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Simulation Results for Highlighting Runway Safety Critical Information on Cockpit Displays of Traffic Information

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RUNWAY SAFETY CRITICAL INFORMATION ON COCKPIT DISPLAYS OF TRAFFIC INFORMATION

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This paper describes the results of a human in the loop simulation that evaluated enhancements to a Cockpit Display of Traffic Information (CDTI). Runway safety critical information was highlighted on the CDTI to facilitate flight crew situation awareness and conflict detection for different groups of pilots (General Aviation and commercial) and under different operational settings (crew and single pilot). The evaluated CDTI enhancements are currently being defined by RTCA Special Committee 186 and based on the use of Automatic Dependent Surveillance-Broadcast (ADS-B). The results suggest that highlighting of certain traffic relevant information is promising to increase pilot's hazard detection over a normal CDTI but requires further refinement. This paper describes the primary simulation performance and subjective evaluation results and offers directions for further research and development.

The International Civil Aviation Organization (ICAO) and the Federal Aviation Administration (FAA) both define Runway incursions (RIs) as any occurrence at an aerodrome involving the incorrect presence of an aircraft, vehicle or person on the protected area of a surface designated for the landing and takeoff of aircraft. RIs at airports in the United States have been a major area of concern for the National Airspace System (NAS) for the past several years.

To address this problem, extensive human factors research has been performed. This research has generally indicated that human behavior is a root cause for runway incursions (FAA 1998). For example, Adam and Kelly (1996) performed an extensive survey with 1437 pilots from two commercial airlines and interviewed a subgroup of them to identify causal factors for RIs. The study identified factors contributing to runway incursions as related to airport characteristics such as signage, markings, lighting, runway geometry, as well as lack of familiarity of pilots with the airport surface and procedures. Other factors are related to the communication of control clearances via auditory communication channels, which frequently represent an information bottleneck under stress conditions, as well as factors concerning crew and air traffic control operational procedures. Overall, contributing errors may be caused by pilots, controllers (Bales, Gillian, & King, 1989; Steinbacher, 1991), or surface vehicle operators.

Over the last years, multiple approaches have been adopted to reduce runway incursions and collisions. In the United States, enhanced airport surface markings (FAA, 2006a) have been introduced and runway occupancy status lighting systems (FAA 2007) have been developed. Also, controller alerting systems such as the Airport Movement Area Safety Systems (AMASS, FAA 2005), and ASDE-X (FAA 2006b) have been developed. New airport designs, such as end around taxiways that allow aircraft to taxi around a runway instead of crossing it have been developed to reduce the occurrence of runway crossings. A Runway Incursion Information Evaluation Program (RIIEP) was created to learn more about runway safety hazards. In addition, the FAA has been providing guidance to airlines for standardizing ground operations (FAA, 2008, FAA 2003), and the FAA and pilot associations have been providing training and education about runway safety to pilots in various formats including workshops, websites, and DVDs. Flight decks have started to be equipped with moving maps that can display the airport and airport surface movement area. Also auditory systems that are intended to increase pilot awareness about surface hazards (RAAS, Honeywell, 2003) have started to be put on airplanes. Further, standards for the Cockpit Display of Traffic Information (CDTI) have been developed for different platforms on the flight deck such as Electronic Flight Bags (EFBs).

International efforts have included the development of an Advanced Surface Movement Control Guidance System (A-SMCGS) that provides surface traffic management, guidance, and alerting functionality to Air Traffic Control (ATC) and pilots (see IFATCA 2003; Roeder et al., 2008). A-SMCGS has been providing safety functionality for ATC and ongoing development are adding functionality for the flight deck (Vernaleken, Urvoy, Klingauf, 2007).

Specifically, a significant amount of research and development activities has been performed on flight deck-based airport surface safety systems (e.g. Jones 2002; Young & Jones 2001). One aspect of that research that has found its way into aviation standards and cockpits are CDTI capabilities that are targeted to increase flight crew situation awareness (see standards "Airport Surface Situation Awareness" and "Final Approach and Runway Occupancy Awareness", RTCA 2003).

