# Tower Controllers' Assessment of the Spot and Runway Departure Advisor (SARDA) Concept

Ty Hoang and Yoon C. Jung
NASA Ames Research Center
Moffett Field, CA. USA

Jon B. Holbrook
San Jose State University
Moffett Field, CA. USA

Waqar A. Malik
University of California, Santa Cruz
Moffett Field, CA. USA

*Abstract*— **Airports are often a capacity-limiting constraint for the rest of the National Airspace System (NAS). A recent effort investigated methods to improve surface operations by supplying optimized scheduling and sequencing advisories for the Ground and Local controllers working at Air Traffic Control Towers. The tool is collectively known as the Spot and Runway Departure Advisor (SARDA). A series of high fidelity human-in-the-loop simulations was conducted to assess scheduling performance and their effects on the human operators. This paper documents the impact of the advisories on controllers' workload, situation awareness (SA), and usability. Fifty-six high fidelity human-in-the-loop simulations were conducted using a matrix of traffic level (normal and high) and advisory display formats (data tag and timeline). Results revealed that the high traffic level increased perceived workload for both Ground and Local controllers. Local and Ground controllers also reported a decrease in subjective SA in the high traffic condition. There was no significant effect of traffic level or advisory usage on the objective SA measure, although their interaction was statistically significant. For Ground, objective SA decreased in the high traffic but not during the normal traffic level. Ground controllers showed a preference for using the timeline format by reducing scans for information and aiding with future planning. Feedback also revealed that future work should focus on harmonization between the optimization model and the human planning model, thus providing a transparent planning and execution strategy.**

*Keywords-component; surface scheduler; optimizer; airport simulator; human factors; workload; situation awareness; usability*

## I. INTRODUCTION

Serving as both an originating point ("source") and a termination point ("sink") for traffic in the National Airspace System (NAS), airports are frequently a bottleneck that adversely affects both the throughput and efficiency of the entire NAS. Highlighting the airports as a bottleneck area, the Federal Aviation Administration (FAA) and its counterpart in the European Union (EUROCONTROL) [5, 6], have applied resources to solve surface congestion problems. Researchers are investigating concepts to alleviate these airport (or groundside) congestion problems such as synthesizing precise runway crossing times [1], and providing safe and efficient taxi timing in collaboration with the flight deck [2]. Various surface optimization concepts and techniques were also researched using fast-time simulations by [3, 4].

The Spot and Runway Departure Advisor (SARDA) concept developed at the NASA Ames Research Center focused on providing air traffic control tower (ATCT) controllers with aircraft departure-timing advisories from the ramp area, along the taxiway, and onto the departure runway. SARDA provides decision support capabilities to the Ground and Local controllers by providing specific timing and sequencing information for each aircraft on the ground.

SARDA algorithms are designed to alleviate potential congestion that will result with the projected increase in traffic [7], by considering environmental impact (fuel burn and engine emissions), providing optimized schedules and sequences while actively meshing arrivals with departures. The optimization method provides metering advisories to individual aircraft; the higher resolution level is necessary to accommodate the anticipated buildup in traffic density. SARDA seeks a system-wide integrated approach to the source-sink problem that exists simultaneously at the airport.

The SARDA research investigates potential effects of introducing ground automation on users' workload, situational awareness, and usability. Preliminary analyses show that the concept could reduce delays and the number of stops, decreased fuel consumption, and engine emissions in heavy traffic situations [8]. The traditional roles and responsibilities of the Local and Ground controllers may change, however, due to these advisories.

The design of the SARDA interface with the human controller is also critical. In general, well-designed tools that perform cognitively difficult tasks for a human can reduce the user's workload associated with performing tasks such as information acquisition and analysis [23]. A tool that is poorly designed, however, can add to task complexity, increasing workload beyond manageable levels and reducing the operators' task performance [24, 25]. The study presented in this paper investigated the human factors related to using the SARDA concept in a simulated operational environment.

## II. BACKGROUND

Recently, research organizations in the United States and Europe have focused on identifying key issues causing inefficient airport surface operations, and developing new concepts, procedures, and supporting technologies to improve the capacity at airports. The management of departures was identified as a key constraint, and analyzing departure traffic could lead to the determination of control points that can affect the runway operations [9]. A conceptual design of a departure planner was developed, composed of functional components (i.e., strategic and tactical departure planners) based on a queuing model approach [10], with each component providing an automation aid to optimize the operation corresponding to the control point (e.g., gate, ramp).

A departure queuing model of surface operations of Boston Logan International Airport was also developed and preliminary results show that using gate holding schemes can reduce congestion [11]. More recently, a framework of coordinated surface operations among gate, ramp, taxiway, and runways was developed [12] with an optimization algorithm to schedule individual aircraft taxiing on a network of nodes and links as part of this framework. A comprehensive optimized taxi scheduler was developed in [13] and later improved by adding detailed physical and operational constraints [14]. Taxi delay reductions compared to a taxi schedule based on the first-come-first-served method were then demonstrated. Efficient runway scheduler algorithms were developed with the objective of maximizing the throughput of runway operations while satisfying various constraints [15, 16]. All of these efforts focused either on a conceptual design framework or on mathematical modeling of components in the proposed system architecture. Human factors considerations were not specifically addressed.

In an attempt to evaluate new concepts and early technologies in the field, the FAA is currently evaluating the Collaborative Departure Queue Management (CDQM) decision support tool at Memphis International Airport [17]. The objective of the tool is to deliver a strategic surface traffic plan that is relatively easy for the tower controller to execute without significant changes in operational procedures. In Europe, the German aerospace research organization (DLR) conducted a field evaluation of the European Airport Movement Management by A-SMGCS, Part 2 (EMMA2) [18], a prototype surface decision support tool at Prague Airport in 2008. In the test, the Departure Manager (DMAN) component provided both ATC and airlines with a target off-block time (TOBT) of individual departure aircraft to meet the operational criteria.

Both CDQM and EMMA2 tools use Electronic Flight Strips (EFS) for communications between the tower controllers and the decision support system. EMMA2 requires a data link capability via a Controller Pilot Data Link Communication (CPDLC) to send both taxi route and runway time information. These experiments were important first steps towards testing and implementing new concepts in an operational environment. The Surface Trajectory-Based Operations (STBO) program, as envisioned by the Next Generation Air Transportation System (NextGen) [7] and Single European Sky ATM Research Program (SESAR) [19], are investigating surface movement concepts that use automation to increase efficiency. The SARDA research aligns with the STBO model.

