRC has access to weather forecasts he or she is likely to have developed a departure metering plan that included expectations of a weather event, as long as the event was forecast.

In such cases where the DRC has direct knowledge of the cause of the disruption, diagnosis will be more about anticipating the likely impact on departures in order to determine how best to adapt the departure metering parameters. However, the DRC may not have such direct information of the cause of the disruption and in such cases may need to engage in a more conventional diagnosis process. For example, the scenarios
involving “silent” increases in the departure reservoir size discussed in Chapter 4 may not provide the DRC with such direct information about the cause.

In the case of the decreased departure rate due to a more conservative local controller, the change in departure rate may be imperceptible until the reservoir size increases above some threshold. Similarly, if a few flights require more time to depart, the cumulative effect on the departure reservoir size may remain small for some time. The DRC may require tools to identify the time when the departure reservoir size started to increase to identify the cause. Once the cause is known, the DRC should be able to characterize the impact on the departure reservoir according to a few general categories in terms of their effect on the departure rate, forecast lead time provided to the DRC, the proportion of departures impacted, the level of variability in the cause, and whether it is a transient or long-term change in departure conditions (Fernandes, et al., 2010).

**Impact on Departure Rate**

A change in airspace or surface conditions may cause the departure rate to increase or decrease. An emergency landing on the departure runway such as that observed at JFK by Borgman and Smith (2010) decreases the departure rate to zero for the runway in question. An equipment failure (Fernandes, et al., 2010), on the other hand, may decrease the departure rate for all runways to a predictable rate.

Similarly to the use of control charts in statistical process control, the chart shown in Figure 25 provides a basis for the DRC to begin diagnosing the reason why airport performance is different than expected. It also provides the DRC information about what to adjust (and when to adjust it) in order to return the airport surface system to the desired state. There are three basic patterns that the graph might display to indicate the impact of a disruption on the departure rate.
Pattern 1: Random Variation about a Stable Asymptote

Figure 25 shows a graph indicating some random variation about a stable asymptote. This indicates that the process is stable and the current runway departure rate is very close to the expected runway departure rate. The stable asymptote may be above or below the planned value, indicating that at some point in time the real airport performance differed from the departure metering parameter values provided to the departure metering procedure management software for allocating the target spot times. This was likely due to a minor difference in departure rate than the expected, perhaps due to rounding error. While the expected average departure rate shown in Figure 25 is 13.8 flights per 15-minute period, 14 flights have departed during each of the last 5 time periods. Therefore, there is a very slow downward trend in the size of the departure reservoir. This implies that even with stable departure conditions, the DRC and/or departure metering procedure management software periodically will need to adjust the departure metering plan. The DRC may choose to make such an adjustment after the departure reservoir size reaches some threshold relative to the target departure reservoir size, or there may be a schedule for such adjustments to be made, say, every hour.

Pattern 2: Increase in Actual Number Active

The graph in Figure 35 shows an increase in the actual number active. This indicates that the actual runway departure rate is lower than expected, and that the cause is not transient. Such a display should lead the DRC to investigate what the true runway departure rate is and modify the departure metering procedure parameters accordingly.

Figure 36 shows a different kind of increase in the departure reservoir size resulting from a ten-minute period during which no aircraft departed. Once aircraft started to depart again, the number active remained at a new asymptote, indicating that the runway departure rate did not change except for a transient event preventing departures. One would expect the DRC to respond differently to the two situations shown
Figure 35. Graph showing an increase in actual number active.

in Figure 35 and Figure 36 because the graph indicates different causes for the increase in the actual number active.

Figure 36. Graph showing increase in actual number active due to transient event.

Pattern 3: Decrease in Actual Number Active

Figure 36 shows one example of the third basic pattern: a decrease in the departure reservoir size. In this case, the decrease is the result of an adjustment to the metering procedure in response to a temporary runway closure. Such a decrease in departure reservoir size also might be the result of an increase in runway departure rate such as due to an increase in visibility allowing flights to depart according to Visual Flight Rules (VFR) after a period requiring Instrument Flight Rules (IFR).

In the departure metering concept evaluation exercise described in Chapter 4, it was hypothesized that each of these patterns on the proposed graph would provide the DRC information about the status of traffic on the airport surface relative to departure metering procedure goals. Further, it was hypothesized that these patterns could guide the DRC in determining the cause of any discrepancy between the actual number of active
aircraft and the target. As noted above, however, few participants used the chart in their monitoring and diagnosis activities.

**Forecast Lead Time**

Events causing changes in departure conditions can occur with varying forecast lead times. An equipment failure such as the Terminal radar outage described by Fernandes, et al. (2010) likely occurs with no warning at all, whereas changing the airport from an arrivals to a departures runway configuration typically occurs at roughly the same time every day and can be planned in advance (Borgman & Smith, 2010).

**Proportion of Departures Impacted**

Some events can differentially impact certain departures. A weather system to the east of the airport is most likely to impact eastbound flights but also may impact flights whose routes are used as offload routes for eastbound flights. A Terminal radar outage, on the other hand, would impact all departures for the duration of the outage (Fernandes, et al., 2010).

The graph shown in Figure 25 represents the size of the entire departure reservoir for a given runway. Such a display may be appropriate for typical departure reservoir monitoring. However, not all disruptions impact all departures. A disruption may impact only one runway or only some flights planning to use a given runway. For example, when an aircraft made an emergency landing on a departure runway, only that runway’s departures were impacted (Borgman & Smith, 2010). If there were other runways in use those reservoirs may not need to change unless runway assignments would be changed as a result. Figure 37 illustrates how a departure reservoir size chart for each runway can help identify that only one runway is impacted, in this case by a runway closure.
Similarly, identifying that the departure reservoir for one runway has been impacted by a disruption can lead the DRC to more closely investigate the source. Figure 38 provides a notional interface allowing the DRC to decompose the departure reservoir for one runway by departure direction. If there were a disruption that impacted only some flights, such a display may support the diagnosis process.

Alerting the DRC to events that are likely to impact departures may help the DRC anticipate – and act to prevent – impacts on the departure reservoir. Borgman, et al. (2010a) illustrated context-sensitive alerts designed to draw a user’s attention to a disruption (in this case a route closure). When the user clicked on the alert, aircraft impacted by the disruption would be highlighted in the flight list and on the surface display. Clicking on the alert also allowed the user to acknowledge that the message was received, supporting coordination and communication (Klein, et al., 2005). Note that Borgman, et al. (2010a) discussed the alerts in an air traffic management context and not
in the context of supporting the DRC. However, a display similar to the one they presented also could be helpful to the DRC.

*Level of Uncertainty*

The impact of a disruption on the departure reservoir and the ability for the DRC to make the “right” adjustments to the departure metering parameters are influenced by the level of uncertainty associated with the event. Highly dynamic weather systems such as “popcorn” storms can be highly variable in terms of the departure routes that are impacted at a given time. This can make it difficult to predict which aircraft will be able to depart over a 30-minute planning horizon. One ramp control director reported that under such conditions “you do the best you can” to keep departures moving and traffic managers at that ARTCC do not amend flight routes more than 30 minutes before they are expected to take off (Fernandes & Smith, 2011b).

On the other hand, more predictable weather systems may impact the same departure routes but facilitate better planning because they move in a more predictable manner. For example, “frontal storms” are easily predictable in terms of the impact on departure routes over time. They are so predictable, said the same ramp control director,
that “you can set your watch by them” (Fernandes & Smith, 2011b). Such systems may be accompanied by wind shifts that require a change in airport runway configuration, but often these configuration changes can be predicted, said one ATCT and TRACON traffic manager. The words used in weather forecasts to characterize the event can indicate to the DRC what kind of disruption to expect. Thus, the DRC should be able to determine the likely impact on the departure reservoir.

**Transient or Long-Term Change in Conditions**

The most appropriate strategy for adapting the departure metering parameters also is impacted by the duration of the change in departure conditions. Some events, such as an equipment outage lasting several days, may cause a long-term change in departure conditions and require a significant change in metering parameters. Other events, such as a report of debris on the runway, may disrupt departures for some period of time but not require a significant change in departure metering parameters.

The same tools that indicate the level of uncertainty in departure conditions help the DRC determine whether it is a transient or long-term change in departure conditions. Listening to the ATCT radio frequencies alerts the DRC to events such as debris on the runway that would close the runway only long enough for the airport operator to sweep the runway and remove the debris. Similarly, the ATCT radio frequency alerts the DRC to an event such as a Terminal radar outage that might decrease the departure rate for an extended period of time (Fernandes, et al., 2010). Table 36 characterizes each of the above events according to the general categories.
Table 36. Sample events and their impact on departures.

<table>
<thead>
<tr>
<th>Event</th>
<th>Impact on Departure Rate</th>
<th>Forecast Lead Time</th>
<th>Proportion of Departures Impacted</th>
<th>Variability</th>
<th>Transient or Long Term</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weather</td>
<td>Decrease</td>
<td>15 minutes to several hours</td>
<td>Aircraft to impacted routes Other aircraft blocked by impacted aircraft</td>
<td>Fairly low to very high</td>
<td>Both</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Debris on runway</td>
<td>Runway closed</td>
<td>None</td>
<td>This runway</td>
<td>Length of closure depends on nature of debris</td>
<td>Transient</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Terminal radar failure</td>
<td>Decrease to stable rate</td>
<td>None</td>
<td>All</td>
<td>Departure rate not variable Length of outage: variable</td>
<td>Minutes or days</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Runway configuration change</td>
<td>Gain departure runway: increase Lose departure runway: decrease</td>
<td>Planned: approximately same time every day Frontal storm: 30-60 minutes Variable winds: none</td>
<td>Aircraft assigned to new runway Aircraft that cannot take lost runway Aircraft behind them in queue</td>
<td>Planned: specific time, duration Unplanned: depends on reservoir size</td>
<td>Transient</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Emergency landing on departure runway</td>
<td>Runway closed</td>
<td>Up to 20-30 minutes</td>
<td>Aircraft departing this runway</td>
<td>Length of closure depends on nature of emergency</td>
<td>Typically transient Some events long term</td>
</tr>
</tbody>
</table>
**Diagnosis Information Requirements**

Table 37 summarizes the information requirements for supporting the DRC in diagnosis. These information requirements represent key considerations for the DRC in determining how to adapt departure metering parameters to maintain metering performance in the face of changing departure conditions.

Table 37. Information requirements to support the DRC in diagnosis.

<table>
<thead>
<tr>
<th>Function Supported</th>
<th>Information Category</th>
<th>Information Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diagnosis</td>
<td>Effect on departure rate</td>
<td>Increase</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Decrease</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Runway closed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Magnitude of change</td>
</tr>
<tr>
<td></td>
<td>Proportion of departures impacted</td>
<td>Which runways impacted</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Which flights impacted</td>
</tr>
<tr>
<td>Forecast lead time</td>
<td>Rate of change in conditions</td>
<td></td>
</tr>
<tr>
<td>Level of uncertainty</td>
<td>Predictability of changes in conditions</td>
<td></td>
</tr>
<tr>
<td>Transient or long-term</td>
<td>Whether change in model of world is required</td>
<td></td>
</tr>
</tbody>
</table>

**Adaptation Functions**

More than identifying the cause of a disruption, the diagnosis process described above requires the DRC to determine the expected effect on the departure reservoir. This can help the DRC determine how best to adapt departure metering parameters so as to maintain (or improve) performance in the face of changing departure conditions. Such adaptation requirements are commonplace in managing complex systems (Hollnagel & Woods, 2005; Sheridan, 2002; Smith, Stone, & Spencer, 2006; Vicente, Mumaw, & Roth, 2004; Woods & Hollnagel, 2006).
Some important considerations in determining how to adapt the departure metering parameters are:

- The above-mentioned considerations in setting departure metering parameters (surface and airspace constraints, departure demand, etc.).
- Diagnosed cause of change(s) in departure conditions and expected impact on departure conditions and the departure reservoir over time.
- Time at which change should be implemented to have the desired effect.