The study that is described in this paper builds on these standards, and is intended to enhance CDTIs to render them more effective for increased runway safety. While traffic displays may increase the situation awareness of pilots under many situations when sufficient time is available to scan the display, pilots may need to find relevant information under safety critical situations more quickly. Specifically, when operating in high traffic volumes on the airport surface, CDTIs may be filled with much traffic that is mostly irrelevant for the flight crew. This would distract from the information that is of critical importance. The research that is described here investigated methods to highlight runway safety critical information on the CDTI that should allow flight crews to better understand the relevant aspects of safety critical situations. In the following sections, first that application is described, then simulation results are presented, and finally conclusions are derived.

DESCRIPTION OF APPLICATION

The described application adds traffic and runway highlighting on a CDTI to help enhance flight crew situation awareness and conflict avoidance. The term "highlighting" is here used to describe the information given to a flight crew to identify traffic and runway status that may become a runway safety hazard even if current conditions are normal (Moertl & Duke, 2008). Such highlighting should not actively attract attention of flight crews and does not represent an alert. It is intended to simplify the pilot task of finding runway safety relevant information on a CDTI before an alerting situation occurs. Highlighting occurs if traffic was either currently on a runway, entered a runway, or was on approach to a runway. Thereby, the flight crew uses the CDTI in combination with other information inside and outside the cockpit to obtain traffic situation awareness and determine the appropriate course of action.

Highlighting as provided in the simulation was context independent and not sensitive to the position, movement, and heading of ownship. The chosen implementation was a preliminary, and relative simple implementation that was intended to collect initial feedback that could then be used to determine if more complex implementations would be required.

A runway could be highlighted as either 'in use' or 'occupied' The "in use" highlighting occurred when an aircraft was currently moving on that runway or was predicted to be moving on that runway at high speed (above 40 knots). A runway was highlighted as "occupied" when an aircraft was stopped or moving on that runway at low speed (at or below 40 knots). For the purposes of this simulation, runway use and occupancy by aircraft was highlighted on all runways ahead of ownship.

Runway and traffic highlighting consisted of both graphical and non-graphical elements. Graphical highlighting included: highlighted runway (A in Figure 1), highlighted traffic (B), and ownship symbol (D). Non-graphical highlighting included a message text box (E), flight ID and groundspeed indications (C), an indicated aircraft data block (F), and a highlighted runway label (H). The graphical runway usage highlighting (G) was not used in the simulation, due to technical limitations. The graphical highlighting was only visible when the zoom setting of the CDTI was such that the traffic and/or runway being highlighted were currently in view. The non-graphical highlighting was visible with all zoom settings. The initial set of highlighting used in this simulation were selected by a panel of pilots and designers, and agreed upon by the working group that developed the application.

Figure 1 displays the graphical and non-graphical highlighting. In that figure, ownship is highlighted as a brown, filled-in triangle in the center of the display, taxiing toward runway 29 behind another aircraft. The highlighted aircraft (UPS 42) has landed and is moving at 118 knots on runway 29.

