Collaborative Airport Traffic System (CATS) to Evaluate Design Requirements for an Airport Surface Departure Management System

Alicia B. Fernandes, Philip J. Smith, Amy Spencer and Eric Wiley
Ohio State University

Dustin Johnson
AMT Machine Systems

Airport surface delays can impact operational costs, environmental emissions, and passenger satisfaction. Departure metering is one alternative approach to airport surface departure management intended to better manage such delays and associated costs. We introduce a simulation environment that can be used to explore human factors issues in the design of such procedures. This includes support for a novel role, the Departure Reservoir Coordinator, responsible for managing the metering procedure, a distributed adaptive planning task. Support for such a novel role can be explored in the Collaborative Airport Traffic System (CATS) simulation environment using prototype information displays, user interaction designs, and a capability for study participants to monitor the impacts of their actions on airport performance in real time. We intend to demonstrate the CATS simulation test bed that facilitates such studies in an effort to better understand human factors requirements for the design of collaborative airport surface departure procedures.

INTRODUCTION

At some airports, departure demand routinely exceeds capacity. Under the traditional "first-come, first-served" approach to managing airport surface traffic, 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 Towers provide taxi instructions to pre-coordinated locations on the airport surface, called Spots, where control is transferred to the Air Traffic Control Tower (ATCT). The ATCT grants access to the active movement surface in the order in which it receives calls from flight crews and taxis them to the departure runway in approximately that order (making adjustments to the final the departure sequence as necessary to improve departure runway throughput).

Although this approach is perceived to be equitable to flight operators, it requires aircraft to physically join the departure queue as soon as possible to secure a place in the departure sequence. When departure demand exceeds capacity, this can lead to longer departure queues than necessary to maintain efficient traffic flow. Aircraft taxiing out for departure are expending fuel, which results in both increased operational cost for flight operators and unnecessary emissions (Brinton, Lent, & Provan, 2010).

Long departure queues also limit flight operator flexibility. Once aircraft are in the departure queue their priority is largely set by their position in the queue. At some airports, flights routinely spend 30 minutes taxiing out for departure (Goldberg & Chesser, 2008), and can taxi longer during irregular operations such as due to weather. During that time a flight operator's measure of priority for a number of flights might change. However, once aircraft are in the physical departure queue the flight operator has little opportunity to modify their relative departure priority.

Departure Metering

Departure metering is one approach to managing departure demand relative to capacity. Departure metering procedures manage access to the active movement area through means such as assigning target spot times. Metering at the spot allows flights to push back from their gates when preferred by the flight operator, but flights must remain in the ramp area (or a pre-designated holding area) until the specified time. Departure metering has been described by several authors (Borgman & Smith, 2010; Brinton, Lent, & Provan, 2010; Burgain, Feron, & Clarke, 2009) and implemented at a few airports.

Existing departure metering procedures were developed by stakeholders at specific airports. They are credited with achieving performance goals such as reducing surface congestion, fuel burn, and departure delays (Borgman & Smith, 2010; Brinton, Lent, & Provan, 2010; Hughes, 2011). They also have identified challenges such as the need to give someone (such as ATC) the responsibility and authority to enforce Target Spot Times (Borgman & Smith, 2010; Brinton, Lent, & Provan, 2010; Doble, et al., 2009). These studies have identified alternative strategies for distributing the roles, responsibilities, and authority for managing demand relative to departure capacity. In addition, they have documented ways in which technology can support people in making decisions and taking actions to manage airport surface traffic. However, most of these are reports on case studies, making it difficult to know whether one approach is best or which system features contribute most to improved surface departure management.

Departure metering produces new requirements for distributed planning and adaptation in airport surface management. In particular, departure metering introduces at least one new role responsible for locally managing the departure metering plan relative to surface and airspace constraints. We refer to that role as the Departure Reservoir Coordinator, or DRC (Surface CDM Team, 2011).

Departure Reservoir Coordinator (DRC)

The Departure Reservoir Coordinator role may be performed by one or more agents that may or may not be colocated. In fact, some of the functions ascribed here to the DRC may be distributed among Traffic Managers at the

ATCT, Terminal Radar Approach Control (TRACON), and/or Air Route Traffic Control Center (ARTCC).