Setting Departure Metering Parameters

Adapting departure metering parameters is similar to setting them in the first place. JFK Metering Desk personnel reported that their existing tools are “good for planning, making an initial allocation.” After the initial allocation they “watch the program,” make sure they “know what runways are in use,” and “talk directly to carriers” to keep them as informed as possible about the state of the operation.

During severe weather events, said one former ARTCC traffic manager, “Sometimes a flight can get forgotten between the tower and the approach control or can’t get a route because of where it wants to go. No one can find an acceptable route for that flight so it starts gumming up the works.” But a JFK Metering Desk controller said that issues arise “not just [from] fixes closing, it’s restrictions on fixes. It’s 15 miles in trail on Robbinsville.” In either situation, the DRC needs to identify which flights may have difficulty departing in order to decide how to modify the flow of flights like them to the departure reservoir.

The DRC also needs to determine the number of aircraft subject to a given restriction that should be allowed into the departure reservoir. One JFK Metering Desk
controller said, “If I hear WAVEY is 15 miles in trail, how many aircraft can I put in there to give them the right number of departures for 15 miles in trail?”

As flights with no route available receive new, less constrained routes, the DRC and/or departure metering procedure management software need to be able to adapt the departure metering parameters according to a model of how such changes will impact the departure reservoir characteristics over time. While changing flight routes can relieve demand for constrained routes, it increases demand for the new routes, potentially causing congestion on the offload routes. The DRC should be able to plan for the impact of such cascading effects of interventions to relieve the impact of the initial disturbance (Woods & Hollnagel, 2006).

In most cases the departure reservoir can act as a buffer against “incorrect” metering parameters set by the DRC. It also acts as a tool for diagnosing whether parameter changes can achieve the desired effect. However, tools that help the DRC anticipate the likely effects of departure metering parameter changes can supplement the DRC’s expertise and may even support the DRC in developing expertise (Sheridan, 2002; Smith, Bennett, & Stone, 2006; Woods & Hollnagel, 2006). Such expertise, “tuned to the future” (Woods & Hollnagel, 2006), can help the DRC/software team to more efficiently adapt the metering procedure parameters than either agent alone.

Diagnosed Change(s) in Departure Conditions

The diagnosis process that the DRC uses to determine the nature of the disruption in departure metering procedure performance provides the DRC with key clues as to what kind of adaptation is required to maintain control over the departure metering procedure. A transient disruption in departures likely requires a different kind of adaptation than a fundamental shift in departure conditions.

Well-designed software for monitoring and managing a departure metering procedure may be able to automatically detect the need to adapt and implement an
appropriate change in the departure metering plan (possibly subject to some restrictions). This is the model set forth in some departure metering procedure concepts, although descriptions of most of these approaches have not explicitly discussed the need for continuous monitoring and adaptation (Brinton, Atkins, et al., 2010; Chen & Hu, 2007; Malik, Gupta, & Jung, 2010). The runway scheduling system described by Atkin, et al. (2008) also did not explicitly consider monitoring and adaption. However, their system performed poorly in one simulation of real traffic because of an action taken by a local controller to improve throughput that the automated system did not take into account.

Software can only reactively adapt to changes in the departure reservoir characteristics unless it is provided information from a human agent somewhere in the system. For example, Atkin, et al. (2008) explained that their system could take controller input to reflect actions taken by controllers to increase throughput. In the case of debris closing the runway for a few minutes, a human DRC may be alerted to the event as soon as it is reported via voice over the local control radio frequency. The human DRC then could immediately modify the departure metering plan based on this information (or instruct the software to adapt the plan). However, in order for the software to automatically monitor and adapt, it would likely have to wait until the departure reservoir size exceeded some threshold or the time since the last aircraft departed exceeded some threshold. Even then, a human DRC is likely to have knowledge about how long the runway is likely to remain closed due to an event such as a report of debris on the runway and what the follow-on effect on the departure reservoir is likely to be.

Certain transient events may require the DRC to adapt the departure metering plan, but once the event has ended departure conditions will be the same as they were before the event. For example, in the case of an emergency landing on the departure runway (Borgman & Smith, 2010) it was clear that the departure rate for that runway was zero for the duration of the closure and that the departure conditions had not otherwise changed. However, it was unknown how long the runway would need to remain closed and therefore the Metering Desk needed to make an adjustment.
After some discussion, the Metering Desk personnel decided that starting 45 minutes later, all target spot times should be delayed by 15 minutes. Once the runway reopened (nine minutes later), aircraft were able to depart at the same rate as before.

In the prototype tools, this is roughly the equivalent of setting the departure rate to zero for the current time period as soon as the runway closure occurs, as shown in Figure 39. In this case the runway in question was closed for 15 minutes and the DRC acted to adapt the metering plan within one minute after the runway was closed. The departure reservoir continued to increase in size during the 15-minute closure because the software did not adjust the target spot times of any flights within the 30-minute static time horizon (Surface CDM Team, 2011).

![Figure 39. Queue length change after response within one minute of runway closure.](image)

Alternatively, if departure conditions have fundamentally changed, the DRC may need to provide the departure metering procedure management software with a new set of departure metering parameters that allows the software to modify target spot times appropriately. Tools to support the DRC should support both kinds of adaptation.
Software can be competent at adjusting the departure schedule as long as the
departure metering parameters represent the true state of departure conditions. However,
if the departure rate has changed, the DRC (or some other knowledgeable agent) needs to
provide the software with a new model of the world before it can reliably adjust the
identified cases in which automated decision support tools were incompetent because
their model of the world was inadequate for the situation at hand. Guerlain, et al. (1996)
applied a software design approach that was able to support the user even in cases where
the software’s model of competence was incomplete.

*Time to Implement Parameter Change*

As in many complex systems, there is a lag between the time that a change in
parameters is implemented and when system performance actually changes (Hutchins,
1995a; Sheridan, 2002; Vicente, Mumaw, & Roth, 2004; Woods & Hollnagel, 2006). In
part, this lag is due to the static time horizon (Surface CDM Team, 2011) but it also is
due to the fact that it takes time to add aircraft to the departure reservoir (prepare aircraft
for departure) or remove aircraft from the departure reservoir (depart aircraft). Therefore,
the DRC must not only determine how to modify departure metering parameters, but also
when to implement those parameter changes to achieve the desired effect.

Figure 39 shows a clear delay between the time the departure runway reopened at
1745Z and the time that the departure reservoir started to decrease in size. There is a
static time horizon built into the departure metering procedure management software that
prevents it from adjusting a flight’s target spot time if the flight is scheduled to arrive to
the spot within the next 30 minutes. Note that the JFK Metering Desk personnel manually
employed a 45-minute static time horizon when they selected the flights whose target
spot times would be adjusted. Similarly, Brinton, Lent, and Provan (2010) reported on the
importance of freezing the allocation “well in advance of the start of each time interval”
to provide flight operators stability in their schedule. During normal operations at JFK
“no times are shuffled [less than] 30 minutes before” their target spot times according to one airport operator representative. During severe weather events this static time horizon is increased to 45 minutes, increasing the queue length because “as soon as it starts opening that queue’s going to come down quick.” Brinton, Lent, and Provan (2010) also reported that flight operators can more easily respond to an increase in allocated capacity than to a decrease in the allocated capacity.

A key consideration in the appropriate time to implement a change in parameters is the likely frequency of such changes. Every time the DRC adjusts the departure metering procedure parameters, the target spot times of some number of flights will change. Such changes impact several flight operator personnel as they prioritize their activities for preparing aircraft for departure at the appropriate time.

The need for the DRC to determine the appropriate time at which to implement changes in the departure metering procedure parameters is a separate issue from that of the static time horizon (Surface CDM Team, 2011), the time horizon during which the departure metering procedure management software will not change a flight’s target spot time. The DRC must consider this additional delay in seeing the impact of a change in departure metering parameters when he or she is determining when to implement metering parameter changes.

As an example, if the departure runway is closed due to an emergency landing the DRC may choose to immediately direct the departure metering procedure management software to adjust aircraft target spot times, assuming that the runway will be closed for, say, 15 minutes. Only flights whose current target spot times are outside the static time horizon will have their target spot times adjusted. This means that over the duration of the static time horizon, say 30 minutes, aircraft will continue to enter the active movement area. Once the DRC receives more information about the duration of the closure, he or she can immediately implement another change in the expected departure rate, initiating another adjustment of target spot times. Imagine that the new information becomes
available after 10 minutes. The second adjustment will also only impact flights whose now-current target spot times are outside the static time horizon (in this case, 30 minutes). Many of these flights are likely to have had their times adjusted the first time.

It may be prudent for the DRC to delay implementing departure metering parameter changes in order to minimize the number of necessary changes. However, such delays increase the risk that the departure reservoir will not allow the ATCT to make efficient use of the departure runway. Such conflicting goals are a classic feature of complex control problems (Hollnagel & Woods, 2005; Sheridan, 2002; Woods & Hollnagel, 2006).

However, changes that the DRC makes are going to be open to interpretation and criticism by other agents involved in the departure metering procedure. What the DRC believes is an effective strategy for adapting metering parameters to changing departure conditions, ramp control operators and ATCT personnel may interpret as changing parameters too often, not often enough, too early, or too late.

The DRC must understand how the departure reservoir is likely to change between the time when the need for adaptation is detected and the time changes in departure metering parameters take effect. Tools that support anticipation may help the DRC to predict such departure reservoir behavior and adapt metering procedure parameters appropriately.

Tools that support anticipating the impact of a parameter change are helpful for maintaining control of a complex system (Hollnagel & Woods, 2005; Sheridan, 2002; Vicente, Mumaw, & Roth, 2004). Figure 40 shows how the chart for tracking departure reservoir size can be used to display the expected impact of a parameter change. The blue line represents the future expected average departure reservoir size over time, assuming that the expected average departure rate is correct. The display provides a preview when
the DRC changes one or more parameters and the DRC can press the Apply button if the plan is expected to achieve the desired effect on the departure reservoir.

![Figure 40. Departure metering management window with anticipated reservoir size.](image)

The conceptual display shown in Figure 40 can help the DRC determine whether the proposed metering parameter change is likely to achieve the desired effect on the departure reservoir. However, it does not indicate how many flights are likely to be impacted by the change. Notifying the DRC of the impact of the parameter change on other people, such as flight operator personnel, can serve as a reminder that every time the DRC makes a change in the departure metering parameters a number of people may have to adapt their activities accordingly.

Therefore, a display showing the departure metering plan and the number of flights impacted by the proposed change might prompt the DRC to make fewer changes, waiting until he or she has more information about how departure conditions will change. This represents one tradeoff that as a participant in a joint activity the DRC must balance between achieving his or her goal and accommodating the needs and priorities of others (Klein, et al., 2005).

Adapt to Shrinking Departure Reservoir

One requirement of departure metering is that the departure queue never goes dry. Personnel at JFK reported that the ATCT considers metering a failure when that occurs,
and such instances are investigated to determine the cause. Borgman and Smith (2010) observed a discussion in which a Metering Desk manager described the situation:

We were running in a [runway] 22/13 configuration, with arrivals on [runway] 13 Right at a good rate when the runway was lost. Because of the demand, [runway] 22 Right took the arrival traffic [effectively stopping departures].

At the Metering Desk, we didn’t know when they would stop using 22 Right for arrivals and give it back to departures. There were 12 to 14 aircraft that had slot times when 22 Right was switched back to departures, but the queue dried up for a few minutes… Very quickly, the queue was back up to six or eight aircraft and stayed there for the next two or three hours… We talked to the tower to take some flights out of metering to get them into the queue…

We try to provide information via the chat or a hotline when we see the runway use changing, but this [knocking out the arrival flow] was a TRACON decision… We established a hotline with the TRACON and talked to the traffic management supervisor there but the information we got from them lagged behind when they would actually shut off departures (p. 41).

