CHAPTER XX

Initial Evaluation of a Conflict Detection Tool in the Terminal Area

Savita Verma, Huabin Tang & Debbi Ballinger
NASA Ames Research Center
California, USA

Thomas Kozon & Amir Farrahi
NASA Ames Research Center/ UARC
California, USA

ABSTRACT

A conflict detection and resolution tool, Terminal Tactical Separation Assurance Flight Environment (T-TSAFE), is being developed to address the inadequacies of the legacy system in the field, Conflict Alert. Since altitude intent information improves T-TSAFE's conflict detection accuracy, this initial human-in-the-loop test of the tool had three T-TSAFE conditions: altitude clearances entered into the tool by the controllers via keyboard, altitude clearances entered into the tool from the flight deck via Automatic Dependant Surveillance-Broadcast (ADS-B), and no altitude entries. Entering altitude clearances into T-TSAFE was expected to reduce false alerts but did not, possibly due to the short duration of the runs. The test conditions also did not significantly impact the duration of the alert or the controller's response time to the alert. The subjective data showed that controllers favored T-TSAFE over Conflict Alert as used in the field due to the ease of use and perceived reduction in false alerts.

Keywords: conflict detection, terminal area, conflict alert

1 INTRODUCTION

Managing terminal area traffic is challenging due to the density of traffic and complexity of trajectories and separation standards. Conflict Alert is a short time horizon conflict detection tool currently in operational use in both the en route and terminal area, but it is often inhibited or desensitized in the terminal area because it generates a high number of false alerts. Conflict Alert uses only dead reckoning to determine when aircraft are in dangerous proximity to each other. Safety is maintained in the current system but at the expense of capacity, since controller workload is often considered as a limitation to capacity (Majumdar et al., 2002).

The objective of the current work is to develop a reliable and effective conflict alerting system. Tang et al. (2011) augmented the legacy dead reckoning approach with flight trajectory intent information to create a short time-horizon tool called Terminal Tactical Separation Assurance Flight Environment (T-TSAFE). The tool was developed to address the inadequacies of the operational Conflict Alert (CA). A comparison of T-TSAFE against a model of Conflict Alert found that T-TSAFE reduced the false alert rate and provided an average alert lead time of 38 seconds (Tang et al., 2011).

Previous Human-In-The-Loop (HITL) research on the predecessor TSAFE tool was conducted in the en route phase of flight (Homola et al., 2009). The current experiment tests the tool for the first time in the terminal environment with current day operations and technology. The experiment varied levels of altitude intent made available to the algorithm and assessed conflict detection performance as well as controller subjective feedback. Eight recently retired controllers served as participants, each controlling simulated traffic in the Southern California TRACON over approximately eight hours. Objective and subjective data are presented that characterize the performance of the Terminal TSAFE prototype.

2 BACKGROUND

The Federal Aviation Administration (FAA) has forecasted an increase in air traffic demand that may see traffic more than double by the year 2025 (JPDO, 2004) (FAA, 2009). Increases in air traffic will burden the air traffic management system, and higher levels of safety and efficiency will be required. Maintaining current levels of safety will be more difficult in a more constrained and crowded terminal air space. Thus, automation is proposed to aid the terminal area controllers with the task of assuring separation.

Terminal airspace has proven to be difficult for tactical conflict detection automation. The factors that contribute to this difficulty include dense traffic, frequent large turns made by aircraft, imprecise flight plans, a complex set of separation standards and the fact that the aircraft operate close to the minimum separation standards due to compression errors on approaches (Tang et al., 2011). In the current-day environment, Conflict Alert, a legacy system, was shown to be inadequate (Paeilli & Erzberger, 2007). Analysis of Conflict Alert by Friedman-Berg et al. (2008) shows that in the terminal area, controllers respond to CA alerts 56% of the time. Also, they analyzed the duration of the alerts, defined as the time between alert onset and the time when the conflict is resolved. Analyses of Conflict Alert durations showed that 36% of the alerts lasted less than 15 seconds. The short duration of CA alerts does not provide adequate time for the controller to respond and have any effect on the situation. Friedman-Berg et al. (2008) estimated that about 81% of all alerts in the terminal area are false, or nuisance, alerts. If automation can take into account aircraft intent, nuisance alerts are expected to decrease in number, improving the controller’s trust in the credibility of the alert. En-route conflict detection automation incorporates some of this intent functionality already, incorporating information about routes and interim altitudes when calculating conflicts, but current terminal area conflict detection automation either lacks this functionality or controllers do not commonly use it.