The DRC is so-called because this role is responsible for managing the Departure Reservoir, a set of flights available as “inventory” for the departure metering procedure. 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., 2010). Reservoirs act as a buffer against contingencies that impact departures, including weather impacting the availability of one or more departure fixes and equipment failures (Fernandes, et al., 2010).

The envisioned role of the Departure Reservoir Coordinator will require distributed, continuous adaptive planning at multiple levels and across varying time scales. The DRC will need to estimate departure capacity in anticipation of ground and airspace constraints (such as weather). It is expected that the DRC will receive input on such values from ATCT and/or TRACON traffic management personnel. However, such input may not be updated with sufficient frequency to adequately manage the departure metering procedure. Thus, tools to support the DRC planning task should provide information about the state of the airport surface and exogenous variables such as forecast weather that are likely to impact the system.

Supporting the DRC in Continuous Adaptive Planning

The dynamic nature of airport departure conditions requires continuous adaptation of traffic management plans to maintain safe and efficient traffic flows (Smith, Beatty, Spencer, & Billings, 2003). The nature of the necessary adaptations depends on several factors, such as the:

- Degree of uncertainty in conditions, such as in how a weather system will develop (Smith, et al., 2003).
- Variation in uncertainty over time.
- 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 (Fernandes, et al., 2010).
- Amount of variability that can be tolerated and still maintain acceptable system performance.
- Lag time between the time a change is implemented by a human manager and the time the change is fully realized in the system (Hutchins, 1995).

The distributed nature of aviation also impacts the adaptive planning task. Departure metering plans must be developed, implemented, monitored, and adapted in an environment where the DRC sets metering control parameters that, in turn, set constraints on the activities of flight operators. This distributed approach to planning separates high-level goal- and constraint-setting from low-level implementation details (Smith, McCoy, & Orasanu, 2001; Smith, Spencer, & Billings, 2007; Suchman, 1987; Woods & Shattuck, 2000).

Tools to support continuous, distributed adaptive planning should help people cope with uncertainty and develop, monitor, and adapt their plans accordingly. The tools should be built on a computational model of the world that corresponds to the human expert’s model of the domain and help them develop accurate models of the state of the system (Smith, Geddes, & Beatty, 2008). In addition, tools should support planning over multiple time scales, anticipate how the system will change over the planning horizon, and provide appropriate feedback about how well the plan fits the changing situation (Sheridan, 2002; Smith, Bennett, & Stone, 2006; Smith, Stone, & Spencer, 2006; Woods & Hollnagel, 2006).

The DRC is likely to have expertise in developing an initial departure metering plan with information acquired from sources such as ATCT and/or TRACON traffic management personnel, weather forecasts, traffic demand forecasts, and historical airport performance. However, such strategies must be adapted as conditions change over time. If the actual departure performance of the airport differs from estimates used to develop the plan, the DRC will need to detect the deviation, diagnose its nature and cause, and decide on the best intervention. DRC tools should support these activities.

A challenge for adaptive planning in departure metering is the time- and space-varying nature of uncertainty in conditions impacting departures (and predictions about those conditions). For example, some weather systems can be highly unpredictable, making it difficult to anticipate whether certain departure routes will be available within the next hour. Tools should support the DRC in developing contingencies to help the system cope with such constraints (Smith, Beatty, et al., 2003).

Figure 1 shows one prototype display for supporting the DRC in the continuous adaptive planning task. It represents a key performance metric, the number of aircraft currently active on the airport surface, as well as parameters for implementing a departure metering plan. The prototype display is implemented in a virtual airport environment, the Collaborative Airport Traffic System (CATS). CATS is a tool for exploring and evaluating design requirements for collaborative airport departure management procedures.

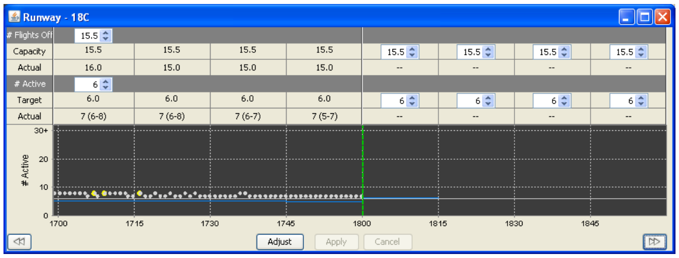

Figure 1. Prototype display to support adaptive planning in airport surface departure management with average departure rate and number of flights in the active movement area as control parameters.