When the DRC detects that there are not enough of the “right” aircraft in the departure reservoir, he or she needs to be able to identify flights that can be quickly added to the departure reservoir. One participant in the departure metering concept evaluation study described in Chapter 4 commented that he used the count of aircraft active in the ramp area to determine if he needed to increase the number of flights joining the departure reservoir:

One of the other numbers I was looking at a lot was the number in the ramp because that gave me an inclination of how many were moving that weren’t active. … [I was] taking those into account with the number active, so if I saw the number active high but nothing in the ramp, I thought okay, we’re going to end up whittling the line down. If I saw an active of… 20… I didn’t have many, if any, in the ramp so I knew that yes there’s a lot moving on the taxiway but there’s nobody else pushing back is the way I was looking at it.
If the departure reservoir decreases in size and there are not flights active in the ramp area, the DRC needs to move some flights earlier if possible. The Selection Tool shown in Figure 32 above allows the DRC to highlight flights that may be able to arrive to the spot early. Such a tool also could be useful to a traffic manager in the ATCT or TRACON to identify flights that might be able to use a different runway or departure fix to make better use of available capacity.

Fernandes and colleagues (2010) described a hypothetical scenario in which the departure reservoir grew smaller than the target because the DRC planned for a longer equipment outage than what occurred. When the equipment was repaired and the departure rate suddenly increased, the DRC increased the departure rate parameter and the software adjusted the target spot times to increase the flow of aircraft to the departure reservoir. Figure 33 shows controls for modifying the departure metering parameters. In the scenario described by Fernandes, et al. (2010) the DRC could use the control for the expected average number of flights off per time period to first decrease and then increase the expected departure rate. In response, the departure metering procedure management software identifies an appropriate number of flights to move to an earlier target spot time.

Note that the static time horizon may be able to be treated differently in the case of providing earlier target spot times than for moving them later. Brinton, Lent, and Provan (2010) noted that it is easier for flight operators to respond to increases in expected capacity than decreases in expected capacity, although the Surface CDM Team Concept of Operations (Surface CDM Team, 2011) applied the static time horizon whether the software moved target spot times earlier or later. The experience of personnel at JFK is that “more often than not, flights are non-compliant because they’re late.” If this is the case, then the DRC may not be able to identify many flights that can increase the size of the departure reservoir.

250
Adapt to Growing Departure Reservoir

The DRC may detect that the departure reservoir is growing due to a decrease in the departure rate such as in the hypothetical Terminal radar outage scenario described by Fernandes, et al. (2010). According to one former ATCT and TRACON traffic manager:

At the time the radar fails the radar screens [in the TRACON] will freeze and go blank. All controllers will be yelling about the radar failure. [The] TRACON supervisor will push [a] button on [the] control panel… to bring up CENRAP. All departures will be stopped momentarily until [the] system comes up (Fernandes, et al., 2010, p. 15).

CENRAP is the Center Radar Presentation system, which allows TRACON controllers to monitor traffic using the ARTCC radar system (Federal Aviation Administration, 1994). It requires 5 nautical miles of separation instead of the typical 3 nautical miles and therefore decreases the departure rate by about one third for the duration of the outage.

Since the new departure rate in such a scenario is predictable, the DRC can use the capacity controls shown in Figure 33 above to modify the average expected number of departures. In this case, he or she might set the expected average number of flights off for all future time periods. Alternatively, he or she might modify the expected number of for specific time periods, choosing to make a short-term capacity change until more information about the expected duration of the outage is available.

In response, the departure metering procedure management software adjusts the allocation of target spot times according to the new expected capacity (respecting the static time horizon).

Adapt to Increased Uncertainty in Departure Conditions

An increase in departure reservoir size might be desirable if departure conditions become more variable since the departure reservoir provides a buffer against uncertainty.
During severe weather events, the JFK Metering Desk increases the target size of the departure reservoir. One Metering Desk controller said, “We build a larger queue to give the [ATCT] flights to pick from.” Rather than metering to a queue length of 10-12 aircraft as they normally do, “there are times we’ll let 20 airplanes out there.”

The larger departure reservoir accomplishes several goals. First, the target spot times are allocated according to departure fix rather than only departure time (“3 per fix” according to one airport operator representative). This ensures that the ATCT has a variety of aircraft for building a departure sequence that allows them to use whatever airspace is available. Second, during severe weather events flights are more likely to be delayed and “the airlines have to free up the gates,” according to one Metering Desk controller.

Allowing more aircraft into the departure reservoir can alleviate gate and ramp area congestion. If they see that “arrivals are waiting a long time,” the Metering Desk can “increase the queue to let the departures off the ramp so that the arrivals can get into their gates.” This is consistent with a concern expressed by several participants in the departure metering concept evaluation study described in Chapter 4 that departure metering would be difficult to carry out because of gate and ramp congestion.

One ramp control operator representative said in a separate interview that at some airports “runway queues might be 20 deep but carriers need to keep the aircraft somewhere so they might as well be in the queue.” Another former flight dispatcher cautioned that ramp space may not always be available for metering aircraft because flight operators use that space for aircraft requiring maintenance. “An aircraft might be in the holding area for days. You can’t do major maintenance at most airports. If you’re waiting for a part that Boeing is producing for you right now, it’s going to take a few days and the hangar space might be more valuable than that pad space.”
Therefore, the DRC needs controls allowing him or her to increase the size of the departure reservoir as well as manage the departure reservoir size by adjusting the average departure rate, as shown in Figure 33 above. However, the concept should be extended to allow the DRC to manage the departure reservoir according to departure fix, either defining departure reservoir targets for each departure fix or defining exceptional departure fixes (such as a particularly heavily impacted fix). Such a control might allow the DRC to specify the maximum number of aircraft to that fix in the departure reservoir or the maximum proportion of this departure reservoir that should be composed of flights to the departure fix in question. Note that the Surface CDM Team Concept of Operations calls for the creation of multiple “metering categories” to accommodate such situations (Surface CDM Team, 2011).

Ensuring Equity for Flight Operators

One challenge to allowing such fine control over the departure reservoir is to ensure that the algorithm for allocating target spot times to flight operators is equitable even when it uses a “ration by route” paradigm. If one departure fix or direction is expected to be particularly heavily impacted by weather, then flights filed to use that fix would be assigned later target spot times than flights filed to a different departure fix. This invites a number of questions.

Suppose the capacity of the Beaty departure fix is expected to be approximately half of normal and it has approximately the same level of demand as all other fixes. Under a scheme by which flights scheduled to use Beaty were metered separately from other flights, flights filed to use Beaty would be assigned later target spot times than they would if they were filed to another fix.

- What should happen to a flight that was filed over Beaty but then is changed to another fix? Should the flight be offered an earlier target spot time? Airport operator representatives at JFK said that when the Metering Desk uses a
“ration by route” model to cope with severe weather, if a flight’s departure fix is changed it can be offered an earlier target spot time. But does offering that flight an earlier target spot time require other flights (originally filed over a different fix) to be moved to later target spot times? Or would the flight originally filed over Beaty be offered an earlier target spot time only if the Metering Desk identified a need for more flights to the alternate departure fix?

• What would prevent flight operators from filing routes over a departure fix other than Beaty in order to get an earlier target spot time but then amending the route to use Beaty instead? What target spot time should such a flight be allocated?

Such issues point to a need for flexibility, communication, and coordination in the departure metering procedure.

Adaptation Information Requirements

Table 38 summarizes the information requirements for supporting the DRC in performing the adaptation task. Note that supporting adaptation requires considering the diagnosis process and the diagnosed cause(s) of the disruption in the departure reservoir.

Effective adaptation requires processes for coordination and collaboration among the agents in the distributed departure management system. Communication between the DRC and the other agents is critical to ensure that the DRC has access to the information required to effectively manage the departure metering procedure. It also is important to ensure that flight operators are able to meet the schedule expected of them to maintain airport departure performance, and to ensure that the ATCT has the departure reservoir it needs to maintain efficient use of the departure runways. Information requirements for effective coordination and collaboration are discussed in the next section, followed by information requirements for effective communication.
Table 38. Information requirements for supporting DRC adaptation functions.

<table>
<thead>
<tr>
<th>Function Supported</th>
<th>Information Category</th>
<th>Information Requirement</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adapt to transient disruption</td>
<td>Schedule adjustment</td>
<td></td>
<td>Move flights earlier</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Move flights later</td>
</tr>
<tr>
<td>Adapt to shift in departure conditions</td>
<td>Anticipated departure rate</td>
<td>Increased</td>
<td>Quickly identify flights to fill departure reservoir</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Decreased</td>
<td>Slow arrival of flights to departure reservoir</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Change target reservoir characteristics</td>
</tr>
<tr>
<td>Runway(s) impacted</td>
<td>One or some</td>
<td></td>
<td>Change runway assignments</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Change target reservoir characteristics</td>
</tr>
<tr>
<td></td>
<td>All</td>
<td></td>
<td>Change target reservoir characteristics</td>
</tr>
<tr>
<td>Flight(s) impacted</td>
<td>Some</td>
<td></td>
<td>Change target reservoir characteristics</td>
</tr>
<tr>
<td></td>
<td>All</td>
<td></td>
<td>Change target reservoir characteristics</td>
</tr>
<tr>
<td>Change in ATCT strategy</td>
<td>New target departure reservoir characteristics</td>
<td></td>
<td>Change target reservoir characteristics</td>
</tr>
<tr>
<td>Choose time to implement parameter change</td>
<td>Anticipated impact of parameter change relative to target reservoir characteristics</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Static time horizon interaction with departure reservoir</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Anticipated change in departure reservoir between detecting need to adapt and when changes will take effect</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Evaluate impact of parameter change</td>
<td>Anticipated impact</td>
<td>Relative to target reservoir characteristics</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Monitoring</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Diagnosis</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Coordination and Collaboration Functions

The departure metering procedure and the DRC role are designed to perform in an environment in which decision-making and other tasks are distributed across multiple agents representing sometimes competing organizations. Ramp control operators, the ATCT, the DRC and even TRACON or ARTCCs each have a role to play in making departure metering successful. Distributing the different roles and responsibilities in a way that aligns with the goals of departure metering can contribute to successful coordination (Smith, Spencer, & Billings, 2007). Supporting each role in effectively coordinating activities and collaborating when necessary supports the joint goals of metering. Such a system requires processes for collaboration and coordination to achieve strategic and tactical decision making.

This includes a design for coordination, here defined as follows:

Process(es) allowing agents to perform one or more tasks relatively independently of others, with the outcome of several independently performed tasks together achieving some common goal.

Using this definition, successful coordination requires relatively independent subtasks to be designed and distributed to agents (Smith, 2011) according to their access to knowledge, data, and authority, and their goals, priorities, and motivations (Smith, Spencer, & Billings, 2007).

Coordination

As an example of a coordination activity, the DRC sets constraints for the departure metering procedure management software, which in turn passes those constraints to flight and/or ramp control operators in the form of capacity allocation. Smith, Spencer, and Billings (2007) described similar constraint propagation functions as coordination activities. Similarly, actions that the DRC takes to adapt the departure
reservoir to changing conditions represent a form of coordination with the ATCT, passing the ground controller a suitable departure reservoir. The departure reservoir can be considered an artifact that these distributed personnel (and organizations) use to coordinate their activities (Hutchins, 1995b; Klein, et al., 2005; Nemeth, et al., 2004).

Different departure metering procedure concepts assume different distributions of roles and responsibilities. For example, those at BOS and EWR (Borgman & Smith, 2010; Burgain, Feron, & Clarke, 2009), discussed in Chapter 2, concentrate decision making in the ATCT. This seems to follow a principle that surface management is an ATCT function. In addition, it reflects a belief that aircraft should be ready to request permission to enter the active movement area before receiving a target spot time (EWR) or being added to a virtual departure queue (BOS).

In contrast, the procedure at MEM (Brinton, Lent, & Provan, 2010) assumed that software would be the chief decision maker regarding when departure metering should be invoked and when the metering parameters should be adapted. Brinton, et al. (2010) did not discuss who should notify the software when departure conditions had changed to the point that a “normal” departure rate would not be appropriate over the planning horizon. On the other hand, the departure metering procedure at JFK relies on human expertise, not located in the ATCT, to set constraints for aircraft entering the active movement area.