The SARDA project developed, implemented, and tested a "mid-term" concept of optimized airport surface operations as part of NASA's surface optimization research, with mid-term representing a targeted timeframe beginning around 2015-2018, as defined by the NASA-FAA research transition team [20]. SARDA contains two optimization engines that produce ground advisories for the Ground and Local controllers. The Spot Release Planner (SRP) produces departure sequences and schedules for the Ground controller while the Runway Scheduler (RS) shows Local controller aircraft release sequences [21].

The objectives of the SARDA research were as follows:

1. Implement mid-term concept of operations for tower controllers

2. Develop decision support tools, such as the SRP and RS, to aid tower controllers

3. Develop procedures for evaluating the algorithms and their benefits

4. Conduct preliminary human performance and workload evaluations

5. Develop a high fidelity real-time human-in-the-loop (HITL) simulation environment to support current and future surface research.

This paper focuses on the fourth objective and presents the controllers' assessment of the SARDA concept. More specifically, this paper investigates the impact of presenting decision support advisories on controller workload and situation awareness.

## III. THE SARDA CONCEPT OF OPERATION

Figure 1 illustrates a generic airport surface layout with a ramp area, taxiways, and runways. Operations in the ramp area include passenger boarding and deplaning, refueling, food catering, and the loading and unloading luggage, etc. Ramp controllers control the push back of aircraft from the gate when the aircraft are ready for departure. Ramp control may fall under the jurisdiction of the airlines, airport authority, or the FAA. In today's operations at airports that use ramp spots (a location in the ramp area, usually marked with a number on the pavement, Fig. 1), the Ground controller clears the aircraft from a spot as soon as possible by directing it onto a taxiway. At such airports, the spot represents the boundary between Ramp controller (airlines) and ground control (FAA/Air Traffic Control Tower (ATCT)) jurisdiction.

After leaving the spot, the Ground controller clears the aircraft from the taxiway into a departure taxi route and hands the aircraft off to the Local controller. In addition to departures, the controller also brings arrivals into the arrival spot after crossing the last runway.
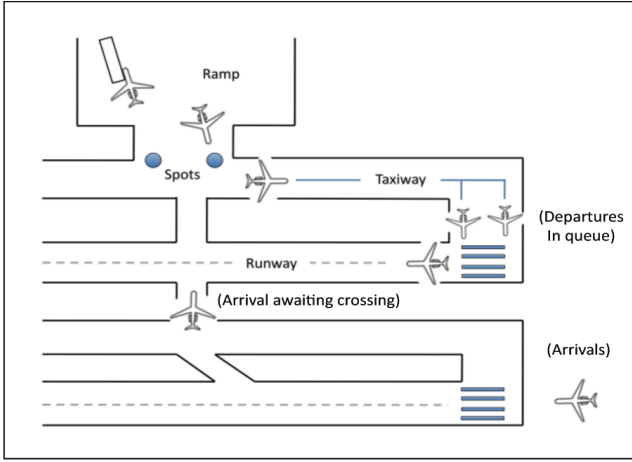
Figure 1.   Generic Airport Surface Layout

The responsibility of a Local controller is to manage runway operations, including takeoff, landing, and runway crossing. Typically, there is a queue or multiple queue lanes of departing aircraft near the runway departure area. Each aircraft moves forward in the departure queue until it receives a takeoff clearance. During busy periods, the runway departure area and taxiways become congested with aircraft sitting in a "stop-and-go" traffic jam. The Local controller determines the sequence of departure, clears aircraft for takeoff, and manages arrivals and runway crossings.

The SARDA concept of operations introduces the concept of time-based metering [21] to the surface domain by imposing delays at the spots during busy periods in order to reduce taxiway and runway queue delays. The domain of interest covers the airport surface where departure and arrival aircraft operate, including ramps, taxiways, and runways. Metering occurs at two locations: spot release into the active movement area (taxiways) and runway departure queues. The Spot Release Planner (SRP) supplies the Ground controller with spot release schedule (e.g., sequence and time), and the Runway Scheduler (RS) supplies the Local controller with the runway queue release sequence and runway crossing schedule for arrival aircraft.

For the Ground and Local controllers, departure operations requires the following decisions: 1) when to release the aircraft from the spot onto the taxiway, 2) specify the taxi route, 3) maintain separation along the taxiway, 4) prioritize movement at intersections, 5) manage queue areas, 6) assign aircraft to an appropriate queue in multiple queue operations, 7) takeoff clearance considerations (in-trail separations, area navigation constraints, arrival rates over departure fixes, etc.), and 8) sequence active runway crossings.

In current operations, most of these decisions are made based on simple rules and controller experience. With increasing traffic levels, localized decision-making may not be able to sufficiently optimize system-wide efficiency. Advanced decision support tools such as SARDA could potentially provide controllers increased situational awareness and optimized automated solutions at decision points that incorporate multiple objectives such as reducing delays and environmental impacts. This, coupled with more efficient departure release/runway crossing planning, could lead to more efficient surface operations.

IV.   THE HUMAN-IN-THE-LOOP SIMULATION

A.   The Test Facility

The SARDA concept was evaluated in a human-in-the-loop simulation at the FutureFlight Central (FFC) facility at the NASA Ames Research Center (Fig 2). The FFC can realistically simulate air traffic control tower operations and includes a high-resolution 360-degree computer-generated out-the-window view. The SARDA test used the Briefing, Test Engineer, and Controller/Pilot rooms to host the SARDA system, Ground and Local controller stations, and pseudo-pilot stations. The out-the-widow capability was not used for this evaluation but is planned for subsequent evaluations of the SARDA concept.

B.   SARDA Software Components

The SARDA simulation consists of two major software components: the Airspace Traffic Generator (ATG) and the Surface Management System (SMS) [22, 29]. ATG generates the traffic (track data) and feeds the data to the SMS, along with aircraft flight plan information. SMS uses this "radar" and flight information to generate aircraft movement advisories, using the SRP and the RS algorithms. The aircraft control advisories are relayed over voice radio to the pseudo-pilot, who then adjusts aircraft movement (route, speed, heading) via inputs into the ATG. ATG then updates the aircraft state and sends the new "radar" hit over to the SMS, thus reflecting the change in aircraft state and thereby closing the control loop. Each pseudo-pilot may control multiple aircraft.