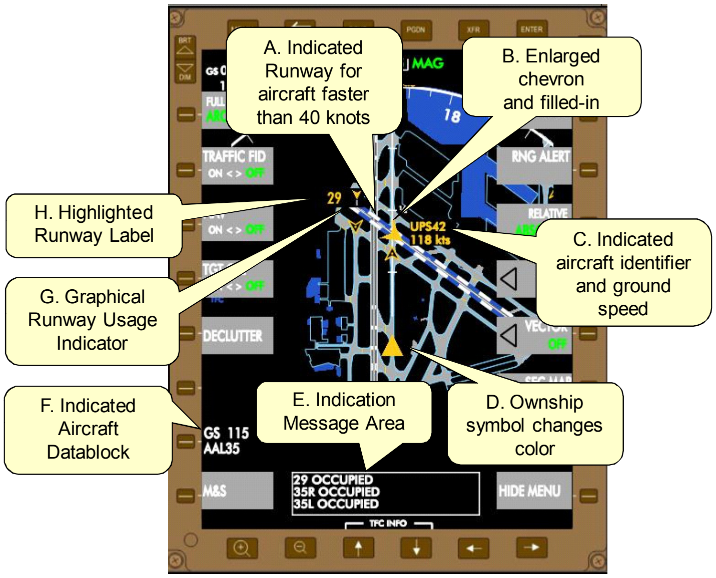

Figure 1 Cockpit Display of Traffic Information and Runway and Traffic Highlighting.

METHOD

The simulation assessed the benefits and limitations of an initial and simple implementation of runway and traffic highlighting on a CDTI under single pilot and crew settings.

Participants

16 pilots participated in this study. Fifteen were male, 1 was female. Eight pilots had private pilot certificates, four had commercial certificates, one was a certified flight instructor, and three had Airline Transport Pilot (ATP) ratings. Their average age was 50 years, ranging from 30 to 73 years, and they had an average flight experience of 3021 hours, ranging from 130 to 20000 hours. A heterogeneous sample of pilots was selected to examine a broad range of human factors related to different pilot experiences, as well as single pilot and crew settings.

Four pilots participated as single pilots, and 12 participated as flight crews. Of the 12 participating as part of a crew, 4 pilots sat in the right seat (pilot monitoring) while a confederate sat in the left seat (pilot flying). The other 8 pilots formed 4 crews of participants.

Scenarios

The simulation used the Louisville Standiford Field International Airport as the setting for all scenarios. The scenarios contained a large amount of traffic to provide an environment where highlighting would be most useful. Participants received clearances from a confederate air traffic controller via radio and heard radio communications with other aircraft that were visible on the CDTI and out the window. All radio communications were on one radio frequency so participants did not have to switch radio frequencies. The pilots monitoring did not perform weight balance or checklists during taxiing to allow them better familiarization with the CDTI. Table 1 shows the eight scenarios with visibility conditions and presence or absence of conflicts. Participants saw scenarios 1, 4, 5 and 8 in the baseline condition (current day CDTI display; no highlighting). They then saw all eight scenarios with highlighting.

Table 1 *Simulation Scenarios*

Scenario	Description	Visibility	Conflict
1	Participant taxies into position, getting a departure clearance while a conflict aircraft is cleared for landing on crossing runway.	High	Yes
2	Participant taxies and crosses runway after holding short for departing traffic.	High	No
3	Participant taxies into position and holds on runway for departing traffic on crossing runway.	Low	No
4	Participant taxies to runway, holds short for landing traffic, then taxies into position and receives a departure clearance while previous landed aircraft has not exited the runway.	Low	Yes

5	Participant is cleared to land while another aircraft is in position and holding for departure on same runway. Aircraft lifts off just prior to participant crossing the threshold.	Low	No
6	Participant is cleared to land while another aircraft receives a land and hold short clearance on an intersecting runway. The participant is told to exit at the end of the runway, causing a conflict with the aircraft that fails to hold short of that runway.	High	Yes
7	Participant lands and is cleared to back-taxi on runway. An aircraft is in position and hold on that runway.	Low	No
8	Participant is cleared to land. After touch down another aircraft lands on the same runway. This requires the participant to initiate an evasive maneuver to avoid collision with the faster moving conflict aircraft approaching from behind.	High	Yes

Simulator

The simulation was performed in a fix-based simulator with a 120 degree out the window view and configured with a primary flight and navigation display. The simulator did not replicate a specific aircraft type and resembled a large, transport category aircraft. The CDTI was shown on an EFB mounted in the left forward field of view for the left seat pilot and in the right forward field of view for the right seat pilot.