The Surface CDM Team Concept of Operations (2011) described a departure metering concept in which air traffic control was responsible for sharing information about airspace and surface constraints and for setting current and expected future departure rates. Like the concept discussed by Brinton, Lent, and Provan (2010), the Surface CDM Team (2011) expected that software would detect the need to invoke a departure metering procedure and monitor demand for the purpose of determining when metering should end. In addition, this concept identified a “Departure Reservoir Management capability” that would calculate departure capacity, develop a plan including an appropriate number of target spot times, and allocate those target spot times
according to that plan. In addition, this Departure Reservoir Management capability may create departure metering categories (multiple departure reservoirs defined according to aircraft characteristics) if “appropriate Stakeholders” agreed it was necessary.

These differing approaches to distributing roles and responsibilities have consequences for the need to coordinate and collaborate across agents and organizations. If a flight operator at EWR wants to modify the priority of their flights, they must make a personal request—typically by telephone—to the ATCT. At JFK, the flight operator would request that the Metering Desk personnel swap their flight with another via text chat and could monitor the status of the request either via a return chat message or a change (or lack thereof) in the target spot time for the flight in question.

When departure conditions change, or are expected to change, who should be responsible for adapting the departure metering plan? If the DRC must obtain information from other agents about the impact of changes in departure conditions, why not design the system such that the source of that information interacts with the departure metering procedure management software to invoke an adjustment in the metering plan? This depends on whether that responsibility aligns with the goals, priorities, and motivations of the individual in question (Smith, Spencer, & Billings, 2007).

In the departure metering concept explored in this dissertation, it is assumed that the DRC is responsible for developing a departure metering plan, for monitoring departure performance relative to that plan, and for adapting the metering plan when appropriate. This responsibility is similar to traffic management responsibilities currently ascribed to controllers, supervisors, and traffic managers in the ATCT, TRACON, and/or ARTCC. However, the goals of minimizing the size of the departure reservoir without starving the runway (as long as there is departure demand) ascribed here to the DRC are different from those of most controllers and traffic managers. (Although one participant in the departure metering concept evaluation study mentioned a similar procedure once managed at LAX in which traffic management personnel used expected traffic demand
over the next 15 minutes to devise a short-term “metering” plan.) Assuming that controllers, supervisors, and/or traffic managers will perform the DRC role may not be appropriate.

However, adding a role like the DRC creates coordination requirements for controllers, supervisors, and/or traffic managers as well as flight and/or ramp control operator personnel. If the DRC is to have the best information about the impact of airspace and surface constraints on departures, it may be important for the DRC to have access to ATCT surface management strategies (particularly for departure staging and sequencing). Access to these strategies may enable the DRC to develop a departure metering plan that directly supports those strategies (particularly since different ATCT personnel may invoke different strategies in response to the same constraint, as shown in Chapter 4). Similarly, under a departure metering procedure ramp control personnel may be expected to coordinate the flow of departures from their ramp areas with the departure metering parameters set out by the DRC.

Pre-Coordination

One strategy frequently used in air traffic management is pre-coordination so that implementing a plan at a later time requires little collaboration (Smith, Spencer, & Billings, 2007). Well-defined procedures and pre-coordination to accommodate likely contingencies also represent a form of coordination in which collaboration and communication during planning periods – when workload is lower – support efficient communications during periods of higher tempo operations. Efficient communications can reduce the need to communicate, and “the fewer communications that are required, the more efficient the system can be,” said one former ATCT traffic manager.

Coded Departure Routes represent one form of pre-coordination that supports efficient coordination, collaboration, and communication. As a coordination device, CDRs allow flight operators to know what routes to prepare for during severe weather
events. That preparation speeds the process for amending departure routes when routes become unavailable. Without pre-coordination, according to one former ATCT and TRACON traffic manager:

If it was a situation where it wasn’t pre-coordinated with the airline, the pilot would get the new route [from ATC]. He would be left in the holding area or he wouldn’t be put out to the runway until he could contact his dispatcher… That may take 5 minutes or 10 minutes, it depends.

On the other hand, with pre-coordination:

If the Center says we can swap all wests to the north, and this was something that was expected and the airlines were already on board, I could do that in no time. I could do that in a minute. All I had to do was enter the new route into the computer and tell the pilot because in that case those are pre-coded routes he just has to [enter the code into his onboard computer]… [It requires only] the time to put it [the CDR] in and issue the new clearance…

[If] we knew we were going to have weather, and it’s been coordinated with the airlines … they’ve already [fueled for the SWAP routes]… When it’s pre-coordinated they [the ATCT traffic management coordinator] look at the next westbound and change the route. They don’t even discuss it with the Center… The SWAP routes are published and are known to the airlines. It’s been pre-coordinated that if westbounds are stopped we’re going to go north. They [the flight operators] get advised of that, and I’d imagine that they tell the crews to expect that. There wasn’t much involved in them coordinating it because the routes are already in their onboard computer.”

Notice how pre-coordination reduces the time and collaboration involved to resolve route availability issues. Pre-coordination can be performed via any available means such as the text chat used to support departure metering at JFK.

Airport Surface Display

Fernandes and Smith (2011b) discussed uses for airport surface surveillance displays as tools for coordination among distributed agents. Surface surveillance displays
also can facilitate coordination in a departure metering procedure. JFK Metering Desk personnel said they use the airport surface display to monitor the state of departures on the surface. They were observed to monitor the amount of time that aircraft had been active with the purpose of ensuring that the ATCT and/or ramp control operator was aware of any flight that had been active for an extended period of time. Their surface display generated an alert when an aircraft (arrival or departure) had been out for 90 minutes and again after 2 hours, consistent with many surface display installations (Fernandes & Smith, 2011b). They said their response to such an alert was to “look at it, confirm with the [airport operator] that they know about it.” Sometimes such flights are delayed because, as one former ATCT traffic manager said, “You taxied that… flight out 20 minutes ago and you parked him someplace because he couldn’t go, and then you were relieved and the new controller forgets about him.”

It is not the responsibility of the JFK Metering Desk to monitor for flights with extended time on the tarmac but they do so in order to support airport performance. It is an attempt on their part to direct the attention of other agents in the joint activity to information they believe is important to those agents’ performance and to the performance of the overall system (Klein, et al., 2005).

**Coordination Information Requirements:**

Who has what information?
Who is responsible for what?
ATCT surface management strategies
TRACON/ARTCC traffic management strategies
Constraints created by departure metering procedure parameters that would be feasible for other agents

A well-designed distributed work system may attempt to define subtasks that are as independent as possible (Smith, 2011), but does not eliminate the need for, or
capability for, collaboration. In particular, adapting to dynamic conditions sometimes requires collaboration.

**Collaboration**

In this dissertation collaboration is taken to mean activities in which agents are actively engaged in a multi-agent work process in order to achieve a common goal such as to solve a problem. Collaboration may require unstructured, synchronous communication among agents whose goals, priorities, and level of workload may not align (Smith, Spencer, & Billings, 2007).

Collaboration may be initiated for a number of reasons. Often one agent has a problem that he or she knows another agent can help solve, or vice versa. This requires that agents have information about the distribution of roles, responsibilities, authority, knowledge, goals, priorities, and motivations in a system (Smith, Spencer, & Billings, 2007). This is similar to the information requirements for coordination highlighted above.

Additionally, procedures can dictate that agents collaborate on specific topics at specific times. Traffic managers and flight operator personnel participate in and/or listen to regularly scheduled planning teleconferences. Such teleconferences are an example of what Smith (2011) described as opportunities for collaboration at times when there may not be a problem to solve that may facilitate collaboration when there is a problem. Such collaboration opportunities may help distributed agents build relationships with each other, which can facilitate success in distributed teams (Bowers, Salas, & Jentsch, 2006).

Procedures like the planning teleconferences that call for collaboration at regular intervals can provide opportunities to detect and repair breakdowns in common ground before they become critical. Collaboration is especially important when one or more agents detect a breakdown in common ground that needs to be repaired (Klein, et al., 2005), which can be difficult (Smith, McCoy, & Orasanu, 2001), particularly when the activities of other agents are not observable.
Klein and colleagues (2005) suggested that the ability to observe the status and activities of other agents involved in a joint activity is an important factor in the ability to maintain common ground. This observability is also required to detect the focus of another agent’s attention and determine whether their attention should be directed elsewhere (Klein, et al., 2005).

Processes for collaboration also should facilitate observability in a way that allows agents to gauge what Klein, et al. (2005) called “interruptability.” Workload may be asymmetric across organizations. There are times when members of one organization are very busy while members of another organization in the distributed system are not as busy, and vice versa. Gauging interruptability enables agents to determine whether they should postpone collaboration if possible, a phenomena that Vicente, Mumaw, and Roth (2004) observed in nuclear power plant control rooms.

To support collaboration, the DRC should be able to observe the status of other agents involved in the joint activity and assess the level of workload of other agents. This information can be used to signal the DRC to take action to alleviate their workload or to postpone collaboration activities if possible. To determine the workload of other agents, the DRC can monitor the amount of chatter on the radio frequencies, the time required for another agent to respond to communications, changes to the departure metering procedure made by other agents such as departure staging strategies or target spot time swaps, or the status of active aircraft.

Information that facilitates collaboration is closely related to activities that facilitate collaboration. These are summarized below.
### Information that Facilitates Collaboration

<table>
<thead>
<tr>
<th>Information that Facilitates Collaboration</th>
<th>Activities that Facilitate Collaboration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distribution of roles, responsibilities, and authority</td>
<td>Procedural collaboration events</td>
</tr>
<tr>
<td>Goals, priorities and motivations of other agents</td>
<td>Collaboration at times when there is not a problem to solve</td>
</tr>
<tr>
<td>Status of common ground (esp. breakdowns)</td>
<td>Relationship building</td>
</tr>
<tr>
<td>Observability of status and workload of other agents</td>
<td>Building and maintaining common ground</td>
</tr>
<tr>
<td>Focus of other agents’ attention</td>
<td>Detecting and repairing breakdowns in common ground</td>
</tr>
<tr>
<td>Interruptability of other agents</td>
<td>Redirecting attention of others when necessary</td>
</tr>
<tr>
<td></td>
<td>Considering workload of others when initiating collaboration</td>
</tr>
<tr>
<td></td>
<td>Acting to alleviate workload of others</td>
</tr>
<tr>
<td></td>
<td>Monitoring status of others</td>
</tr>
</tbody>
</table>

### Managing Multiple Perspectives

The JFK Metering Desk also supports coordination and collaboration by incorporating multiple NAS perspectives into managing the departure metering procedure. They have two people on staff every day. One formerly worked in the ATCT and the other formerly worked for one of the ramp control operators. This supports coordination by helping Metering Desk personnel understand the goals and constraints of others in the joint cognitive system and anticipate their needs (Klein, et al., 2005).

It may not be feasible for the DRC role to always be performed by a team representing both ATCT and ramp control operator expertise. However, understanding how people in these different roles perceive departure management, as well as their goals and priorities, can help the DRC facilitate coordination. It may require the DRC to have access to both the spatial displays that highlight priorities in the ATCT as well as tabular displays that highlight flight operator and ramp control operator priorities.
Coordination and Collaboration Information Requirements

Table 39 summarizes information requirements for supporting the DRC in constraint setting as a form of coordination among the DRC, ATCT, and ramp control operators. The table outlines the kind of information from others that the DRC requires to engage in effective coordination and collaboration. From the flight and/or ramp control operators, the DRC needs updated flight status and readiness information to determine whether the departure metering procedure needs to be adapted and how it should be adapted. Similarly, the ATCT should provide updated information about desirable departure reservoir characteristics.

Table 39. Information requirements for supporting constraint setting for coordination.

<table>
<thead>
<tr>
<th>Information Category</th>
<th>Information Requirement</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constraints from ATCT, TRACON, and/or ARTCC</td>
<td>ATCT departure staging strategy</td>
<td>Desired aircraft characteristics for each</td>
</tr>
<tr>
<td></td>
<td></td>
<td>departure reservoir</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Desired number of aircraft in each reservoir</td>
</tr>
<tr>
<td></td>
<td>Airspace constraints</td>
<td>Route availability</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Separation requirements</td>
</tr>
<tr>
<td>Constraints from flight operators and/or ramp control operators</td>
<td>Departure demand</td>
<td>Departure runway, fix, destination</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Aircraft type</td>
</tr>
<tr>
<td></td>
<td>Flight readiness status</td>
<td>Delayed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ready early</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mechanical issue</td>
</tr>
<tr>
<td></td>
<td>Flight status</td>
<td>Active</td>
</tr>
<tr>
<td></td>
<td></td>
<td>In ramp</td>
</tr>
<tr>
<td></td>
<td></td>
<td>At gate</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Off</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Filed / scheduled</td>
</tr>
</tbody>
</table>
Table 40 summarizes information requirements for supporting the DRC in adapting departure metering parameters as part of a coordinated surface management activity.