Most of the research on the parent TSAFE tactical tool has focused on en-route airspace. En-route prototypes have been developed and HITL studies were performed at NASA Ames. These studies compared conflict detection and resolution done manually by the controller to conflict detection and resolution performed by TSAFE. The concept of operations in these studies required new technologies such as Automatic Dependent Surveillance-Broadcast (ADS-B) and a Required Navigation Performance (RNP) of 1.0, making it a mid- to far-term concept. All the aircraft in the test airspace were capable of performing trajectory-based operations via datalink communications. For the flights that maintained their trajectory, TSAFE was responsible for the detection and resolution of strategic conflicts. Trajectory changes to resolve conflicts were uplinked directly to the aircraft without the controller's involvement. Overall results showed that using TSAFE resulted in better resolution of tactical conflicts and fewer separation violations than without TSAFE. These studies investigated TSAFE in the en-route airspace with far-term concepts of operations and technologies. Adapting TSAFE to the terminal environment and using it with a near term or current day concept of operations became the focus of this study.

A new algorithm for tactical conflict detection (T-TSAFE) developed by Tang et al. (2011) aims to address the inadequacies of Conflict Alert and incorporates some of the recommendations made by Friedman-Berg et al. (2008). The T-TSAFE algorithm uses a single analytic trajectory that takes into account both flight intent information and the current state of the aircraft. In addition to the flight plan, it takes into consideration Area Navigation (RNAV) departure routes, segments of nominal TRACON routes, speed restrictions, and altitude clearances inferred from the recorded track data. Tang et al. (2011) compared the T-TSAFE algorithm with a model of the Conflict Alert algorithm using recorded data from Dallas/Fort Worth TRACON that included 70 operational errors. An analysis of fast-time simulation data showed that T-TSAFE yielded a false alert rate of 2 per hour with 38 seconds of lead alert time, giving the controller adequate time to address conflict situations before they became critical. When the algorithm has information about where and which aircraft will level off, fast-time analyses showed further significant reductions in false alerts. The potential benefit from additional altitude intent information was the rationale for asking controllers to enter some commanded altitudes in the current investigation.

Although Terminal-TSAFE has undergone considerable fast-time testing, this study was the first to test terminal TSAFE with humans-in-the-loop, and also to evaluate the algorithm under current-day operational conditions. This study also investigates the feasibility of having controllers enter the level-off altitudes, into the automation, which they also gave the pilots verbally for the purpose of reducing the number of false alerts.

3 METHODS

This study compared T-TSAFE's alerting performance with an emulation of Conflict Alert in a human-in-the-loop test. As noted earlier, TRACON controllers currently do not provide input into Conflict Alert with commanded altitudes, as is current practice for en-route controllers. Prior studies (Tang et. al, 2011) have shown the rate of false alerts drops dramatically if altitude intent information can be provided to conflict detection automation. This is because, with altitude information, the algorithm knows where aircraft will level off and will not predict conflicts based on a presumption of continued descent. This study included one condition that required the controllers to enter the altitudes at which they verbally commanded aircraft to level off, and another condition where the commanded altitude information was provided via short-term intent broadcast over ADS-B from the flight deck.

3.1 Experiment matrix

The three conditions in the experiment described in this paper are shown in Table 1. The experiment included a baseline condition where Conflict Alert was emulated, but those objective results are not described in detail in this paper. The Conflict Alert emulation used in this study was simply represented with only 1000 ft vertical separation and 3 nmi lateral separation requirements between aircraft, and it did not provide meaningful alert data. However, the subjective results comparing Conflict Alert and T-TSAFE still have value because controllers related their experience with the fielded version of Conflict Alert to the T-TSAFE tool. Thus, Conflict Alert data are only discussed in the subjective results.