C.   Controllers Setup

The Ground and Local controllers sat next to each other on the Controller side of the Controller/Pilot room (Fig. 2). The Ground controller had three displays showing the east side terminals and taxiways as shown in Fig. 3. The airport map was rotated 90-degree clockwise (north pointing right) to show the
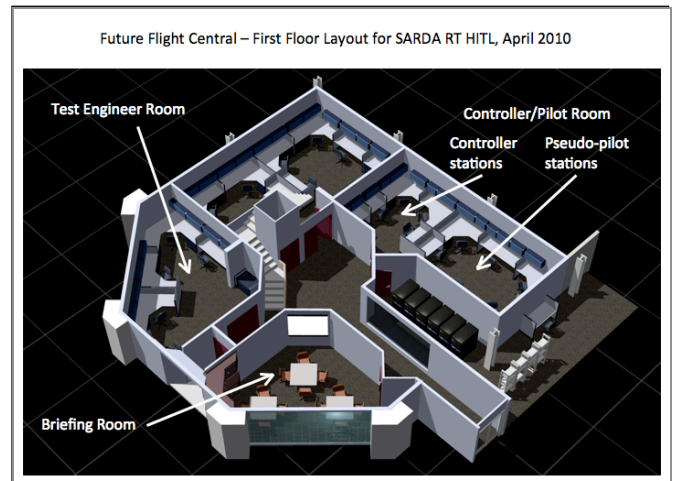


Figure 2.   FutureFlight Central's First Floor Layout.

ramp areas for all three terminals, and to approximate the simulated view of looking "down" the taxiway, in lieu of an out-the-window environment (Fig. 3). An SRP timeline advisory window was displayed on the right hand side of the right screen. This will be described in a following section.

Fig. 4 shows the Local controller displays. The top-half of the display is similar to the Ground controller and shows the terminals. The bottom left of the display shows arrivals (awaiting active runway crossings) and the lower-right portion shows the departure queue area.

### D.  Airspace

The simulated airport area was modeled after the Dallas-Fort Worth International Airport (DFW).  Although the entire airport was modeled, only the east side of the airport was studied. The simulated scenario included the east side of the airport with arrivals on runways 17L and 17C, and departures on 17R. The interaction between arrivals and departures on the east and west side was simulated with traffic along the "bridge" taxiways, which connects the two sides of DFW. All of the west side traffic, including arrivals and departures on 18L, 18C, and 18R, were automated. Gate pushback and ramp area taxiing were controlled automatically by the ATG, as were airborne arrivals on final approach, and departures after wheels-up.

### E.  Developmental Stages

Testing of the SARDA concept occurred in three stages, with each stage expanding the application of the technology. The first test simulated operations around Terminal A of DFW and included the SRP tool. The second test simulated operations around Terminals A, C, and E (east side of DFW), running with the SRP and RS tools. Finally, a two-week data collection test in April 2010 simulated operations on both east and west sides of the airport with the SRP and the RS tools providing advisories to the controllers (only the east side traffic was actively managed).

### F.  Test Conditions and Matrix

The test in April 2010 simulated traffic on both the east and west sides of the airport with the SRP and the RS providing advisories to the controllers managing the east-side traffic. Independent variables were traffic level, and type of advisory. The test matrix is presented in Table 1. The traffic level was rated either normal (No) or high (Hi), with normal representing
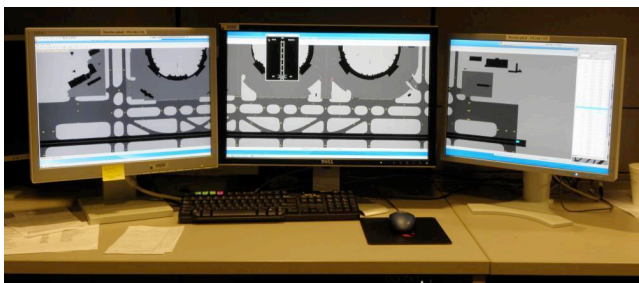


Figure 3.   Ground Controller Display



Figure 4.   Local Controller Display

current day traffic (89 aircraft/hour) and the high level representing about 50% more traffic (134 aircraft/hour). For each traffic condition, two different scenarios were used to prevent the controllers from becoming familiar with the runs (e.g., Hi2 represented the second high traffic scenario). Table 1 also depicts the controller's staffing position (i.e., Controller 1 worked the Ground (G) position on Day-1 Run-1, then switches to the Local (L) position on the next run).

Controllers were asked to control traffic under the following advisory conditions: Baseline-1 (no advisories – controllers used their experience), Advisory Data-tag (AD) format, or Advisories Timeline (AT) format. Details of the advisory formats are described in later section. In the Baseline-2 (B2) condition (highlighted in Table 1), controllers were asked to meter departures from the spot without the aid of automation. The test matrix comprised of 24 test cases (repeated twice) and eight additional B2 runs. A total of 56 forty-five minute runs were conducted.

TABLE I.        SARDA DATA COLLECTION TEST MATRIX

| Day 1 | Day 2 | Day 3 | Day 4 | Day 5 |
|---|---|---|---|---|
| G-No1-AD | G-Hi2-AD | L-No1-B1 | L-Hi2-B1 | G-Hi1-AT |
| L-No1-AT | L-Hi2-AT | G-No1-AT | G-Hi2-AT | L-Hi1-B1 |
| G-Hi1-B1 | G-No2-B1 | L-Hi1-AD | L-No2-AD | G-No1-AD |
| L-Hi2-AD | L-No1-AD | G-Hi2-B1 | G-No1-B1 | L-No2-AT |
| G-No2-AT | G-Hi1-AT | L-No2-AT | L-Hi1-AT | G-Hi2-B1 |
| L-No2-B1 | L-Hi1-B1 | G-No2-AD | G-Hi1-AD | L-Hi2-AD |
| **Day 6** | **Day 7** | **Day 8** | **Day 9** | **Day 10** |
| L-Hi1-B2 | L-No1-B1 | G-Hi2-AT | L-Hi2-B2 | L-Hi2-B1 |
| G-Hi1-B2 | G-No1-AT | L-Hi1-AD | G-Hi2-B2 | G-Hi2-AD |
| L-No2-AD | G-Hi1-B2 | G-No1-B1 | L-Hi1-AT | |
| G-No2-B1 | L-Hi1-B2 | L-No1-AT | G-Hi1-B1 | |
| L-Hi2-AT | G-No2-AD | G-Hi2-B2 | L-No1-AD | |
| G-Hi1-AD | L-No2-B1 | L-Hi2-B2 | G-No2-AT | |

L/G – Local/Ground position; No/Hi – Normal/High traffic level; AT/AD – Timeline/Data-tag format

## V. Human Factors Investigation

The Ground and Local controller's assessment of the SARDA concept was made by analyzing workload, situation awareness (subjective and objective) and usability measures. The measures of user and system performance collected during these simulations can be used to indicate the effectiveness of SARDA in helping controllers be more efficient.