Procedure

Participants were briefed about the purpose of the study and then received an introductory briefing on the CDTI and the highlighting. They were given a short training manual to read through, followed by an introduction to the use of the flight simulator. Participants were then shown three scenarios to practice using the simulator and using the CDTI.

After the practice scenarios, participants were fitted with an eyetracker that was used to collect information about pilot's attention allocation during the scenarios. Eyetracking data results are not presented here.

For data collection, participants saw scenarios in two conditions: a baseline condition with a current day CDTI and no highlighting, and the experimental condition with the highlighting of traffic and runways. Participants saw all four baseline scenarios first, followed by the eight experimental scenarios. Scenario order was randomized within both conditions. The experimental condition was presented second to focus feedback on the highlighting after gaining sufficient familiarity with a baseline CDTI.

After each scenario, participants completed a questionnaire. After the last scenario, pilots also completed a post simulation survey and then participated in a debriefing session with the experimenter.

RESULTS

This report presents preliminary simulation results. Analysis of the remaining data is ongoing and will be presented at a future time.

Pilots were asked if they found the highlighting helpful in determining critical runway safety information. A majority of pilots (14 of 16) agreed or strongly agreed that highlighting were helpful. This is a statistically significant finding using chi-square ($\chi^2 = 9$, $p < 0.01$, df = 1). Pilots were also asked if the highlighting provided them with additional information as compared to the baseline CDTI information. Pilots reported that the highlighting did provide additional information ($\chi^2 = 15$, $p < 0.01$, df = 1). Pilots also reported that the highlighting helped them locate relevant traffic ($\chi^2 = 12.25$, $p < 0.01$, df = 1).

Pilots were asked to rank the seven functioning CDTI highlighting features according to usefulness (excluding the runway usage indication). The pilots' rankings were averaged, and are shown for each of the 7 highlighting features by operation type (arrival, departure, taxi) in Figure 2. Lower numbers equate to better ranking. The four best ranked features were: A. runway highlighting; C, highlighting of FID and ground speed; B, enlarged target; and D. Runway Message Area (see also Figure 1). The rankings confirmed pilot comments and observations made during the simulation by the experiment observers. Specifically, the graphical runway and traffic highlighting seemed to provide pilots a fast and intuitive indication of runway occupancy that stood out against other traffic. Participants stated they found the indicated ground speed useful in determining traffic movement on the runway which was especially relevant during approach scenarios. In contrast, the highlighted runway label (H) was ranked as less useful. Finally, runway usage information was also available to pilots via the runway status text box independent of the current range setting of the CDTI. Several pilots reported that the runway status text box could be used as a procedural trigger to initiate a sequence of actions, such as setting a CDTI range allowing them to determine the traffic situation. Though some pilots commented on the highlighting of ownship (D) as a useful general indicator about runway occupancy, pilots overall did not seem to find ownship highlighting overly helpful as that information was available in other places. Finally, pilots reported they did not find the indicated data block (F) useful. That data block indicated FID and groundspeed of the aircraft that was closest to ownship. This low perceived usefulness may have been because the non-graphical nature of this highlighting made it hard for pilots to relate the traffic to ownship, or because it was difficult to determine which traffic it was related to.