Table 1. Experiment Matrix

Altitude Intent	Condition
No Altitude Entry	Condition A
Altitude Entry via Keyboard	Condition B
Altitude Entry via ADS-B	Condition C

The three T-TSAFE conditions described in the results were: T-TSAFE with no additional altitude information (Condition A); T-TSAFE with controllers entering verbally commanded level-off altitude, if the altitude was for conflict resolution (Condition B), and T-TSAFE where the controller assigned an altitude for conflict resolution by voice and an ADS-B broadcast returned the altitude entered by the pilot to T-TSAFE (Condition C). In conditions B and C, the assigned altitude was shown in green in the second line of the data tag with 'A' prefixed to the three-digit altitude. Four traffic scenarios were exercised with each of the conditions for a total of 12 runs.

3.2 Air Traffic Control Tools and Procedures

The study simulated five arrival streams and one departure stream into Los Angeles International Airport (LAX) using current airspace and procedures within the TRACON. The scenarios were designed to create many situations that would result in a loss of separation between aircraft unless a controller intervened. Controllers in the study occasionally were able to successfully avoid conflicts for extended periods due to early intervention. It was therefore necessary to add conflicts to the scenarios using observers collaborating with pseudo pilots. Each scenario contained the traffic equivalent of heavy current-day traffic, with all LAX traffic under Instrument Landing System (ILS) simultaneous rules. The controller's goal was to avoid losses of separation. The controllers worked the East Feeder and Zuma feeder sectors, and Downe and Stadium approach sectors in the Southern California TRACON, rotating positions after each run.

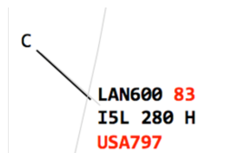

Figure 1. T-TSAFE data tags

T-TSAFE used 1000 feet minimum vertical separation, wake turbulence lateral separation standards, and a look-ahead time of 120 seconds to calculate conflicting trajectories. T-TSAFE predicted wake encounters as well as physical losses of separation, and factored in flight plan information and standard procedures, as well as using dead reckoning to predict conflicts. T-TSAFE alerts the controllers to a conflict by placing the number of seconds to predicted Loss of Separation (LoS) on the end of the first line in the data block, and the call sign of the conflicting aircraft in the third line of the data block, both in red. If more than one other aircraft is involved in a conflict, the third line shows the call sign of the aircraft closest to a loss of separation (Figure 1). The controller could also roll the cursor over any aircraft showing a conflict, and the data blocks of all other conflicting aircraft on the display would turn yellow for 5 seconds, e.g., UAL842 and MXA902 as other conflicting aircraft with the conflict shown in Figure 1.

3.3 Experiment Procedures

The study was conducted over a two-week period with two teams of controllers, each participating for a week. Each controller team consisted of four controllers that had retired recently from Southern California TRACON. Both controller teams were briefed on the T-TSAFE concept, the T-TSAFE interface, and the conditions of the study. During each week, the controller team completed twelve runs, four runs each of the three different conditions, rotating through four different traffic scenarios. Controllers rotated between sector positions after each run. Pseudo-pilots flew all the aircraft in the scenarios. All controllers completed questionnaires after every run and took part in a debrief session at the end of the study.

4 RESULTS & DISCUSSION

The metrics discussed in the paper include the following: total number of alerts, total number of false alerts, workload and usability of the T-TSAFE interface.