### A. General Methodology

The SARDA concept was evaluated in a human-in-the-loop simulation during a two-week period. Each testing day comprised 6 forty-five minute runs followed by questionnaires for participants. On the afternoon of the last day, participants engaged in a structured debrief to provide feedback about the SARDA systems and the evaluation procedures.

Two recently retired air traffic controllers participated in the study. Both participants had over 25 years of air traffic control experience, each with over 20 years of experience working in the DFW control tower. Both participants had retired from DFW within three years prior to the study. Neither participant was familiar with the SARDA concept and decision support tools (SRP and RS) prior to the study.

### B. Questionnaires

#### 1) Controller post-run questionnaires

Three brief questionnaires were issued to the controller participants following each run to gather data on workload, subjective situation awareness, and objective situation awareness.

#### a) Workload

Perceived workload was measured using the NASA Task Load Index (TLX) scale [26]. The NASA TLX is a multi-dimensional scale of workload that can provide both a global measure of workload, as well as a measure of workload along each of the subscales, which include mental demand, physical demand, temporal demand, performance, effort, and frustration. A global workload score can be determined from an average of ratings on the various subscales.

During the training phase, controller participants completed a worksheet designed to assess the relative importance of each of the TLX subscales in actual ATC tasks. The results of this assessment were used to weight each of the subscales in computing a global subjective workload score. To compute an overall workload rating, the inverse of the rating for the performance subscale was used to align the valence of all subscales. On this global workload scale, lower scores indicate lower perceived workload. System users completed the TLX questionnaires after each data collection run.

#### b) Situation Awareness (SA)

This study collected both subjective and objective SA measures. Subjective SA was measured using modified version of the Mission Awareness Rating Scales (MARS) [27], which consists of two subscales. One subscale assessed SA content and the other assessed SA workload. Each subscale consisted of four questions that address the three levels of SA – identification, comprehension, and prediction. An additional fourth question dealt with how well task goals could be identified. The four workload subscale questions require the respondent to indicate how much mental effort was required to identify, comprehend, predict, and decide in the given run. All questions were rated on a four-point scale. Overall subjective SA was computed by averaging across all eight items in the questionnaire. Lower scores indicate lower SA. The subjective SA ratings were divided by four and compared with the objective SA ratings.

Objective SA was measured using a modified version of the Situation Awareness Global Assessment Technique (SAGAT) [28]. Prior to the study, a series of objectively verifiable queries related to Ground and Local controller tasks and objectives were generated by human factors specialists and vetted by an ATC subject matter expert. Typically, using SAGAT, these queries would be administered during planned interruptions in task performance. It was not feasible to pause the simulation during a run, therefore, the objective SA queries were administered immediately upon completion of each run, and query responses were based on what was happening in the simulation at the moment the run ended.

This modified procedure limited the assessment of Level 3 SA (i.e., prediction) [28], because of difficulties with objectively verifying statements about controllers' plans once the run was over. Researchers took snapshots of the Ground and Local controller displays at the end of each run and used these pictures to assess the "ground truth" answers for the SA queries. The Ground controller's objective SA questionnaire had five queries while the questionnaire for the Local controller had eight queries. All responses were scored as either correct (1) or incorrect (0). Global objective SA assessments were calculated by averaging scores across all queries for that position.

#### 2) Post-run de-brief

After completing the simulation, participating controllers were asked a series of open-ended questions about the SARDA concept and advisories, the realism of the simulation environment, and the quality of the training provided. Participants' qualitative responses to these questions provided insights into their behaviors during the simulation as well as ideas for future research and development.

### C. Controller Display Options

Considerations in determining an optimal method for displaying the advisories at the Ground and Local controller stations included the time criticality of information, supporting information the operator may need to incorporate into the decision-making process, and the concurrent tasks the operator is performing.

To explore and optimize the controller advisory user display, two versions of each SARDA advisory were presented to controller participants during the simulation. A "data-tag" version of the advisories incorporated the advisory into the data-tags of relevant aircraft on the map displays. A "timeline" version of the advisories presented the advisories in a separate window on the workstation adjacent to the map displays. Details of each display types are described below.

## 1) Ground Controller Displays – SRP Advisory

### a) Data-tag Advisory

In all advisory conditions (Baseline-1, Data-tag, Timeline, and Baseline-2), data-tags for aircraft waiting in the ramp area prior to spot release included the aircraft ID, aircraft type, departure fix, and spot. With advisories enabled, a spot release sequence number and a spot release countdown timer, both generated by the SRP, were added to the data-tag, as shown in Fig. 5. The sequence number indicated the computed optimized order in which controllers should release aircraft from the spot, and the countdown timer showed a time-window for spot release (e.g., Fig. 5 shows AAL9094 is first in line, releasing from Spot 9, with 4 seconds left in the current release window).

Controllers were instructed to release aircraft from the spot in the order indicated by the sequence number when the countdown timer was between 0 – 60 seconds. When the release time was greater than 60 seconds, the countdown time was displayed on a blue background. Between 0 and 60 seconds, the countdown time was displayed on a flashing green background. After 0 seconds, the timer counted up in negative numbers, and the background turned yellow. When the countdown timer was greater than 300 seconds, or sequence number was greater than 20, the advisory information was not displayed in order to reduce display clutter.

### a) Timeline Advisory

In the Timeline advisory condition, the SRP information was displayed in a window to the immediate right of the airport map display. The timeline advisory indicated the current time along with a scrolling "tape" that advanced from the top to bottom of the window as shown in Fig. 6. This tape represented a view several minutes into the future (above the 23:20:00 current time mark in Fig. 6), ticking continuously down toward the current time. Departure aircraft awaiting spot release in the ramp area were displayed in sequence on the timeline based on their SRP release schedule. The data field included aircraft ID, departure fix, and spot location (e.g., in Fig. 6, EGF4375, release from spot 22 at time 23:22, departing via the CLARE departure fix).