Table 40. Information requirements for adapting metering parameters.

<table>
<thead>
<tr>
<th>Information Category</th>
<th>Information Requirement</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Departure reservoir state</td>
<td>Current</td>
<td>Characteristics of aircraft in each reservoir</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Departure rate for each reservoir</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number of aircraft in each reservoir</td>
</tr>
<tr>
<td></td>
<td>Expected</td>
<td>Number of aircraft expected to join each reservoir over the planning horizon</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Expected departure rate for each reservoir over the planning horizon</td>
</tr>
<tr>
<td></td>
<td>Desired</td>
<td>ATCT departure staging strategy</td>
</tr>
<tr>
<td>Actions taken by others to modify reservoir</td>
<td>Flight operators</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ramp control operators</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ATCT</td>
<td></td>
</tr>
<tr>
<td></td>
<td>TRACON and/or ARTCC</td>
<td></td>
</tr>
</tbody>
</table>

Table 41 summarizes information requirements to support the DRC in participating in coordinated surface management activities. Such knowledge of the distribution of roles and responsibilities, particularly with respect to access to knowledge and data, is important in understanding which agent(s) in the distributed system might be able to help one solve a problem.
Table 41. Information requirements for coordination in surface management.

<table>
<thead>
<tr>
<th>Information Category</th>
<th>Information Requirement</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distribution of roles, responsibilities, and authority</td>
<td>Which agent develops the departure metering plan?</td>
<td>Creates target spot times</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Allocates target spot times to flights</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Controls order of flights in metering plan</td>
</tr>
<tr>
<td></td>
<td>Which agent decides…?</td>
<td>When to invoke metering</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Value of each metering parameter</td>
</tr>
<tr>
<td></td>
<td></td>
<td>When to adapt metering parameters</td>
</tr>
<tr>
<td></td>
<td></td>
<td>When to end metering</td>
</tr>
<tr>
<td></td>
<td>Which agent enforces target spot times?</td>
<td></td>
</tr>
<tr>
<td>Distribution of access to knowledge and data</td>
<td>Which information is each agent expected to share with others?</td>
<td>Strategies</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Goals</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Constraints</td>
</tr>
<tr>
<td></td>
<td>Which agent has access to the best information about…?</td>
<td>Departure constraints</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Departure demand</td>
</tr>
<tr>
<td></td>
<td></td>
<td>How to set departure rates</td>
</tr>
<tr>
<td>Goals, priorities, and motivations of distributed agents</td>
<td>Performance metrics relative to departure metering goals</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Basis of expertise</td>
<td></td>
</tr>
</tbody>
</table>

Table 42 summarizes information requirements for supporting collaboration in surface management.

Table 42. Information requirements for collaboration in surface management.

<table>
<thead>
<tr>
<th>Information Category</th>
<th>Information Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goals, priorities, and motivations of distributed agents</td>
<td>Who is responsible for initiating collaboration?</td>
</tr>
<tr>
<td>Procedures for collaborating before there is a problem</td>
<td>What is the purpose of the collaborative activity?</td>
</tr>
<tr>
<td></td>
<td>What is my responsibility in the collaboration?</td>
</tr>
<tr>
<td></td>
<td>With whom am I collaborating?</td>
</tr>
</tbody>
</table>
Table 43 summarizes information required to build and maintain common ground in coordinated surface management.

Table 43. Information requirements for building and maintaining common ground.

<table>
<thead>
<tr>
<th>Information Category</th>
<th>Information Requirement</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Status of common ground</td>
<td>Opportunities to detect and repair breakdowns</td>
<td></td>
</tr>
<tr>
<td>Observability of other agents’ activities and status</td>
<td>Interruptability of other agents</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Focus of other agents’ attention</td>
<td>Activities performed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Activities expected but not performed</td>
</tr>
<tr>
<td></td>
<td>Changes made to departure reservoir</td>
<td>Desired reservoir characteristics</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Target spot time swaps</td>
</tr>
<tr>
<td>Level of workload of other agents</td>
<td>Time required to respond to communication</td>
<td>Telephone</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Text messages</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Modification of departure reservoir</td>
</tr>
<tr>
<td></td>
<td>Radio chatter</td>
<td>Strategies invoked</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Time flights are active</td>
</tr>
</tbody>
</table>

Just as coordination and collaboration information requirements are influenced by the distribution of roles and responsibilities, so too are requirements for communication, discussed in the next section.

**Communication Functions**

Many of the collaboration and coordination responsibilities of the DRC require communication with others located in the ATCT and in ramp control operator facilities. Important considerations in distributed work system design that directly impact communication requirements are distribution of knowledge and data among agents (Smith, Spencer, & Billings, 2007). Information about some of the constraints that the
The DRC may need information from others and will need to determine the best agent from whom to seek the information. This choice should be made according to which agent has the best access to the needed information (Smith, et al., 2012; Smith, Spencer, & Billings, 2007). The decision also depends on which agent(s) has the authority and time to share that information. Therefore, communication requirements are closely related to the distribution of roles and responsibilities as well as support for coordination and collaboration requirements.

If departures are stopped due to weather, the ATCT will be contacted first and must then pass the information on to the DRC and to flight and/or ramp control operators. In response, said a former ATCT and TRACON traffic manager, “the Tower calls the Center TMC, going what’s with the stop, what can we do, and that’s how they get the reroutes going.” The DRC may not know anything about the reason for the stop or for how long departures will be stopped unless and until the ATCT notifies him or her. Thus, the DRC will need information from the ATCT about the stop in order to develop an expectation for the impact on departures and, in turn, determine how to adapt the departure metering plan.

Similarly, flight operators are likely to have the best information about when their aircraft will be ready. ARTCC or TRACON traffic managers are likely to have the best information about impacts of weather and traffic volume constraints on the departure capacity, and they typically communicate these constraints to the ATCT in the form of separation restrictions (miles in trail or minutes in trail).
ATCT Surface Management Strategies

In today’s world, ramp control operators often do not know the surface management strategy the ATCT is using and so they do not know how best to feed those queues. If the ATCT traffic manager communicates their surface management strategy to the DRC, the DRC can use that information to build a “good” departure reservoir and then the ramp control operators may not have much immediate need for that information. However, coordination can be more effective if different agents have access to a shared problem representation (Cannon-Bowers & Salas, 2001). The surface management strategy is one way in which ATCT personnel express their interpretation of airspace and surface constraints. Providing access to that strategy for ramp control and/or flight operator personnel as well as the DRC may help ramp control and/or flight operator personnel prioritize their activities in preparing aircraft for departure.

While the Metering Desk is constantly trying to anticipate which departures will best be able to use available airspace, the ATCT often seems more reactive because they want to ensure fair treatment of all flights. According to one former ATCT and TRACON traffic manager, “Up until the time they can’t go, they’re going to be treated as anyone else. I don’t know that they’re not going to go. … I can’t deny service based on what may happen.”

Mechanisms for the ATCT to share their needs and strategies with the DRC should help the DRC meet those needs. Typically, said one former ATCT and TRACON traffic manager:

The TMC announces the game plan. [Maybe] the game plan is, we’re taking all the west- and northbounds to the center runway… and the eastbounds and certain southbounds to the east runway… If the game plan changes then they [the traffic management coordinator] need to change it.
To support the DRC in building an appropriate departure reservoir, the ATCT traffic management coordinator (or supervisor or ground controller, if there is not a traffic management coordinator) needs to communicate their strategy to the DRC. One airport operator representative at JFK said, “If the [ATCT] tells me who they want” the Metering Desk has an appropriate goal for building an appropriate inventory of flights. A Metering Desk controller said, “Sometimes the tower will get on the chat [to say there is a] big in-trail on Robbinsville so they need non-Robbinsvilles.”

The current assignment of target spot times to flights should be known by ramp control operators, the DRC, and under some departure metering concepts, by the ATCT. This list represents the priorities of flight and/or ramp control operators to the extent that they have made swaps to ensure that their higher priority flights depart before lower priority flights. However, at times they may have needs that are not directly accommodated by the target spot times, particularly if departure conditions are dynamic. For example, a flight to a restricted departure fix may have a curfew and so it may need its reroute processed right away, even if this is not reflected by its current position in the departure metering plan. Unless the flight and/or ramp control operator communicates this directly, ramp control operators still have the best information about flight operator priorities and can use their target spot time allocation to express those priorities.

Table 44 summarizes the information that should be communicated to the DRC by others. The table is organized according to the general purpose of the information (i.e., updating the departure metering plan, general system knowledge, and maintaining common ground), the most likely source for the information in the departure metering concept explored in this dissertation, and the process by which it contributes to the general purpose.
### Table 44. Summary of information DRC may require from others.

<table>
<thead>
<tr>
<th>Purpose of Information</th>
<th>Source of Information</th>
<th>Information</th>
<th>Intermediate use of Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Update departure metering plan</td>
<td>ATCT, TRACON, and/or ARTCC</td>
<td>Departures stopped due to weather</td>
<td>Develop expectation for impact on departures</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Impacts of weather and volume on departure capacity</td>
<td>Update expectation for departure rate(s)</td>
</tr>
<tr>
<td></td>
<td>ATCT</td>
<td>Surface management strategy</td>
<td>Develop/update targets for departure reservoir</td>
</tr>
<tr>
<td>Flight and/or ramp control operators</td>
<td></td>
<td>When aircraft will be ready</td>
<td>Update expectation for departure demand</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Flight and/or ramp control operator priorities</td>
<td>Update expectation for how flight and/or ramp control operators want to use target spot times</td>
</tr>
<tr>
<td>Help flight operators meet priorities</td>
<td>Flight and/or ramp control operators</td>
<td>Current assignment of target spot times to flights</td>
<td>Update expectation for how flight and/or ramp control operators want to use target spot times</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Flight to restricted departure fix has curfew</td>
<td>Anticipate needs not directly accommodated by target spot times</td>
</tr>
<tr>
<td>System knowledge</td>
<td>System design</td>
<td>Which agent(s) has access to which information</td>
<td>Develop plan for who to contact to obtain needed information</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Which agent(s) has authority to share information and currently has time</td>
<td>Develop plan for who to contact to obtain needed information</td>
</tr>
<tr>
<td>Maintain common ground</td>
<td>Procedure</td>
<td>Periodic communication to ensure distributed agents share sufficient portions of situation model</td>
<td></td>
</tr>
</tbody>
</table>

*Information Residing with the DRC*

The DRC also has access to information that may be needed by others. Identifying what a teammate “needs to notice” and directing his or her attention accordingly is
challenging (Klein, et al., 2004). Thus, the DRC should have a means to identify information that would be useful to others and share that information.

The emphasis of the DRC role on anticipating future departure reservoir state may provide the DRC with information that may be useful to others, particularly during dynamic conditions. For example, if the DRC anticipates that demand for departure fixes that the ATCT expects to use as splitters will be insufficient to maintain efficient use of the runway, he or she can notify ramp control and/or flight operators that some of their flights may leave sooner if they were filed to use a splitter route. Alternatively, the DRC could notify the ATCT that demand for splitter routes may be insufficient.

Similarly, if the DRC anticipates that the departure reservoir size will decrease below some threshold, he or she can identify flights that may be able to leave early and offer them earlier target spot times. The ability to effectively identify information that may be helpful to others and to share that information requires the DRC to have a model of which agent(s) need the information. This can be facilitated by similar knowledge as that for supporting coordination and collaboration, namely, an understanding of the distribution of roles and responsibilities, access to knowledge and data, and the goals and priorities of others. In addition, the ability to observe the activities and status of other agents can enable the DRC to know whether they actually need the information or if they already have it and are acting on it (or have decided to not act on it).