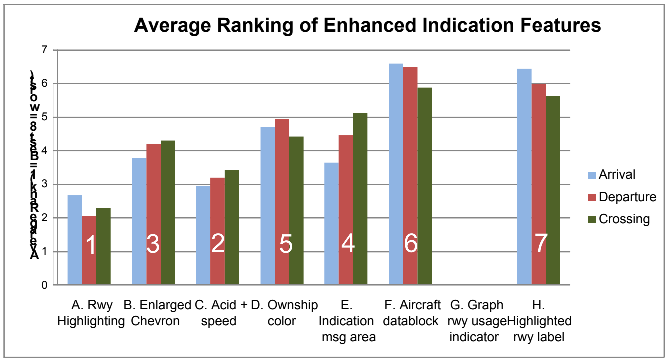

Figure 2 *Pilots' Averaged Rankings of Highlighting Feature Usefulness*

Participants indicated that zoom usage depended on whether highlighting was presented or not. There was a difference in agreement to the statements on zoom usage when pilots used a baseline CDTI versus when they used highlighting (5 response levels, $\chi^2 = 24.67$, $p < 0.001$, $df = 3$). A majority of pilots expressed that zoom usage increased workload in the baseline condition ($\chi^2 = 4.8$, $p < 0.05$, $df = 1$) but not so in the highlighting condition ($\chi^2 = 1.8$, $p > 0.05$, $df = 1$). This perceived difference in workload for adjusting the zoom level between the conditions was rather small compared to the overall scenario workload, where no difference in workload between conditions could be detected.

In the baseline condition participants did not reach agreement on the statement of whether the CDTI distracted them from surface operations or not. In the highlighting condition, pilots reported that the CDTI did not distract them from operating the aircraft ($\chi^2 = 12$, $p < 0.01$, $df = 1$).

While participants generally agreed on the usefulness of the enhanced display, participants also commented on display limitations. Specifically, participants did not reach agreement on the question if the right amount of traffic was highlighted. However, five pilots commented that too much traffic was highlighted and that this could be confusing. Pilots also asked that only safety information that was relevant to ownship should be highlighted.

To estimate the effectiveness of highlighting and how it might increase pilots' conflict detection, participants were exposed to conflict scenarios. Participants saw three of these conflict scenarios in both the baseline and the experimental condition. Reported conflict detection was compared between the two conditions to determine if highlighting traffic and runways increased conflict detection performance. Results are shown in Figure 3.

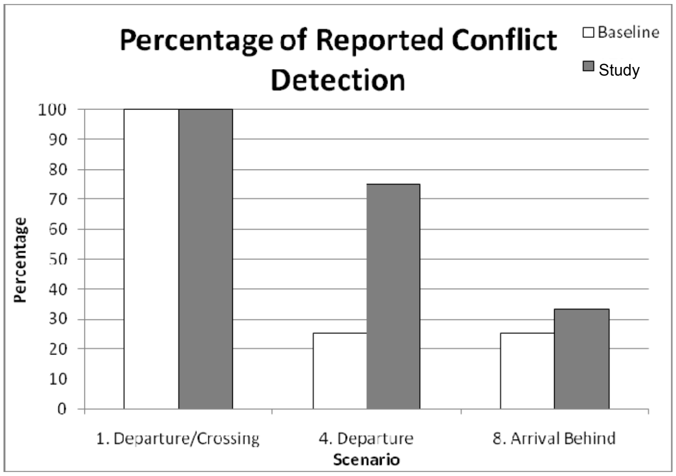

Figure 3 *Conflict Detection Performance with Highlighting (Study) and Without (Baseline)*

Results showed that highlighting seemed to increase reported conflict detection in two scenarios though it did not reach statistical significance. In the departure scenario (4) participants were cleared for takeoff while an aircraft was ahead on the runway. In that scenario, the percentage of reported conflict detection went from 25% to 75% and fewer pilots initiated a takeoff than in the baseline condition, however this was not a statistically significant finding. The increase in reported conflict detection in the experimental condition was likely due to the fact that pilots had to set the CDTI at the appropriate range setting to detect traffic on the departure runway in the baseline condition, but were provided with safety information in the experimental condition independent of zoom setting. In the arrival behind scenario (8), an aircraft landed behind and converged with ownship while the pilots taxied on a runway. In the baseline condition, pilots would have needed to have the zoom set to a level that included the approach area to see the conflict aircraft, while in the highlighting condition, pilots were provided with highlighting regardless of the zoom setting. However, there was no statistically significant difference in reported conflict detection between the two conditions. Four pilots who reported not detecting the conflict, did state that they had noticed highlighting on the CDTI. This finding suggests limitations of highlighting in cases where pilots cannot see the conflict aircraft out the window.