Similar to the data-tag information and color scheme, aircraft information was presented in blue text if the advisory indicated a spot release time of greater than 60 seconds from



Figure 5.   Spot Release Planner (SRP) advisories in Data-tag format.
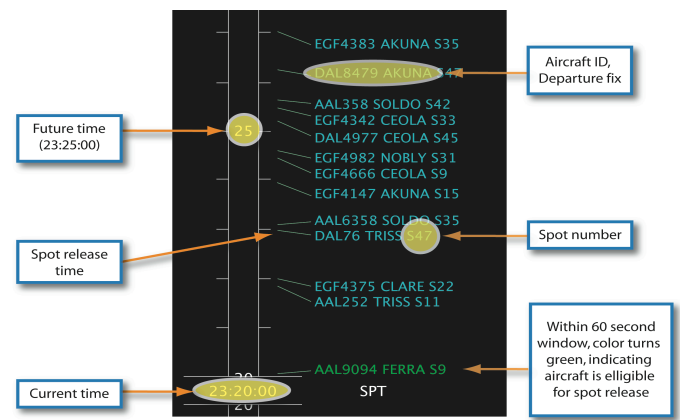


Figure 6.   Spot Release Planner (SRP) advisories in timeline format.

the current time. Aircraft information turned into green if the advisory indicated a spot release time within 60 seconds of the current time. If an aircraft passed the current time without being released from the spot, the aircraft information turned yellow. If the controller took no action within a given duration, the system would recalculate and reassign the aircraft a new release time. Slewing and clicking on an aircraft's data field would highlight that aircraft's information in a green box on both the timeline and the map display. Controllers were instructed to release aircraft from the spot in the sequence represented on the timeline (i.e., from bottom to top), and to try to taxi aircraft into the movement area between 60 and 0 seconds of the advised spot release time on the timeline (when the aircraft information turned green).

## 2) Local Controller Displays – RS Advisory

### a) Data-tag Advisory

In all advisory conditions, data-tags for aircraft in the Runway 17R departure queue contained the aircraft ID, aircraft type, departure fix, and assigned taxi route as shown in Fig. 7. The DFW Runway 17R queuing area supports up to three queue lanes, which are designated as the Outer (O), Inner (I), and Full length (F). The Ground controller can assign a spot release aircraft into one of these queue lanes by entering the route selection into the scheduler via keyboard entry. The Local controller could see the routing data on the aircraft tag, indicated as I, O, or F (Fig. 7).

In the Data-tag advisory mode, the data-tag for aircraft in the 17R departure queue also included a sequence number generated by the RS, displayed in white text (Fig. 7). The Local controllers were instructed to depart traffic in the order given by the sequence number. The RS also assigned sequences to arrivals waiting to cross Runway 17R heading toward the terminals. If an arrival had a sequence number of '1', that aircraft should be instructed by the Local controller to cross Runway 17R prior to clearing the next departure, which would have a sequence number of '2'. Multiple arrivals might be given the same sequence number by the RS, indicating that these aircraft should cross the runway together. Unlike the SRP advisory, the RS advisory does not provide timing information to the controller.
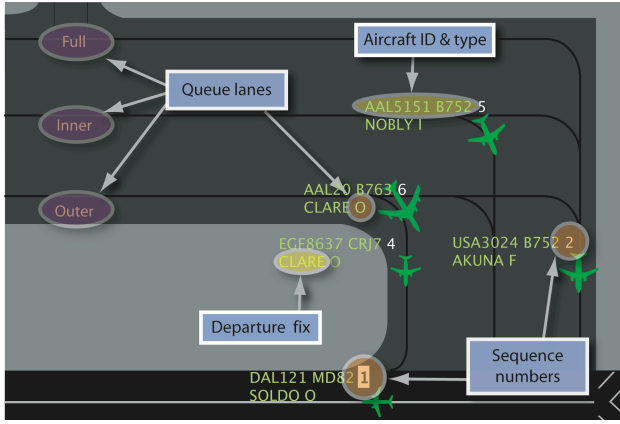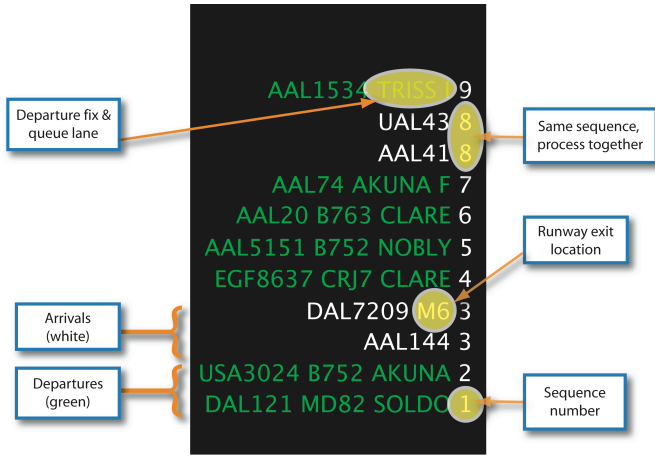
Figure 8.   Runway Scheduler (RS) advisories in Timeline
(Sequence list) format.

### b) Timeline (Sequence List) Advisory

The RS Timeline advisory condition provided a sequence list format that interleaved departure with arrival runway crossing advisories in a single column (Fig. 8). Similar to the Ground controller timeline, the sequence list showed a vertical column of aircraft with the first aircraft to be cleared at the bottom of the column. Fig. 8 shows departures in green text, displaying aircraft ID and type, departure fix, and RS-generated release sequence number (e.g., DAL121, aircraft type MD82, departing through the SOLDO fix, has a control sequence of one). Arrival aircraft were presented in white text, showing aircraft ID, arrival runway exit, and RS-generated sequence number (e.g., DAL7209, expected to take the M6 runway exit, and third in the sequence, along with AAL144).

## VI.   RESULTS

The findings on controller workload, objective and subjective situation awareness, and usability of the SARDA concept based on two variables (traffic load and advisory usage) are presented in this section. It should be noted that the results were gathered from just two test subjects, which may limit the generalization of the findings. The results gathered from this phase of research will be use to guide future development. Validation of these findings will be pursued via planned follow-on SARDA studies and HITL simulations.

Controller workload, subjective SA, and objective SA for Ground and Local controller positions were examined through separate Analysis of Variance (ANOVA) tests. For each position, a total of six ANOVAs were performed using three – 3 (advisory modes) x 2 (traffic level) repeated measures. The advisory modes consisted of Baseline-1, Data-tag, Timeline, and the traffic levels were Normal and High. In addition, three separate repeated measures ANOVA examined four levels of advisories (B1, Data-tag, Timeline, and B2) with results from the high traffic condition only. Furthermore, the B1 condition was used as a baseline, from which pair-wise comparison was made against (i.e., B1 vs. Data-tag, B1 vs. Timeline, B1 vs. B2). The results from the human factors analysis of the SARDA concept are presented in Figs. 9 through 11.

### A.   Workload

Results revealed that the high traffic level increased perceived workload for both Ground and Local controllers, as this was anticipated. Compared to Baseline-1 in Fig. 9, the introduction of SARDA advisories imposed little impact on participants' perceived workload.