Information sharing also can be defined in a procedural step calling for the DRC to share certain information with a certain agent(s) when it becomes available. Such communications may be direct, such as in the form of a telephone call, or indirect, such as communicating target spot times to flight and/or ramp control operators via the departure metering procedure management software.

Alternatively, the DRC can detect other agents’ need for information by observing the departure metering procedure state or the behaviors of other agents. For example, JFK
Metering Desk personnel reported that during a severe weather event they monitor for aircraft that have been holding in the active movement area for long enough that they may have been forgotten by the ATCT and/or the ramp control operator:

I’ll see a San Francisco departure sitting out there with the White departures [when White is closed], but Coate’s open [and is appropriate for a SFO flight]. I’ll contact the airline to tell them they might get him out on another fix.

Table 45 summarizes information the DRC has access to that may be useful to other agents.

Table 45. Summary of information the DRC may have that may be useful to others.

<table>
<thead>
<tr>
<th>Information</th>
<th>Receiving Agent</th>
<th>Potential Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expected future departure reservoir state</td>
<td>ATCT</td>
<td>May need to adapt surface management strategy to accommodate changing demand</td>
</tr>
<tr>
<td>Demand for splitters insufficient</td>
<td>ATCT</td>
<td>May need to initiate reroutes</td>
</tr>
<tr>
<td></td>
<td>Ramp control operators</td>
<td>May be able to get some flights out sooner</td>
</tr>
<tr>
<td></td>
<td>Flight operators</td>
<td>May need to initiate reroutes</td>
</tr>
<tr>
<td>Departure reservoir will decrease in size</td>
<td>Ramp control operators</td>
<td>Identify flights that can leave sooner</td>
</tr>
<tr>
<td>Target spot times updated</td>
<td>Ramp control operators</td>
<td>May need to reprioritize activities</td>
</tr>
</tbody>
</table>

Evaluating Communication Effectiveness

Feedback also is an important aspect of communication (Klein, et al., 2005; Smith, Bower, & Spencer, 2009). One form of feedback is acknowledging that a message was received, and such acknowledgements are standard procedure for many air traffic management communications. One TRACON traffic manager was observed to pass an airspace restriction to an airport electronically via the National Traffic Management Log. He expected the ATCT to acknowledge receipt of the restriction. “They acknowledge. If they don’t acknowledge I have to call them.”
Mechanisms for information recipients to acknowledge that they received a message and for senders to see that the communication was acknowledged should be embedded in the digital tools used to communicate among the various agents and organizations involved in the departure metering procedure. The DRC can determine whether the information was received if the receiving agent directly acknowledges the information.

However, acknowledging that the message was received is not the same as ensuring that the message was understood. Once the DRC has acted to communicate with another agent, he or she should be able to evaluate the effectiveness of the communication. The DRC can monitor a message recipient’s behaviors to determine whether he or she is acting on the information as expected. For example, when the JFK Metering Desk notifies a ramp control operator that his or her flight might be able to depart more quickly on a different route they can monitor whether the flight’s route is changed, thereby determining whether they need to re-send the information.

Some forms of communication can more easily have embedded in them mechanisms for verifying correct interpretation of information, such as the requirement that flight crews read back instructions received via radio from air traffic controllers. In the absence of such direct feedback, perhaps because communications are asynchronous, the DRC can request specific feedback from the recipient of the information to gauge whether it was understood. In addition, the DRC can use behavioral indicators to gauge whether the message was understood. Smith, Bower, and Spencer (2009) found that Army officers detected misconceptions when they used a multimedia asynchronous communication tool to review plans developed by subordinates.

It is important that the DRC knows which agent(s) has access to needed information, has a means for obtaining that information, and can ensure that it is up to date. Tools to support the DRC should provide a measure of how current the information is so the DRC can judge whether to request an update from the appropriate agent.
Tools to Support Communication

Supporting effective communication between the DRC and other agents involved in the departure metering procedure goes beyond providing communication technologies (Hollnagel & Woods, 2005; Woods & Hollnagel, 2006). One feature of effective communication across organizations is a domain language sufficient for expressing the information needs and information products of each agent (Smith, McCoy, & Orasanu, 2001). A domain language contributes to short, coded communications that are unambiguous in context (Klein, et al., 2005) and can be embedded in displays that allow the distributed agents to track the status of the other agents and of the joint activity.

Well-Defined Domain Language

Aviation already uses a well-defined domain language to support coded radio communications, particularly between air traffic controllers and flight crews. Radio communications follow standard phraseology to facilitate understanding and to manage radio frequency congestion. Similarly, departure metering procedures require a language for flight crews to notify the ATCT of their metering status and intended metering location. A flight crew that needed to go to a holding area on the active movement surface for metering might say, “[Call sign] request taxi to East holding pad for metering, target spot time [target spot time].” When the aircraft’s target spot time arrives the flight crew might contact the ATCT again saying, “[Call sign] metering in East holding pad, ready for taxi to runway 18L.”

The phraseology used for radio communications between flight crews and the ATCT is well-defined to facilitate mutual understanding. This principle should be extended to all aspects of the domain language. One issue with the Ground Delay Program that one former dispatcher raised is the opportunity for ambiguity in some terms. “We have 3 definitions for exactly the same event in the GDP and that’s ‘off’. There’s controlled off, there’s predicted off, there’s PTime off. We need to be better at our
naming these events so they’re more precise.” It is important that the meanings of terms used to manage the departure metering procedure are consistently applied across agents and organizations.

Having a domain language in which terms are well-defined can go a long way to supporting efficient, effective communication. This in turn supports effective coordination and collaboration. A well-defined domain language also can facilitate efficient human-human communication by allowing some of the communication burden to be offloaded onto digital tools.

Domain Language Embedded in Software Tools

Many ramp control operators have software that helps them manage ramp control activities such as determining when a flight should push back. Incorporating target spot times into these software tools – and automatically sharing some information from these tools with the departure metering procedure management software – may reduce the need for ramp control operators to communicate directly with the DRC when target spot times needed to be changed.

If the ramp control management software detects that a flight’s target spot time is incompatible with the aircraft status (perhaps because the aircraft will arrive late), the software could alert the ramp control operator. The ramp control operator could decide how to resolve the conflict (perhaps by swapping the aircraft’s target spot time with a later time). The swap request could be submitted automatically to the departure metering procedure management software, which would ensure that the new allocation of target spot times would not violate any constraints on the departure reservoir. If there was no conflict, the swap could be made automatically. If there was a conflict the swap request would be rejected.

The ramp control operator may want to override the constraint, in which case the ramp control operator may need to communicate with the DRC in order to determine
whether the ramp control operator’s request can be accommodated. Note that this reflects a philosophy of management by exception (Smith, McCoy, & Orasanu, 2001).

Automated communication also can be useful for communication functions such as informing ramp control operators of their target spot times, ramp control operators requesting a different target spot time for a flight, alerting the system to flight readiness status relative to the target spot time when appropriate, informing the DRC and ramp control operators when airspace and/or surface constraints change or when the ATCT expects to change surface management strategies, or informing the ATCT of what inventory they should expect in the departure reservoir so they can think about how to build their departure lineup.

What should be communicated to different agents, and what they should be expected to communicate to others, depends on each agent’s perspective on the system. For example, the departure metering procedure management software might compute the plan according to expected off (wheels up) times. However, the flight operator has little to no control over a flight once it enters the active movement area and is under ATCT control. Said one former flight operator dispatcher, “as a rule I would say give the person the time he can control the most. Off time is your goal here. But in reality the best the airline can do is give you an out time. That’s where his level of control begins to decrease significantly.” Since the ramp control operator retains control over the aircraft until it reaches a spot and is handed over to ATCT control, the target spot time is a fair time to expect them to achieve.

It may be useful for the ramp control operator to also see an Out time expected to allow the flight to reach the spot in time for its target spot time. This could support them in planning flight push back or determining the latest time a flight could push back and still be compliant with its target spot time. Alternatively, it may be useful for the ramp control operator to have access to the expected Off time. In particular, the expected time spent actively taxiing may impact the amount of fuel required on the aircraft.
Communication Technology

While communication technology is not the only consideration in supporting communication in a distributed system (Hollnagel & Woods, 2005; Smith, 2011; Woods & Hollnagel, 2006), it is an important consideration nonetheless. In particular, direct human–human communication when necessary must be supported. Existing examples in tactical air traffic management include radio, telephone, and text chat.

Radio communication is most appropriate when flight crews are involved. An advantage of radio communication with flight crews is the ability for interested parties to monitor the frequency and gauge the status of the operation. Likewise, information communicated via the radio can be broadcast to a number of agents at once.

An additional advantage of text chat over radio communication is its ability to support asynchronous communication. If the intended recipient of the message is busy, the message can wait in a queue for the recipient to acknowledge it. In contrast, if the intended recipient of radio information is not attending to the radio frequency at the time a message is sent, it is very likely that the message will not be processed by the intended recipient and must be repeated.

But when information is needed by only one party in the distributed system, the telephone is still a tool that is widely used to support collaboration in air traffic management. The telephone is particularly useful when a person’s attention needs to be directed to a specific piece of information such as a digital communication that was sent but not acknowledged. However, stories abound of the telephone going unanswered when agents are busy, even if the communication is critical.

Text Chat

The text chat tool used at JFK is used in much the same way as radio communication. It is particularly useful for broadcasting information to all interested
agents. It supports coordination and collaboration not only by allowing the ATCT to communicate to the Metering Desk which flights best fit into the ATCT strategy, but also by broadcasting that strategy to the ramp control operators who can ensure they have the “right” flights prepared for departure. Because information shared via the chat is broadcast to all users, JFK airport operator personnel credit the technology with supporting transparency in departure metering procedure management.

**Time Stamps**

Another important aspect of communication is currency and accuracy of the information. Communicating via digital means facilitates time stamping messages when they are sent, received, and/or acknowledged. Since the DRC must track multiple information streams at once and conditions can change rapidly, knowing how current information is can support the DRC in evaluating its accuracy.

Some data may have a built-in expiration time, such as target spot times for flights that are extremely delayed. In such cases, the DRC (and possibly other agents) should be alerted before the target spot time expired. One important feature of the Departure Spacing Program (DSP) cited by ATCT personnel was a warning before a flight plan would time out of the system. According to a traffic management coordinator, “It takes seconds to update the PTime, but it takes a lot of coordination to re-file” the flight plan if it times out (is invalidated by the system).

While it is not expected that requesting a new target spot time for an extremely delayed flight would require the same level of coordination as re-filing a flight plan with TFMS or the Host computer, such an alert serves multiple purposes. First, it alerts the DRC, ramp control operator, and/or ATCT of a flight that may have fallen through the cracks. Second, it can prompt the DRC to confirm a realistic departure time for the flight so as to improve the accuracy of the departure metering procedure.
Knowing how current information is also can prompt the DRC to request an update from the appropriate party if the information is important to the current operation. This, of course, requires the DRC to have knowledge of how information is distributed across the departure management system (Smith, Spencer, & Billings, 2007). It also requires the DRC to have a physical means of communicating with others.

Communication Information Requirements

Table 46 summarizes the requirements for supporting the DRC in communication with others. The chief functions are to help the DRC identify the need for communication and to evaluate the effectiveness of the communication.

Table 46. Information requirements to support DRC communication with others.

<table>
<thead>
<tr>
<th>Function Supported</th>
<th>Information Category</th>
<th>Information Requirement</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identify need for communication</td>
<td>Have information needed by others</td>
<td>Agent(s) needing information</td>
<td>Procedure requiring certain information to be shared with a certain agent(s) at a certain time(s)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Observed state or behaviors</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Distribution of roles and responsibilities</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Agents’ goals, priorities, and access to information</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Best medium for sharing information</td>
<td>Number of recipients</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Feedback required</td>
</tr>
<tr>
<td>Needs information from others</td>
<td>Best agent from whom to retrieve information</td>
<td>Access to needed information</td>
<td>Authority to share needed information</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Interruptability</td>
</tr>
<tr>
<td>Evaluate effect of communication</td>
<td>Information received</td>
<td>Receipt acknowledged</td>
<td>Behavioral indicators</td>
</tr>
<tr>
<td></td>
<td>Information understood</td>
<td>Feedback</td>
<td>Behavioral indicators</td>
</tr>
<tr>
<td></td>
<td>Information correct</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Chapter Summary

Requirements for tools to support the DRC can be taken directly from the planning, monitoring, diagnosis, adaptation, coordination, collaboration, and communication requirements of the role. Tools to support these functions should make salient changes in airspace and surface constraints and ATCT strategies for managing those constraints. They should help the DRC anticipate the impact of those changes on departure conditions. This allows the DRC to determine how best to adapt the metering procedure to maintain system performance.