COLLABORATIVE AIRPORT TRAFFIC SYSTEM

The CATS test bed is used to identify and explore human factors requirements for supporting integrated management of airport surface and airspace constraints. CATS can be used as a fast time simulation. It also can accommodate cognitive walkthroughs and more formal studies with humans playing key roles. It allows designers to ensure that humans managing the departure metering procedure are able to anticipate and adapt to changing conditions. CATS can be used to explore behavior of such procedures in response to different scenarios.

Design and development of CATS is driven by hypotheses about departure metering procedure features worthy of study in a simulation environment. These are based on studies of existing systems (Borgman & Smith, 2010; Brinton, Lent, & Provan, 2010), as well as key features of successful distributed work systems (Bowers, Salas, & Jentsch, 2006; Hinds & Kiesler, 2002; Smith, McCoy, & Orasanu, 2001; Smith, Spencer, & Billings, 2007). Among these are the:

- Distribution of roles, responsibilities, and authority to different agents and organizations.
- Information requirements for agents in various roles.
- Design of user interfaces with effective representations for the tasks assigned to different agents.
- Appropriate algorithms to support adaptive planning.

CATS scenarios involve managing a notional airport, "Major Airport" (MJA). Simulation displays include an airport surface map, weather forecasts, and flight lists such as those shown in Figure 2, as well as performance statistics and prototype displays for supporting the DRC role such as Figure 1.

CATS facilitates exploration of issues such as support for the DRC role through cognitive walkthroughs and formal studies involving air traffic management experts.

Cognitive Walkthroughs

Cognitive walkthroughs can support user interaction and decision support tool design (Smith, Stone, & Spencer, 2006). In particular, CATS is being used to perform cognitive walkthroughs to explore and evaluate design requirements for tools to support the envisioned DRC role. A cognitive walkthrough was performed with three experts:

- Expert 1 is a former traffic manager at an ATCT and at a TRACON.
- Expert 2 is a former traffic manager at an ARTCC.
- Expert 3 is a former flight dispatcher and ATC coordinator at a flight operator.

The experts were shown the prototype displays and airport departure traffic scenarios implemented in CATS. They were asked to explore requirements for departure metering procedure design and support for the envisioned DRC role. Some insights gained from the process are discussed here.

DRC information requirements. Input from these subject matter experts indicates that a digital surface display alone is not sufficient for effectively supporting the DRC, although that is the chief monitoring tool provided personnel responsible for managing current metering procedures (Borgman & Smith, 2010). When shown such a display, Expert 1 commented, "Hopefully whoever's doing this has more than this screen." Expert 2 suggested, before seeing the prototype shown in Figure 1, "Would you want something that gives you a nominal [departure] rate right on the display… so you don't have to count it yourself?"

Influence of surface management strategies. Surface management strategies used by the ATCT – and not likely under the control of the DRC – may strongly impact requirements for the control parameters provided to the DRC for managing the departure metering procedure. Thus, there needs to be some process for communication between the ATCT and the DRC regarding plans for using particular surface management strategies, and for management metering at the Spots in a manner that is consistent with these strategies.

Departure fix capacity is a key departure metering parameter. When weather conditions are likely to differentially affect departure fixes, it is important to be able to manage the metering procedure according to the departure fix (or departure gate) that flights are expected to use. This creates non-trivial requirements for displays providing information and about the capacity of departure fixes, as well as for software algorithms that allocate departure capacity to flights.

Planning windows for different organizations. The DRC is not likely to make high-confidence predictions about departure conditions far enough into the future for flight operators to sufficiently plan their operations. It is likely better for flight operators if the DRC propagates plans far into the future, even if they are based on low-confidence predictions.

Expert 2: "Probably beyond 2 hours the DRC is not going to be… sure of his predictions… Would the customers [flight operators] want those times [Target Spot Times] set that far out [even if they are based on low confidence predictions]?" Expert 3: "There are some decisions that you have to make 5-6 hours before, and it may be risky, but you make them because you need to do something. So you don't want to limit someone else's decision because otherwise they always end up with a very short decision window." Expert 2: "So you'd rather propagate [plans] out but make it clear that [they are not high confidence] so they [flight operators] can make decisions?" Expert 3: "Yes….However, you might be able to just indicate the assigned departure order for flights more than 2 hours from pushback, without assigning specific times. That way swaps involving these later flights could be made without the need to pretend that they have been assigned accurate metering times."