#### 1)   Ground Controller

Although one might expect the advisories to alleviate controllers' workload by offloading responsibility for spot release and runway usage decisions, the advisory conditions differed from the baseline in ways that may have counteracted this potential benefit. For example, the advisories' goal (metering traffic to the departure queue from the spot) differed from historical objectives of the Ground controllers, which is to minimize aircraft wait time on the ramp. In post-study interviews, controllers indicated some disharmony between the SRP advice and their nominal operations, potentially contributing to an increase in perceived workload.

To better understand the difference in controller expectations and goals between the Baseline-1 and advisory conditions, a fourth advisory condition (Baseline-2, B2) was introduced where Ground controllers were asked to meter traffic from the spot without SRP advisories. These results, shown in Table II, revealed that Ground controllers perceived this task to be more demanding than the baseline condition (workload rating increased from 0.45 to 0.67 in Table II). This increase in perceived workload appeared to be offset when the SRP advisories were included.

Controllers echoed this finding during the post-study interview, indicating that if they were given the task of metering traffic from the ramp area, they would prefer to have an advisory tool like the SRP. Although this notion of metering departures from the spot is not currently integrated into ground control standard operating procedures, many major airports occasionally employ gate-hold procedures that share important features with the spot-metering concept. Application of the SRP algorithms to current-day gate-hold procedures is a potential avenue for further study.
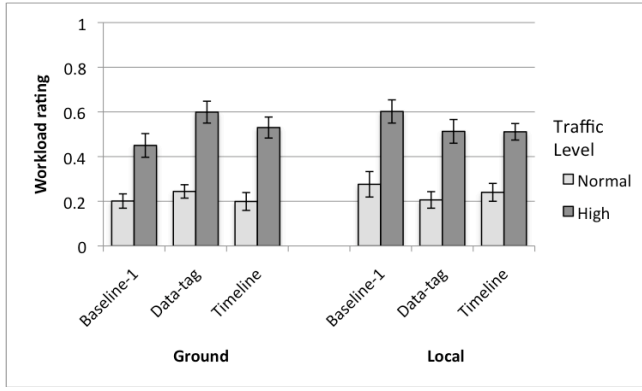
Figure 9. **Workload.** Effects of Advisory (Baseline 1, Data-tag, Timeline) and Traffic Level (Normal, High) on controllers.

TABLE II. ANOVA RESULTS EVALUATING EFFECT OF ADVISORIES ON CONTROLLER WORKLOAD

| Effect of Advisory on Workload (Performance Metric: Workload) | | | Mean (Std. Err.) | | | |
|---|---|---|---|---|---|---|
| Position (Normal or High Traffic) | Statistical Test | Statistical Significance | Base-line 1 (B1) | Data-tag (AD) | Time-line (AT) | Base-line 2 (B2) |
| Ground (High Traffic) | $F(3,21)=2.94$ | p=0.057 | **0.45 (0.05)** | 0.60 (0.05) | 0.53 (0.05) | **0.67 (0.05)** |
| Local (High Traffic) | $F(3,21)=3.06$ | p=0.050 | **0.60 (0.05)** | 0.51 (0.05) | 0.51 (0.04) | **0.40 (0.05)** |

Means highlighted in bold text are statistically different at p<0.05.

Observations of the initial shakedown runs showed (under normal traffic condition) little change to the queue size, with or without the use of advisories. This indicated that the traffic level was not adequate for the controllers to accomplish manual spot metering. The high-traffic scenario provided enough demand, thus allowing them opportunities to exercise manual spot metering (Baseline-2 conditions). Hence B2 runs were made with only high traffic scenarios.

*2) Local Controller*

Changes in perceived workload ratings between Baseline-1 and advisory conditions were not statistically significant for Local controllers (Fig. 9). Like the Ground controller, the result showed no significant interaction between the use of advisories and traffic level.

The pair-wise comparison between B1 and B2 under high traffic load in Table II, showed statistically significant decrease in perceived workload (from 0.6 to 0.4). It is likely the Ground controllers, who experienced higher perceived workload in this condition, were highly effective in metering traffic to the departure queue, and thus reduced Local controllers' task. Like the ground position, there is no significant interaction between the use of advisories and traffic level.

*B. Subjective SA*

The results show that the main effect on subjective SA is traffic level (Fig. 10). Local and Ground controllers reported a decrease in subjective SA in the high traffic condition.

*1) Ground Controller*

Ground controllers showed a consistent pattern of decreased situation awareness when using the SRP advisories, compared to Baseline-1, using planned pair-wise comparisons. This finding is consistent with controllers' comments in post-study interviews. Controllers stated that it was challenging to integrate checking the advisory with their natural flow/scan of the map, making it difficult to get into a rhythm. Controllers also reported that the advisory updating function, which could potentially change the spot release sequence and timing, was very disruptive to their own mental planning process, which is critical to developing and maintaining situation awareness. The interaction between the use of advisories and traffic level on subjective SA was not statistically significant.

*2) Local Controller*

Situation awareness was not impacted by the RS advisories for the Local controllers. This finding is also consistent with controllers' post-study feedback where they indicated that the schedules provided by the RS were frequently consistent with their own plan. It is, perhaps, not surprising that controllers would find the SRP advisories to be less consistent with their own plans than the RS advisories. First, the goal of the SRP advisories is not consistent with Ground controllers' present method of operation, whereas there is much greater alignment between the goals of the RS and the Local controller. Second, the number of possible solutions that the SRP could generate was much greater than the number of possible solutions generated by the RS, which considered a more constrained problem space. The likelihood that the SRP will propose a plan inconsistent with the Ground controller's plan is greater; therefore, updates to the SRP advisories are more likely to result in changes that disrupt the controller's planning. The interaction between advisory and traffic level on subjective SA is not statistically significant for Local controller.

*C. Objective SA*

*1) Ground Controller*

The objective SA results for the ground position, shown in Fig. 11, showed no statistically significant effects of traffic level or advisory type on the objective SA. The interaction between advisory and traffic level for objective SA is statistically significant, however. The objective situation awareness decreased at the high traffic level, but not in the normal traffic.