However, other agents have a role to play in maintaining procedure performance. The DRC can more effectively manage the flow of traffic to the departure reservoir if the ATCT communicates their surface management strategy to the DRC. This recommendation stands in contrast to assumptions made in other departure metering concepts that airspace constraints are sufficient knowledge for setting an anticipated departure rate. While understanding how airspace constraints are likely to impact the departure rate is an important area of expertise for the DRC, the impact of those constraints on the departure reservoir depends on how the ATCT chooses to manage the surface in response to (or in anticipation of) those constraints. As shown in the ATCT surface management decision making study described in chapter 4, different ATCT personnel may use different strategies in response to the same constraints. Thus, if the DRC is to manage a departure reservoir that supports the ATCT, the DRC should have direct access to that strategy.

Similarly, the DRC can best ensure that reservoir targets are met if ramp control operators manage their target spot times such that the DRC can anticipate which aircraft will join the departure reservoir and when. Tools supporting the departure metering procedure need to facilitate the kinds of coordination, collaboration, and communication that make this possible.
Well-designed tools to support the departure metering procedure allow the cognitive work of the DRC to be “well-adapted cognitive work,” which “occurs with a facility that belies the difficulty of the demands resolved and the dilemmas balanced” (Woods & Hollnagel, 2006, p. 171). The JFK Metering Desk today strives to perform well-adapted cognitive work. In the words of one Metering Desk controller, “My personal feeling is, I want them to forget I’m here.”

Tools to support the DRC do not have to represent revolutionary technology. In fact, many tools already exist that can support many of the functions required of the DRC if they are properly integrated with each other and with the departure metering procedure management software. Providing a means to integrate the various tools used today in air traffic management would represent a victory in itself, as a chief complaint of traffic managers is the lack of integration among their tools and displays. Poorly integrated tools can add to, rather than reduce, the cognitive complexity of work.

A key requirement of tools to support the DRC is that they help the DRC manage the cognitive complexity of administering the allocation of target spot times and adjusting the program as conditions change. They should support the DRC and ramp control operators in building a departure reservoir that meets the characteristics required for the ATCT to carry out an efficient surface management strategy. They also should support the ATCT and the DRC in considering flight operator priorities in making departure management decisions.

If these requirements can be met, then departure metering has the potential to produce huge savings for flight operators and for the ATCT. One flight operator reported that reducing an average of 1 minute in departure delay per year translates into $1 million savings over the course of a year (Spencer, Smith, & Billings, 2005). If the assumptions cited by Nakahara, et al. (2011) are correct and departures from JFK are saving 5 million gallons of fuel due to metering, the potential for emissions reduction and cost savings are huge.
Chapter 6: Conclusions, Emergent Themes and Future Work

The main goal of the work described in this dissertation was to identify the functional needs and information requirements presented in Chapter 5 for supporting a Departure Reservoir Coordinator (Surface CDM Team, 2011) responsible for managing a departure metering procedure. However, several additional themes and research questions emerged over the course of the research. A number of these are presented in this chapter. Some have been discussed previously, but the key lessons are reiterated here.

In particular, the studies described here highlighted the role of different problem representations to support the work by distributed personnel with differing expertise, responsibilities, and priorities. They also highlighted some strategies used by ARTCC, TRACON, and ATCT personnel to cope with uncertainty (Klein, 1999; Smith, Bennett, & Stone, 2006; Woods & Hollnagel, 2006) and complexity (Smith, 2011; Smith, Spencer, & Billings, 2007). These issues are discussed in terms of potential consequences for departure metering procedure design. In addition, the notion of translating weather information into traffic flow management strategies arose as an important consideration in supporting efficient and effective departure metering programs.

Problem Representations

Different goals and perspectives within a system may necessitate the use of different problem representations, even when practitioners are acting on the same underlying information. The human-centered design literature very clearly states that information representations should be designed according to the responsibilities,
knowledge, goals, and priorities of the user (Carroll, 2000; Smith, Bennett, & Stone, 2006; Norman, 2002; Smith, Stone, & Spencer, 2006; Woods & Hollnagel, 2006).

In addition, it is known that different information displays induce different internal representations (Smith, Bennett, & Stone, 2006; Zhang & Norman, 1994), which may not always be effective in supporting performance on the associated task (Smith, Bennett, & Stone, 2006; Smith, McCoy, & Layton, 1997). The literature on supporting distributed work focuses on the need to support distributed team members in developing shared representations when collaboration is required (Bowers, Salas, & Jentsch, 2006; Hinds & Kiesler, 2002; Klein, et al., 2005; Salas, Cooke, & Rosen, 2008). As an example, Caldwell (2006) mentioned the individual displays of experts in space flight teams, but only in the context of shared displays to facilitate communication and shared representations among team members. However, there is still a great deal to learn about designing displays and representations to support practitioners in fulfilling their individual responsibilities while effectively coordinating with each other without the need for active synchronous or asynchronous collaboration.

Our investigations make explicit differences in problem representations among distributed practitioners in the NAS. These differences became apparent in the domain language used to describe the strategies of traffic management personnel responsible for airspace and surface operations as well as between those responsible for ARTCC and TRACON airspace. In addition, such differences became apparent in the artifacts used by flight operator personnel as opposed to air traffic control personnel.

Air Traffic Managers and ATCT Personnel

Airspace constraints typically are communicated in terms of spacing restrictions (such as miles in trail). Indeed, in the interview with ARTCC and TRACON traffic managers described in Chapter 4, traffic managers responsible for airspace translated the location, severity, and trajectory of forecast weather into such spacing requirements for
aircraft entering their airspace. The TRACON traffic manager reported the constraints he would pass on to ATCT traffic management in terms of miles in trail “off the ground.”

Figure 41 shows example airspace restrictions – in terms of miles in trail off the ground – that would impact departures from runway 18C at MJA. This is similar to the information that the TRACON would share with the ATCT and that would be displayed on screens in the ATCT using a very similar representation.

<table>
<thead>
<tr>
<th>SOUTH [5 x 10 MIT]</th>
<th>10 MIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start: 1700Z</td>
<td>End: 2000Z</td>
</tr>
<tr>
<td>Extension: HIGH</td>
<td></td>
</tr>
<tr>
<td>WHALT and WYMON as 1</td>
<td>Using WYMON</td>
</tr>
<tr>
<td>Start: 1800Z</td>
<td>End: 2000Z</td>
</tr>
<tr>
<td>Extension: MODERATE</td>
<td></td>
</tr>
<tr>
<td>WILEY, WICKR and WORTH as 1</td>
<td>Using WILEY</td>
</tr>
<tr>
<td>Start: 1800Z</td>
<td>End: 2000Z</td>
</tr>
<tr>
<td>Extension: MODERATE</td>
<td></td>
</tr>
</tbody>
</table>

Figure 41. Airspace restrictions impacting 18C departures.

However, ATCT traffic managers and ground controllers do not directly work to separate aircraft by 5 miles or 15 miles. Rather, they are responsible for building a departure sequence such that when aircraft depart the miles in trail restrictions are respected. This requires a translation from “miles in trail” (or “minutes in trail”) to staging locations and “number of splitters” in the departure sequence. ATCT traffic managers and ground controllers seemed to perform this translation with ease.

Figure 42 illustrates a potential plan for managing the constraints impacting departures from runway 18C that are shown in Figure 41. Constrained aircraft are staged on taxiway G holding short of the intersection with taxiway F. Unconstrained aircraft are staged on taxiway H, also holding short of F, so they can be used as splitters for the constrained aircraft. Meanwhile, the constrained aircraft on taxiway G are sequenced, as much as possible, such that there are at least two flights between any two flights to a
Figure 42. Surface plan based on airspace constraints.

southbound departure fix (Phils, Smith, or Chasz) because those flights are subject to a 10 miles in trail restriction. In addition, no two flights to the same route are back to back on either taxiway G or H. Note that Whalt and Wymon are considered one route (“as 1”) and Wiley, Worth, and Wickr are also considered one route. Those aircraft filed to use Whalt or Wymon are highlighted to represent the strategy of avoiding a sequence in which two aircraft to the same route are sequenced back to back.
The plan in Figure 42 shows a marked difference in problem representation from the restrictions shown in Figure 41. This difference is induced by differences in the specific responsibilities of the agents using each representation. The transformation in representation seemed to be performed automatically by ATCT personnel as an expression of the expertise they had developed with their experience.

Despite this difference in problem representation, both surface and airspace personnel discussed constraints in terms of separation requirements. In fact, the only external representations of such constraints observed in either surface or airspace air traffic control facilities were displays showing lists of airspace restrictions in the form of miles in trail or minutes in trail. This artifact in the world reflects the distribution of control in the NAS according to its semi-hierarchical design and the direction in which constraints are most frequently propagated. In addition, it likely has informed suggestions that the Departure Reservoir Coordinator have access to such airspace restriction information such as in Chapter 5 of this dissertation and in the departure metering concept of operations published by the Surface Collaborative Decision Making Team (2011). However, informing the DRC of the airspace constraints alone may not be enough to enable the DRC to develop a departure metering plan that effectively supports ATCT surface management strategies (particularly since different ATCT personnel may invoke different strategies in response to the same airspace constraints).

**ARTCC and TRACON Traffic Managers**

Even among airspace air traffic managers, problem representations can differ somewhat. For example, even though they used the same language – miles in trail – to express their constraints, the ARTCC and TRACON traffic managers did not produce the same restrictions. The TRACON traffic manager, responsible for airspace in which aircraft travel at lower altitudes and slower speeds than in the ARTCC, consistently produced smaller spacing requirements for aircraft “off the ground” than the ARTCC traffic manager required when they entered ARTCC airspace. These smaller requirements
reflected the amount of additional separation between aircraft the TRACON traffic manager believed that TRACON air traffic controllers could achieve between the time the aircraft left the ground and when the TRACON handed them off to the ARTCC.

In fact, TRACON air traffic controllers routinely increase the separation between aircraft before handing them off to the ARTCC, as implied by the 3 miles minimum separation typically required in the TRACON versus the 5 miles minimum separation typically required in the ARTCC (Federal Aviation Administration, 2010b).

The difference in system perspectives represented by air traffic control and flight operator personnel also induces different representations. These are illustrated in the artifacts used by personnel in the two different kinds of organizations, discussed next.

_Air Traffic Control Personnel and Flight Operators_

A difference in perspective on the system between flight operators and air traffic controllers and traffic managers is evident in the artifacts of each domain. Flight operators tend to be equipment-, flight crew-, and passenger-focused. That is, flight operators use displays that focus on the flow of individual aircraft from one airport to another, into and out of gates, through maintenance facilities, etc. (Borgman & Smith, 2010). Their day to day operations involve ensuring that specific aircraft and crew complete the flight legs scheduled for them. According to one former dispatcher:

The things the dispatchers’ display deals with generally lend themselves to tabular displays. He’s looking at allowable takeoff in pounds, fuel in pounds, crew time… It’s better to look at several flights in relation to each other in a table… Pictures tend to be snapshots of now. Dispatchers are trying to control quasi-simultaneous events in the future. Controllers’ displays seem very graphical in nature. If you look at [a particular dispatcher display it] has a lot to do with organizing flights by time and by origin and destination… The initial task for a dispatcher might be to look through the tabular display… But the table doesn’t tell me anything about the geospatial location of the flight. Then I can look at the geospatial display to see where that flight is. The controller doesn’t know how
late any of the flights on his graphical display is, but he can look at the flight in a table and see [how long it has been delayed]…

In contrast, air traffic controllers and traffic managers view each flight – what a flight operator considers only a flight leg – as an individual entity. Day to day operations in air traffic control involve ensuring that each of the flights in their physical area of control are safely and efficiently handled and handed off to the next physical area of control. This is reflected in the fact that the displays they use tend to focus on a geographic area (Billings, Spencer, & Smith, 2001; Borgman & Smith, 2010) and the demands and constraints on that area over time.