In the departure/crossing scenario (1), while conflict detection was relatively easy, pilots reported using different information for initial conflict detection in the baseline versus the highlighting condition. More pilots used the CDTI to detect the conflict in the highlighting condition (80 % of trials) than in the baseline condition (50 % of trials, marginally significant difference between conditions, $\chi^2 = 3.6$, $p < 0.06$, df =1).

SUMMARY

Pilots with varying degrees of experience evaluated a set of display features for highlighting traffic and runways on a CDTI. Highlighting was based on a simple algorithm that graphically indicated runway usage and occupancy. Pilots also evaluated the highlighting features as a way to improve detection of critical runway safety information and hazards by using the CDTI both with and without highlighting. Preliminary simulation results demonstrated that participants generally reported runway and traffic highlighting was helpful in locating relevant traffic information on the CDTI though no statistically significant performance differences could be found. Pilots rated the usefulness of the various aspects of highlighting features. They rated runway highlighting, enlarged chevron, aircraft flight ID and groundspeed, and text message box as more useful than the other highlighting features. Pilots also identified shortcomings and areas for improvement with the highlighting. Pilot comments related to areas for improvement will be reported at a later time.

Several pilots expressed their preferences for fewer highlighting, and, specifically only if traffic was relevant for ownship. We take this to mean runway and traffic highlighting may be improved by making it sensitive to ownship's context of operation.

We also identified limitations of the experimental methodology. Because we assessed the CDTI usage under a broad range of pilot experience and cockpit settings, the generalizability of results for a specific environment is limited. Also, because we did not always task pilots to the levels of workload that they would experience under real world operations, we may have allowed our participants more time to dedicate to the CDTI than they would likely have had available in their real work place. On the other hand, under real operational conditions, pilots would have had more time to become familiar with the system and likely had more training. Therefore, we consider the results of our study as somewhere in-between maximal and minimal expected benefits.

In terms of hazard detection, highlighting was not associated with deterioration in pilot reported conflict detection performance. Highlighting seemed to be less effective in supporting conflict detection when the traffic was behind ownship and not visible in the forward field of view. In the departure scenario, while there seemed to be improvement in reported conflict detection, there was no significant difference between conditions. This suggests the need for further research into the benefits of highlighting over a baseline CDTI, looking specifically at objective performance data.

The findings of this study point toward important considerations for the usage of CDTIs. The amount of information on a CDTI can be considerable. It can include runway and taxiway layout information, buildings, hold lines, centerlines, traffic, traffic movement and interrelations thereof. This information is shown in a relatively small display area that needs to be continuously adjusted to ensure needed information is in view. For example, during taxiing, a flight crew may select a close-in zoom setting to confirm their intended taxi- and runways. However, while crossing a runway, they may use a different zoom setting that allows them to check for traffic on the entire runway. Extracting the needed information requires a planned effort by the flight crew and needs to be considered as part of the flight crew activities. Based on pilot comments on the amount of highlighted display features on the CDTI, future research will attempt to reduce the amount of highlighted safety information. The displayed information should match a minimum set of information that allows pilots to determine hazards in few, quick glances while minimizing the amount of interactions with the CDTI. “Only give me the information that I need” describes what we frequently heard from pilots.

These simulation results will be used to refine the display and triggering rules of traffic and runway highlighting. A subset of the seven initial highlighting features will be used and more context dependent triggering rules will be implemented. In addition, we think to have determined a need for alerting because pilots had difficulty detecting a conflict either when their attention was not dedicated to the CDTI or when the traffic was outside their field of view. An auditory and visual alert message should help pilots to resolve such situations. We expect that alerting will play a significant role in increasing conflict detection and resolution because alerts will actively attract the attention of flight crews toward critical safety information and thereby facilitate faster responses. We are continuing our work by designing and evaluating an added alerting capability and will report this work in the future.