*2) Local Controller*

The Local controllers showed no main effects or interactions for objective situation awareness
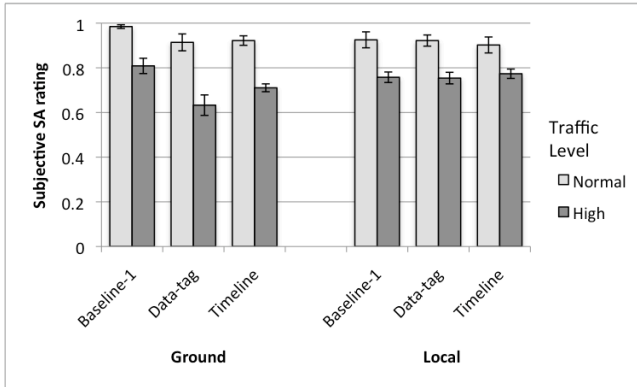
Figure 10. **Subjective Situation Awareness.** Effects of Advisory (Baseline 1, Data-tag, Timeline) and Traffic Level (Normal, High) on controllers.
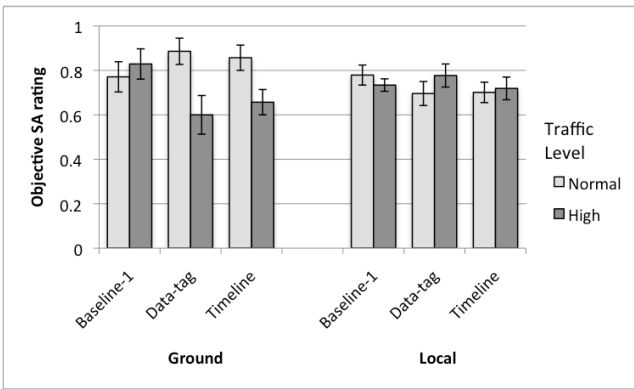


Figure 11. **Objective Situation Awareness.** Effects of Advisory (Baseline-1, Data-tag, Timeline) and Traffic Level (Normal, High) on controllers.

## D. Usability

No differences emerged in controller metrics between the Data-tag and Timeline advisories; however, there was a consistent numerical trend for higher workload and lower SA when Ground controllers used the Data-tag advisory. This trend is consistent with controllers' post-study feedback, where they expressed a preference for the Timeline over the Data-tag format on the ground control position. Controllers indicated that the Timeline advisory made it easier to plan ahead, kept clutter off the map, and they felt like they recognized updates and sequence changes more quickly. Controllers also reported difficulty locating the next-in-sequence aircraft on the map when using the Data-tag format.

The controllers noticed some artifact in the simulator that may affect workload and SA. Factors included: limited route selection (inner, outer, and full), little bridge traffic (east-west terminal crossings), and uniform taxiing speed. These artifacts made the testing appeared too simulated. Some of these artifacts will be addressed in the next series of simulations, like applying non-uniform taxiing speed.

## VII. SUMMARY AND CONCLUSION

The SARDA human-in-the-loop study investigated the concept of providing Ground and Local controllers with optimized metering advisories at the spot release and runway queue departure locations. The study also investigated different methods of presenting the advisories to the users.

The results indicated that the high traffic condition increased perceived workload of controllers. More importantly, the results also indicated that the SARDA advisories posed little impact on the Ground and Local controller's perceived workload.

The Ground controller showed decreased situation awareness when using the SRP advisories. Disharmony between the controller's mental/planning model and SRP-derived advisories was the main factor. Their goals were not synchronized. Interaction between Local controller and RS was more favorable because their goals were more closely aligned.

Concerning advisory format, Ground controllers preferred the Timeline advisory to the Data-tag format due to the difficulty of scanning for the next-in-sequence aircraft across all spot locations.

Future development should focus on integrating the user's planning model with the scheduling algorithm to enhance workload and situational awareness. One possible approach might allow tower manager to set a planning preference into the system, like favoring departures over arrivals for the next hour. The system then builds advisories based on this setting.

As the research moves, the lessons gathered here will help define the methods needed to transition the advisories into the tower's workspace, where working heads-down in front of the computer monitor is not the normal procedure. The electronic flight strips may be one mechanism in presenting the SARDA advisories, and warrants further investigation.

## REFERENCES

[1] S. Verma, T. Kozon, S. Lozito, L. Martin, D. Ballinger, and V. Cheng, "Human factors of precision taxiing under two levels of automation," Air Traffic Control Quarterly Vol. 18, No. 2, p. 113-141, 2010

[2] V. Cheng, A. Yeh, D. Foyle, "Evaluation plan for an airport surface-operation automation concept", AIAA Aircraft Technology, Integration, and Operations (ATIO) Forum, Denver, CO, November 17-19 2003.

[3] K. Griffin, P. Yu, D. Rappaport, "Evaluating surface optimization techniques using a fast-time airport surface simulations," 10th AIAA Aviation Technology, Integration, and Operations (ATIO) Conference, Fort Worth, Texas, Sept. 13-15, 2010

[4] J. Tsao, W. Wei, A Pratama, "Integrated taxiing and take-off scheduling with reordering at runway holding points for optimization of airport operations", FAA/Eurocontrol International Air Traffic Management R & D seminar, ATM-2009, Napa, USA, 2009.

[5] E. Mueller and G. Chatterji, "Analysis of aircraft arrival and departure delay characteristics," AIAA Aircraft Technology, Integration, and Operations (ATIO) Forum, Los Angeles, CA, USA, October 1-3, 2002.

[6] S. Zelinski and T. Romer, "An airspace concept evaluation system characterization of national airspace system delay," AIAA 4th Aviation Technology, Integration, and Operations Forum, ATIO, Chicago, IL, United states, September 20, 2004 - September 23, 2004.

[7] Joint Planning and Development Office, "Concept of operations for the Next Generation Air Transportation System Version 2.0," June 13, 2007, http://www.jpdo.gov/library/NextGen_v2.0.pdf

[8] Y. Jung, T. Hoang, J. Montoya, G. Gupta, W. Malik, L. Tobias, "Performance evaluation of a surface traffic management tool for Dallas/Fort Worth International Airport", 9th USA/EUROPE Air Traffic Management R&D Seminar, Berlin, Germany, June 14 – 17, 2011.

[9] H. Idris, B. Delcaire, I. Anagnostakis, W. Hall, N. Pujet, E. Feron, R. Hansman, J. Clarke, and A. Odoni, "Identification of flow constraint and control points in departure operations at airport systems," Air Traffic Control Quarterly Vol. 7, No. 4, 2000.

[10] I. Anagnostakis, H. Idris, J. Clarke, E. Feron, R. Hansman, A. Odoni, and W. Hall, "A conceptual design of a departure planner decision aid," 3rd FAA/Eurocontrol International Air Traffic Management R & D seminar, ATM-2000. Naples, Italy, 2000.

[11] N. Pujet and E. Feron, "Input-output modeling and control of the departure process of congested airports," Air Traffic Control Quarterly Vol. 8, No. 1, 2000, pp. 1-32

[12] H. Balakrishnan and Y. Jung, "A framework for coordinated surface operations planning at Dallas/Fort Worth International Airport," AIAA Guidance, Navigation, and Control Conference, Hilton Head, SC, United states, August 20, 2007 - August 23, 2007.