Consequences for Departure Metering Procedure Design

The use of different problem representations has consequences for design. It serves as a reminder that distributed work system designs must simultaneously consider design for individuals as well as for the group. Designs also need to consider how those representations are used as a domain language to facilitate coordination and collaboration (Woods & Hollnagel, 2006) and how practitioners transform them in their problem-solving and decision-making activities. In the end, the jargon that practitioners use when they discuss domain constraints with each other may not reflect the most effective representation on which to base information requirements and display designs for one or more practitioners in the distributed work system.

In the case of departure metering procedures, this suggests that airspace restrictions may not be the only representation to provide the DRC for developing target departure reservoir characteristics. The DRC may also need access to the surface management strategy that ATCT personnel expect to use in response to the airspace restrictions. Not only would ATCT strategies provide the DRC a more direct representation of how airspace constraints are likely to impact departures on the airport surface, but the ATCT decision-making study discussed in Chapter 4 found that different ATCT personnel use different strategies in response to the same airspace restriction.
This suggestion also has implications for the distribution of work in departure metering procedures. If the DRC is to act on the surface management strategy that ATCT expect to use, then ATCT personnel must be responsible for communicating what they consider to be desirable departure reservoir characteristics to the DRC. This recommendation, in turn, leads to the following questions for future research:

**Question:** Can departure metering procedure performance be improved if ATCT personnel communicate their desired departure reservoir characteristics to the DRC and/or departure reservoir management software?

**Question:** What is an appropriate domain language for communicating ATCT and departure metering procedure strategies in the distributed system? What displays could support communication of such strategies? What displays should be provided to help the DRC evaluate whether these strategies are being implemented effectively?

**Question:** How can the design of a departure metering procedure be robust to individual differences in strategies invoked in response to a given set of constraints?

---

**Strategies for Coping with Uncertainty**

One of the challenges faced in air traffic management is the level of uncertainty inherent in critical constraints such as weather and traffic volume. Indeed, coping with uncertainty is a key theme in cognitive systems engineering (Klein, 1999; Smith, Bennett, & Stone, 2006; Woods & Hollnagel, 2006). Previous authors have described some of the strategies used by air traffic management personnel, such as contingency planning (Smith, Beatty, Spencer, & Billings, 2003) and constraint propagation (Smith, Spencer, & Billings, 2007). In addition, air traffic management personnel exhibit strategies known to be successful in complex adaptive systems, such as creating margins of maneuverability so the system has capacity to adapt to changing conditions (Woods, 2006) and shifting decision-making in time (Woods & Hollnagel, 2006). Specifically, ATCT traffic
managers in the study described in Chapter 4 built departure reservoirs that allowed them to delay making a final decision on departure sequence, hence delaying commitment to a course of action. In addition, traffic managers increased aircraft separation minima in order to create, literally, additional room for maneuverability in the airspace.

**Consequences for Departure Metering Procedure Design**

The departure metering procedure explored in this dissertation takes the form of constraint propagation, particularly if the ATCT is involved in setting the target departure reservoir characteristics. The ATCT would receive information about departure constraints from the TRACON and/or ARTCC and propagate those constraints to the departure metering procedure through their target departure reservoir characteristics. The DRC, in turn, would use those reservoir characteristics to set constraints for the departure metering procedure management software. The software would implement the metering plan by propagating the reservoir constraints to ramp control operators via target spot times. The ramp control operators and/or flight operators would then choose how best to use the target spot times to manage their business constraints.

Similarly, departure metering would allow flight operators to delay committing their aircraft to a specific order in the departure queue. Such a delay in commitment would allow them to prioritize their departures according to the best available information about delays and other constraints to which those departures have been subjected. In this case, delaying commitment to a course of action may reduce the need for the ramp control operator to request special treatment for a departure from the ATCT.

Thus, the departure metering procedure is specifically designed to allow NAS personnel to extend strategies that they already use. However, the longer one waits to commit to a course of action, the more adaptable a system must be. For example, the longer the ATCT waits to provide its target departure reservoir characteristics to the DRC, the less time the DRC has to build a metering plan and the less time flight
operators have to plan how to use their target spot times. However, if the ATCT and the DRC commit too early to a departure metering plan, the target spot times that are allocated to flight operators are more likely to change before flights depart.

As Brinton, Lent, and Provan (2010) found, this dilemma creates a tradeoff between delaying commitment to a course of action and acting before all information is available. They resolved the issue by creating a “freeze horizon” after which target spot times could not be changed. Personnel responsible for the departure metering procedure at JFK instituted a similar time horizon, and the Surface Collaborative Decision Making Team included a static time horizon in their departure metering procedure concept (Surface CDM Team, 2011). However, if departure conditions change dramatically, such a static time horizon may cause the ATCT to have an unsuitable departure reservoir for some period of time before a modified departure metering plan can be implemented.

Therefore, there are open questions regarding the best approach to creating stability in the design of a departure metering procedure, such as:

**Question:** How long before a flight’s current target spot time can it be assigned a later target spot time by the departure metering procedure management software? How long before its current target spot time can a flight be assigned an earlier target spot time by the departure metering procedure management software?

**Question:** How long before a flight’s current target spot time can a ramp control operator or flight operator change its target spot time?

**Question:** How should the departure metering procedure, possibly including the static time horizon, be adapted if a dramatic change in departure conditions causes the departure reservoir to be unsuitable?
Strategies for Coping with Complexity

The distributed nature of the NAS already represents a key strategy for coping with complexity, that is, of limiting the amount of knowledge and data for which any one agent is responsible (Smith, Spencer, & Billings, 2007). Not only is work in the NAS distributed, but it is distributed into relatively independent subtasks where possible with procedures for coordinating and collaborating when necessary (Smith, 2011).

In the NAS, procedures are specifically designed to be forms of coordination between agents. For example, they help air traffic controllers and flight crews quickly build common ground using short, coded communications (Klein, et al., 2005). They also enable traffic management personnel to shift collaborative decision-making workload in time (Woods & Hollnagel, 2006) by pre-coordinating contingency plans (Smith, Beatty, Spencer, & Billings, 2003). In addition, they help manage complexity for individual agents, reducing the solution space in a four-dimensional environment.

Procedures require the ATCSCC to schedule events such as routine teleconferences that facilitate collaboration among personnel from different traffic management and flight operator facilities (Smith, Spencer, & Billings, 2007). Such teleconferences provide opportunities for event-driven situation assessment (Vicente, Mumaw, & Roth, 2004) that can help distributed practitioners maintain a shared representation of current and expected near future conditions in the NAS. However, it is known that procedures can be brittle because it is impossible to specify a procedure for every potential contingency (Reason, 1991). In fact, this is acknowledged in NAS procedures, such as by the ability to adapt Playbooks to the current operational situation. Playbooks provide an example of a procedure that is specifically designed to be adapted to the situation at hand.

Thus, one reason to keep humans in positions of responsibility even in highly automated worlds is to take advantage of their ability to continually assess the state of the
world and ensure that the model of the world assumed by the procedure (or automation) is sufficiently accurate. If and when the world moves into a state that causes the procedure to be inappropriate, these human agents should have sufficient authority to adapt their actions even if those actions violate the procedure, particularly if the actions preserve a safe operating environment (Woods, 2006; Woods & Shattuck, 2000; Smith, Spencer, & Billings, 2009).

Consequences for Departure Metering Procedure Design

The departure metering procedure is an example of a procedure that can facilitate coordination by decreasing uncertainty in behaviors of others. However, there are likely to be situations in which the departure metering procedure, as specified, will be inappropriate. Therefore, one or more agents involved in the procedure should have the authority to modify it if necessary (or to coordinate a modification to the procedure with other agents) to better fit the situation at hand. This, naturally, invokes questions such as:

**Question:** Which agent(s) should have the authority to modify (or terminate) a departure metering procedure if it seems inadequate for the situation at hand? How should such modifications be coordinated?

**Question:** What design considerations are necessary to ensure a smooth transition from using a departure metering procedure to not using the procedure?

Translation of Weather into Traffic Flow Management Strategies

Others have worked to characterize and predict flight crew responses to weather and used these insights to translate weather forecasts into traffic flow management decisions (DeLaura, et al., 2008; Evans, Weber, Wolfson, Clark, & Newell, 2009). The air traffic management decision-making study described in Chapter 4 identified some
strategies used by 2 airspace traffic managers. This represents a very small sample size, but it leads to the following propositions that can be explored in future research:

**Proposition 1:** Weather forecasts are useful to air traffic management personnel as planning tools, but tactically air traffic managers develop airspace restrictions according to flight crew weather avoidance behaviors and sector controller requests to reduce traffic volume.

**Proposition 2:** Air traffic management personnel generate more conservative traffic management initiatives when they do not receive feedback from the environment in terms of aircraft deviations and air traffic controller responses.

In addition, the ATCT decision-making study reported on in Chapter 4 identified strategies used by 12 ATCT traffic management coordinators, supervisors, and ground controllers. Again, this represents a small sample size, but leads to the following propositions that can be explored in future research:

**Proposition 3:** ATCT personnel conceptualize weather-related constraints in terms of how to group aircraft into departure queues, where to build departure queues, and how to build a departure sequence from those departure queues using other aircraft as splitters as appropriate.

**Proposition 4:** Weather forecasts are of use to ATCT personnel as planning tools, but tactically they respond to constraints generated by others (e.g., TRACON traffic managers and flight crews) in response to weather. In fact, given a certain level of complexity in departure restrictions ATCT personnel may not consult weather forecasts because their constraints are truly determined by the departure restrictions.
Conclusion

Aviation is a prototypical application domain for cognitive systems engineering. The NAS is a complex system that has a number of interconnected components (Hollnagel & Woods, 2005; Rasmussen, 1986; Smith, Spencer, & Billings, 2007; Woods & Hollnagel, 2006). As a result of the complexity, work in the NAS is highly distributed (Smith, Spencer, & Billings, 2007). A number of people in different (often competing) organizations together are responsible for safe and efficient use of the airspace. Much of their work must be coordinated to maintain safety and efficiency.

In addition, aviation is a domain that is constantly challenged by changing constraints both in the short term and the long term. It is said that no two days in the NAS are alike because there are so many different ways in which constraints can interact. The constraints can change rapidly, creating additional challenges in an already high-tempo environment. These constraints require practitioners to manage many different tasks at once (Woods & Hollnagel, 2006), coordinate and collaborate with multiple other people (Smith, Spencer, & Billings, 2007), and collaboratively solve problems quickly enough to avoid safety hazards (Smith, et al., 1995).

The research described in this dissertation resulted in a set of information requirements and display concepts for supporting a departure reservoir coordinator responsible for managing a departure metering procedure. The departure metering procedure represents one approach to managing departures on the airport surface when demand exceeds capacity. Along the way, the research afforded opportunities to further explore strategies used by decision-makers in the NAS to cope with complexity and uncertainty. Through these explorations, additional themes in aviation as a complex, distributed work system emerged. These themes provide a basis for future investigations.
References


Fernandes, A. B., & Smith, P. J. (2011a). Human-centered design to support flexibility and adaptability in airport surface management. *16th International Symposium on Aviation Psychology.* Dayton, OH.


Fernandes, A. B., Weaver, K., & Smith, P. J. (2012). *Defining ramp control tool requirements.* Ohio State University, Cognitive Systems Engineering Laboratory, Columbus, OH.


305


Smith, P. J. (2011, March 4). *Distributed work systems design concepts*.


Spencer, A., Smith, P. J., & Billings, C. E. (2001). Sample scenarios provided by an airport coordination center at JFK. Technical Report #2001-18, The Ohio State University, Institute for Ergonomics, Columbus, OH.