4.1 Total Number of T-TSAFE Alerts and Total Number of False Alerts

Figure 2 shows that the total number of alerts is similar between the three conditions. Each controller dealt with about 14 conflicts on average every run. There was no statistical difference in the number of alerts per condition. The false alerts were defined as a condition where an alert was provided, but the two aircraft did not lose separation, even though the controller did not intervene from 60 sec before the alert through the predicted loss of separation time. As shown in Figure 2, the number of false alerts was about 1 false alert per run, which were not statistically different between the different conditions. Contrary to the expectation, the altitude entries did not reduce the number of false alerts. This was possibly because controllers were able to enter commanded altitudes for conflict resolution only once or twice each run. It is likely that there was insufficient data to evaluate the impact of altitude entries on the number of false alerts.

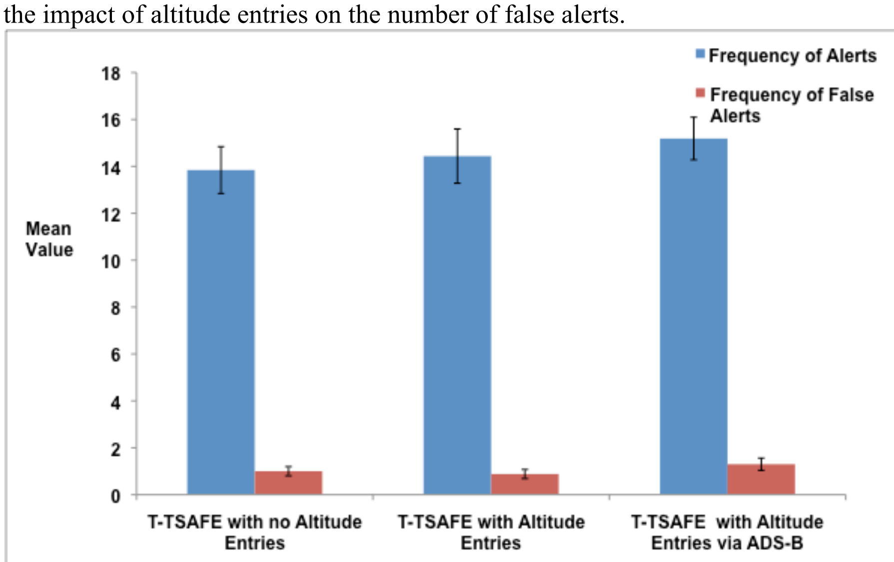

Figure 2. Total Number of T-TSAFE Alerts Compared with False Alerts (Mean Value Per Controller Per Run)

4.2 Duration of the Alert and Response Time to Alert

The duration of alert was defined as the time between the alert onset and the time when the conflict was resolved, which is dependent on several factors. One factor was the look-ahead time that the T-TSAFE algorithm used to predict conflicts. The average duration of an alert across different conditions was about 110 sec (Figure 3). The mean alert durations were slightly shorter in the two conditions where altitude clearances were provided via keyboard or ADS-B, as compared to the condition with no altitude entries. However, these differences did not reach statistical significance.