These and other insights are being used for:

- Improving the design of CATS.
- Continuing development of human factors guidelines for the design of departure metering procedures.
- Evolving interaction designs for DRC support.

Future cognitive walkthroughs with CATS will examine these and other issues in the design of coordination and collaboration procedures for managing airspace and airport surface constraints. CATS also can be used in formal studies evaluating airport performance under a variety of conditions.

Formal Studies

The cognitive walkthroughs described above use CATS to provide an environment in which experts can explore proposed interaction designs for managing airport performance in a variety of scenarios. A working airport simulation is helpful – but not necessary – to gain useful insights in these settings. Implementing prototype displays in a working airport simulation, however, facilitates comparative evaluations of the impacts of a variety of factors on airport performance, including:

- Information display and user interaction designs.
- Distribution of roles and responsibilities and support for human-human coordination and collaboration.

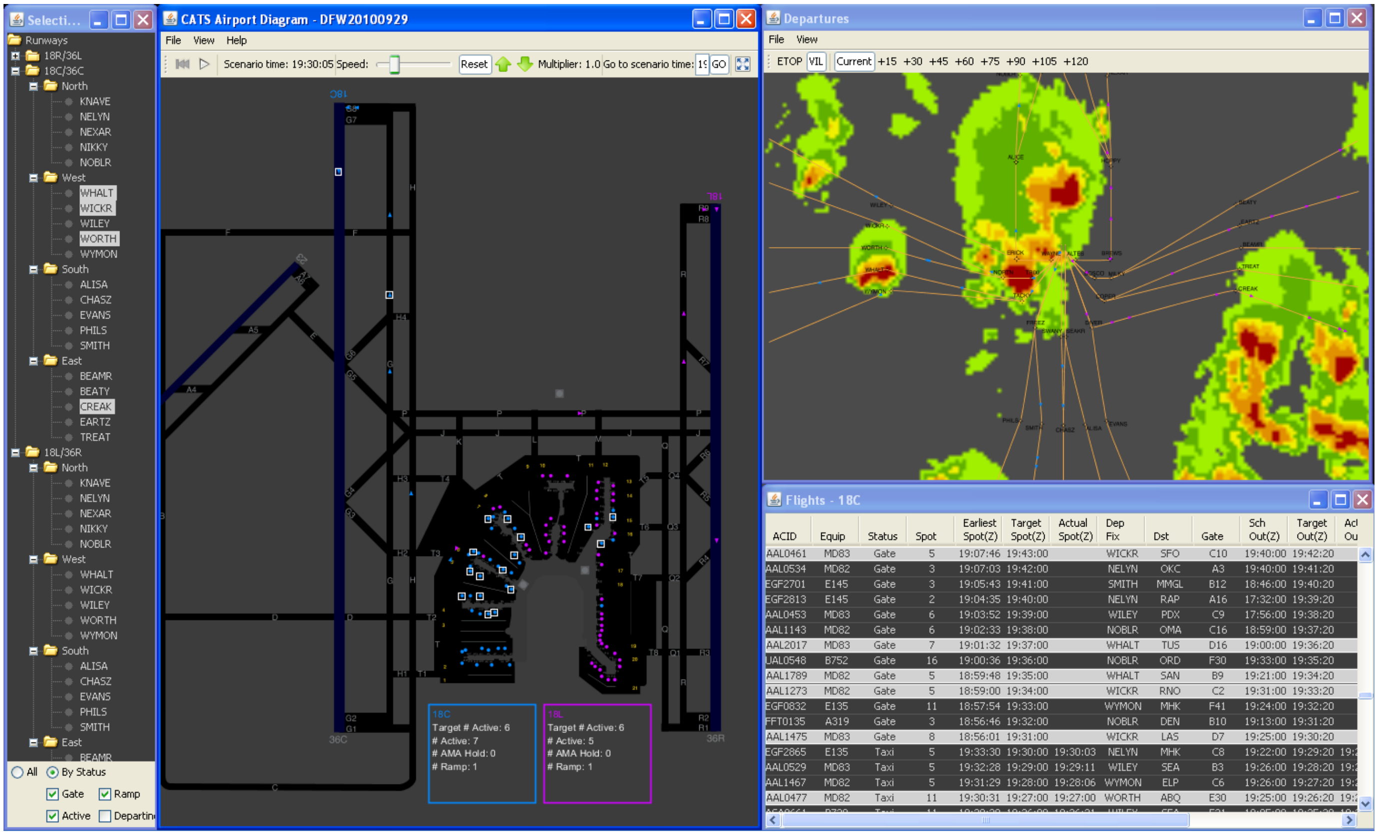

Figure 2. Prototype user interface for monitoring surface status. Weather data from Corridor Integrated Weather System (CIWS), courtesy of MIT Lincoln Laboratory.