[13] J. Smeltink, M. Soomer, P. de Waal, and R. Van Der Mei, "An Optimisation Model for Airport Taxi Scheduling," Thirtieth Conference on the Mathematics of Operations Research, Lunteren, The Netherlands, January 2005.

[14] S. Rathinam, J. Montoya, and Y. C. Jung, "An Optimization Model for Reducing Aircraft Taxi Times at the Dallas Fort Worth International Airport," 26th International Congress of the Aeronautical Sciences (ICAS). Anchorage, Alaska, 2008, pp. 14-19.

[15] G. Gupta, W. Malik, and Y. C. Jung, "A Mixed Integer Linear Program for Airport Departure Scheduling," 9th AIAA Aviation Technology, Integration, and Operations Conference (ATIO), Hilton Head, South Carolina, September 21-23, 2009.

[16] S. Rathinam, Z. Wood, B. Sridhar, and Y. C. Jung, "A Generalized Dynamic Programming Approach for a Departure Scheduling Problem," AIAA Guidance, Navigation, and Control Conference, Chicago, Illinois, August 10-13, 2009.

[17] C. Brinton, "Field Test Results of Collaborative Departure Queue Management (Draft version)," 29th Digital Avionics Systems Conference, Salt Lake City, UT, USA, October 3-7, 2010.

[18] M. Biella, "European Airport Movement Management by A-SMGCS, Part 2 (EMMA2): Validation Test Plan PRG." 1 ed., Deutsches Zentrum für Luft und Raumfahrt (DLR), Braunschweig, Germany, 2010.

[19] European Commision and EUROCONTROL, "European Air Traffic Management Master Plan, Edition 1 – 30 March 2009" , SESAR Joint Undertaking, 2009. (http://www.eurocontrol.int/sesar/public/subsite_homepage/homepage.html)

[20] NGATS-JPDO, "Accomplishing NextGen Research to Implementation Establishing NASA-FAA Research Transition Teams", Presentation by J. Scardina, October 22, 2007

[21] Y. Jung, T. Hoang, J. Montoya, G. Gupta, W. Malik, and L. Tobias, "A concept and implementation of optimized operations of airport surface traffic," 10th AIAA Aviation Technology, Integration, and Operations (ATIO) Conference, Fort Worth, Texas, Sept 1-15, 2010

[22] Science Applications International Corporation (SAIC), "Airspace Traffic Generator: User's Manual Supplement, Revision 2.6.", Moffett Field, CA, USA, 2006.

[23] J. Hollands and C. Wickens, "Engineering Psychology and Human Performance", 3 ed. Upper Saddle River, NJ, USA: Prentice Hall, 2000.

[24] A. Degani and A. Kirlik, "Modes in human-automation interaction: initial observations about a modeling approach," Proceedings of the 1995 IEEE International Conference on Systems, Man and Cybernetics. Part 2 (of 5), October 22, 1995 - October 25, 1995. Vol. 4, IEEE, Vancouver, BC, Can, 1995, pp. 3443-3450.

[25] N. B. Sarter and D. D. Woods, "How in the world did we ever get into that mode? Mode error and awareness in supervisory control," Human Factors Vol. 37, No. 1, 1995, pp. 5-19

[26] S. G. Hart and L. E. Staveland, "Development of a multi-dimensional workload rating scale: Results of empirical and theoretical research," Human Mental Workload. Vol. 52, Elsevier, Amsterdam, The Netherlands, 1988, pp. 139-183.

[27] M. Matthews, S. Beal, and R. Pleban, "Situation awareness in a virtual environment: Description of a subjective assessment scale (Research Report 1786)." U.S. Army Research Institute for the Behavioral and Social Sciences, Alexandria, VA, USA, 2002.

[28] M. R. Endsley, "Situation awareness global assessment technique (SAGAT)," IEEE 1988 National Aerospace and Electronics Conference - NAECON 1988., IEEE, Dayton, OH, USA, 1988, pp. 789-795.

[29] Mosaic ATM, "Surface Management System (SMS): System Administration Guide.", Leesburg, VA, USA, 2007.

## AUTHOR BIOGRAPHY

**Ty Hoang** received his B.S and M.S. in aeronautical engineering at the California Polytechnic State University at San Luis Obispo, USA.

He began his career working on a pseudo-aircraft piloting system at NASA then participated in the field-testing of the Traffic Management Advisor (TMA) system at the Dallas/Fort Worth International Airport in the mid 1990's. In 2003, he led the development of the Multi-Center TMA (McTMA) simulator. The robustness of the simulator contributed to the successful field-tests in 2004; he now leads the development of the airport surface simulator.

Mr. Hoang is a Senior Member of American Institute of Aeronautics and Astronautics.

**Dr. Yoon Jung** received both B.S. and M.S. from Seoul National University, Seoul, Korea, and Ph.D. degree in mechanical engineering from University of California, Davis.

He is an aerospace engineer at NASA Ames Research Center, Moffett Field, California, USA, since 2000, specializing in research on airport surface operation. Prior to joining NASA, he worked at Advanced Rotorcraft Technology and Raytheon.

Dr. Jung is a Senior Member of American Institute of Aeronautics and Astronautics.

**Dr. Jon Holbrook** earned his Ph.D. in cognitive science from Vanderbilt University, Nashville, Tennessee, USA, in 2000, where he studied human memory and attention.

He was awarded a postdoctoral fellowship through the National Research Council to study aviation decision making, and has since remained in the field of aviation cognition. He is currently working as a Senior Research Associate in the Human Systems Integration Division at the NASA Ames Research Center through a program at San Jose State University. His research interests include prospective memory, naturalistic decision making, the skilled performance of experts, and the application of cognitive engineering practices to system design.

Dr. Holbrook is a member of the Human Factors and Ergonomics Society.

**Dr. Waqar A. Malik** received the B.Tech. degree in mechanical engineering from the Indian Institute of Technology, Kharagpur, India, in 2001 and the M.S. and Ph.D. degrees in mechanical engineering from the Texas A&M University, College Station, in 2003 and 2007 respectively.

He is currently an Associate Research Scientist at University of California, Santa Cruz, where he is involved in developing a surface management system aimed at enabling significant increase in efficiency and throughput of airport surface operations while maintaining safety. He has previously worked on the synthesis of fixed structure controllers, combinatorial motion planning, collision avoidance and path planning for unmanned vehicles.