DISCLAIMER

REFERENCES

Adam, G., D. Kelley, J. G. Steinbacher, 1994, Reports by Airline Pilots on Airport Surface Operations: Part 1. Identified Problems and Proposed Solutions for Surface Navigation and Communications, Mclean, VA, The MITRE Corporation, MTR 94W0000060.

Adam, G., D. Kelley, 1996, Reports by Airline Pilots on Airport Surface Operations: Part 2. Identified Problems and Proposed Solutions for Surface Operational Procedures and Factors Affecting Pilot Performance, Mclean, VA, The MITRE Corporation, MTR 94W0000060, v2.

Bales, R. A., M. R. Gilligan, & S. G. King, 1989, An Analysis of ATC-Related Runway Incursions, with Some Potential Technological Solutions, Mclean, VA, The MITRE Corporation, MTR-89W00021.

Federal Aviation Administration's Runway Incursion Program Office (ATO-102) (1998), Airport Surface Operations Safety Action Plan to Prevent Runway Incursions and Improve Operations, Washington, DC, Department of Transportation.

Federal Aviation Administration (2003), Advisory Circular 120-74A Guidelines to standardize Flight Crew Procedures during Taxi Operations, Washington, DC, Department of Transportation, Federal Aviation Administration.

Federal Aviation Administration (2003), Advisory Circular 91-73 Single Pilot Procedures During Taxi Operations, Washington, DC, Department of Transportation, Federal Aviation Administration.

Federal Aviation Administration (2005), AMASS Specifications, Washington, DC, FAA-E-2069a.

Federal Aviation Administration (2006a), Advisory Circular – AC 150/5340-1J, Washington, DC, Federal Aviation Administration.

Federal Aviation Administration (2006b), ASDE-X Interface Control Document, Washington, DC, NAS-IC-24032410-xx.

Federal Aviation Administration (2007), Runway Status Light Engineering Briefing, Washington, DC, 64a.

Federal Aviation Administration (2007) Automatic Dependent Surveillance Broadcast (ADS-B) Out Performance Requirements to Support Air Traffic Control (ATC) Service, Notice of Proposed Rulemaking, Washington, DC, Department of Transportation, RIN 2120-AI92.

Honeywell (2003). Product Description Runway Awareness and Advisory System. Unpublished document.

IFATCA (2003), A-SMGCS Implementation in Europe, Publication of the International Federation of Air Traffic Controllers' Associations.

Jones, D. (2002). Runway Incursion Prevention System Simulation Evaluation. Presented at the 21st Digital Avionics Systems Conference.

Moertl, P. M. & J. Duke (2008) Enhanced Traffic Situational Awareness on the Airport Surface with Indications and Alerts (ATSA SURF IA) Application Description, Version 1.2.1. (Working document, contact pmoertl@mitre.org for a copy.)

Roeder, M., Jakobi, J., Nuzzo, A., Teotino, D. (2008), EMMA2 Airport Surface Management, Presentation at ASAS TN, April 14-15, 2008, Paris, France.

RTCA (2003) Minimum Aviation System Performance Standards for Aircraft Surveillance Applications (ASA), DO-289, Washington, DC, RTCA.

Steinbacher J. G., 1991, An Analysis of ATC-Related Runway Incursions in the National Airspace, Mclean, VA, The MITRE Corporation, WP 91W00234.

Vernaleken, C., Urvoy, C., Klingauf, U. (2007). International Symposium Enhanced Solutions for Aircraft and Vehicle Surveillance. March 6-7, 2007, Bonn, Germany.

Young, S. D.; and Jones, D. R. (2001): Runway Incursion Prevention: A Technology Solution. Proceedings of the Flight Safety Foundation 54th Annual International Air Safety Seminar, Athens, Greece, Nov. 5 – 8, 2001.