- Strategies for surface and airspace management.
- Software algorithms to support functions such as scheduling and coordination.

A potential study might evaluate support for the adaptive planning task to be performed by the DRC. The airport surface display, weather forecast, and flight schedule shown in Figure 2 represent displays that can be expected to be available to any DRC. However, such displays do not take advantage of representations that have been found to be effective in supporting adaptive planning in other domains, such as trends in key variables to help anticipate the need to adapt the current metering plan (Sheridan, 2002; Smith, Stone, & Spencer, 2006; Woods & Hollnagel, 2006). Thus, one important research question focuses on potential benefits that could result from providing the DRC with other types of information displays.

Figure 1 above represents one possible approach to supporting the adaptive planning task. This display is based on a hypothesis that the key parameters for managing a departure metering plan are departure capacity and target average number of active departures (i.e., departures in the active movement area). This hypothesis is informed by the literature (Brinton, Lent, & Provan, 2010) as well as observations of metering procedures in practice (Borgman & Smith, 2010).

The display in Figure 1 also embodies a hypothesis that the number of departures in the active movement area is useful for monitoring effectiveness of the metering plan. Trends in this value can help the DRC diagnose deviations from the target. Other information can be incorporated into the display in an effort to represent spatial constraints over time.

In addition to information hypothesized to be useful for anticipating the need to adapt the plan, the display in Figure 1 includes controls for changing the departure metering plan. To provide planning flexibility to the DRC, and to make salient the time-varying nature of constraints, these controls are associated with individual time periods.

A formal study might use CATS to investigate whether the hypothesized control parameters are sufficiently compatible with the cognitive processes invoked by the metering management task (Roth, Patterson, & Mumaw, 2002; Smith, Stone, & Spencer, 2006). A study participant acting as the DRC might be tasked with managing the departure metering procedure using either the baseline display (e.g., Figure 2) or the baseline display augmented with an adaptive planning display such as that shown in Figure 1.

Such a study would allow a comparative evaluation of performance measures such as airport departure throughput, and number of aircraft in the active movement area. In addition, such a study would allow exploration of strategies that participants use in developing, monitoring, and adapting metering plans. Such strategies and behaviors may be more realistic in a simulation environment than in a storyboard environment in which participants would not be allowed to interact with a working representation of the airport system.

Thus, CATS is a simulation environment that can be used to explore a variety of issues in collaborative management of traffic on the airport surface.

CONCLUSION

The Collaborative Airport Traffic System is a simulation tool that can be used to explore a variety of human factors issues in collaborative air traffic management. It currently is being used to explore design considerations in supporting a novel adaptive planning role in airport surface departure management. In particular, CATS is supporting cognitive walk-throughs and more formal studies to evaluate information displays, user interaction designs, design for coordination and collaboration, and appropriate software support.

A simulation environment such as CATS, that facilitates both fast-time and human-in-the-loop simulation and a variety of scenarios, is useful for exploring new roles and responsibilities for people and for technology, as well as supporting new forms of human-human and human-machine interaction.

ACKNOWLEDGMENTS

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

REFERENCES

Borgman, A. D., & Smith, P. J. (2010). *The integrated management of airport surface and airspace constraints for departures: An observational study of JFK, EWR, and IAH*. Columbus, OH: Ohio State University Technical Report #CSEL2010-09.

Borgman, A. D., Smith, P. J., Beatty, R., Billings, C., Evans, M., & Durham, K. (2010). Integrating airspace and surface constraints in pre-departure traffic planning and management. *HCI-Aero 2010: Crew-Ground Integration*. Cape Canaveral, FL. November 3-5, 2010.

Bowers, C., Salas, E., and Jentsch, F. (2006). *Creating high-tech teams: Practical guidance on work performance and technology.* Washington, DC: American Psychological Association.

Brinton, C., Lent, S., & Provan, C. (2010). Field test results of Collaborative Departure Queue Management. *Proceedings of the 29th Digital Avionics Systems Conference (DASC)*. Salt Lake City, UT. October 3-7, 2010.

Burgain, P., Feron, E., & Clarke, J.-P. (2009). Collaborative Virtual Queue: Fair management of congested departure operations and benefit analysis. *Air Traffic Control Quarterly, 17*(2), 195-222.

Doble, N. A., Timmerman, J., Carniol, T., Klopfenstein, M., Tanino, M., & Sud, V. (2009). Linking traffic management to the airport surface: Departure Flow Management and beyond. Proceedings from ATM 2009: *Eighth USA/Europe Air Traffic Management Research and Development Seminar*. Napa, CA. June 29-July 2, 2009.

Fernandes, A. B., Smith, P. J., Durham, K., Evans, M., Beatty, R., and Spencer, A. (2010). *Airport surface management in response to a terminal radar outage*. Columbus, OH: Ohio State University Technical Report.

Goldberg, B., & Chesser, D. (2008). *Sitting on the runway: Current aircraft taxi times now exceed pre-9/11 experience*. Special Report SR-008, U.S. Department of Transportation, Bureau of Transportation Statistics.

Hinds, P., and Kiesler, S. (2002). *Distributed work*, Cambridge, MA: MIT Press.

Hughes, D. (2011). Shorter lines at JFK may entice other airports to line up. *The Journal of Air Traffic Control*, *53*(1), 47-48.

Hutchins, E. (1995). *Cognition in the Wild*. Cambridge, MA: MIT Press.

Roth, E. M., Patterson, E. S., & Mumaw, R. J. (2002). Cognitive Engineering. In J.J. Marciniak (Ed.), *Encyclopedia of software engineering* (2nd ed., pp. 163-179). New York: Wiley.

Sheridan, T. (2002). *Humans and automation: System design and research issues*. Chisdester, England: Wiley.

Smith, P. J., Beatty, R., Spencer, A., & Billings, C. (2003). Dealing with the challenges of distributed planning in a stochastic environment: Coordinated contingency planning. *Proceedings of the 2003 Annual Conference on Digital Avionics Systems*. Chicago, IL. October 12-16, 2003.

Smith, P. J., Bennett, K., and Stone, R. B. (2006). Representation aiding to support performance on problem solving tasks. In R. Williges (Ed.), *Reviews of human factors and ergonomics, volume 2* (pp. 74-108). Santa Monica, CA: Human Factors and Ergonomics Society.

Smith, P. J., Geddes, N., & Beatty, R. (2008). Human-centered design of decision support systems. In A. Sears, & J. Jacko (Eds.), *Handbook of Human-Computer Interaction* (2nd Ed.). Mahwah, NJ: Lawrence Erlbaum Associates.

Smith, P. J., McCoy, E., & Orasanu, J. (2001). Distributed cooperative problem-solving in the air traffic management system. In G. Klein and E. Salas (Eds.), *Linking expertise and naturalistic decision making* (pp. 369-384). Mahwah, NJ: Erlbaum.

Smith, P. J., Spencer, A. L., & Billings, C. E. (2007). Strategies for designing distributed systems: Case studies in the design of an air traffic management system. *Cognition, Technology, and Work*, *9*, 39-49.

Smith, P. J., Stone, R. B. and Spencer, A. (2006). Design as a prediction task: Applying cognitive psychology to system development. In W. Marras and W. Karwowski (Eds.), *Handbook of industrial ergonomics, 2nd edition*. New York: Marcel Dekker, Inc.

Suchman, L. (1987). *Plans and situated actions: The problem of human-machine communication*. Cambridge, England: Cambridge University Press.

Surface CDM Team (2011). *U.S. Airport Surface Collaborative Decision Making (CDM) Concept of Operations (ConOps) in the Near-Term: Application of Surface CDM at United States (U.S.) Airports*. February 1, 2011.

Woods, D. D., & Hollnagel, E. (2006). *Joint cognitive systems: Patterns in cognitive systems engineering*. Boca Raton, FL: CRC Press.

Woods, D. D., & Shattuck, L. G. (2000). Distant supervision--local action given the potential for surprise. *Cognition, Technology, and Work*, 2, 86-96.