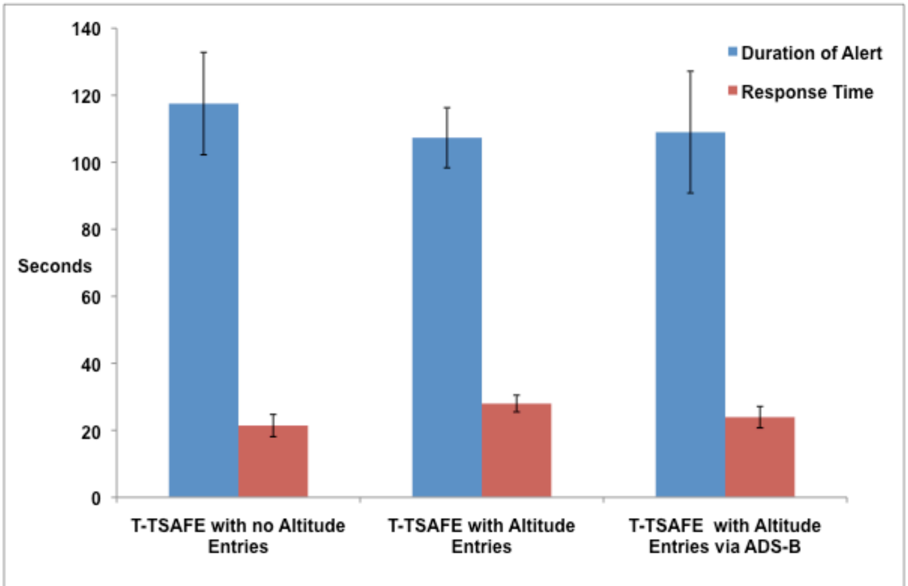

Figure 3. Comparison of Duration of Alert and Response Time to an Alert

The response time to an alert was measured as the difference between the onset of the alert and the time the pseudo pilot responded to the controller's commands. Figure 3 shows that the time to respond to an alert was 22 sec on average. It seems the duration of the alerts was more than adequate for the controller to see the conflict, determine a resolution, inform the pilots, and for the pilots to initiate the commands issued by the controllers. The controllers also mentioned that they used the "time to predicted loss of separation" provided in the data block to prioritize their tasks. The feedback provided by the controllers made it clear that in the TRACON environment they often address other high-priority emerging situations first and act to resolve a conflict in the last 25-30 sec prior to the predicted loss of separation.

4.3 Subjective data - Workload

Participants completed the NASA TLX workload questionnaire (Hart et al., 1988) after every run. As mentioned earlier, the subjective data include a baseline condition where the Conflict Alert model was simulated. Data were collected on each of the six TLX workload measures, and a variable measuring overall workload combining all six of these measures was derived, for a total of seven workload measures. The overall workload variable, also known as the "composite" measure, once derived, was then scaled down to match the 1-to-5 scale for direct comparison with the other six measures. Also, the "performance" measure was analyzed on an inverse scale, so a higher score would actually mean lower performance and a lower score is indicative of better performance. Results on all 7 of these measures, comparing the four experimental conditions, are summarized in Figure 4.

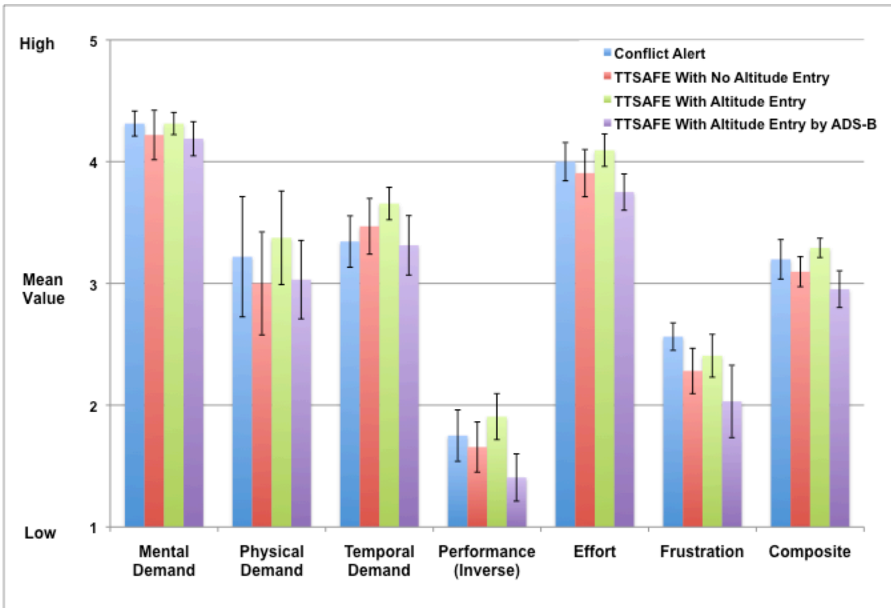

Figure 4. Workload Across the Experimental Conditions

The directionality of the mean values for most of the workload categories shows that controllers reported higher workload when using the Conflict Alert model and T-TSAFE runs where commanded altitude entries were made via keyboard, as compared to the other two conditions. TRACON controllers are not used to making data entries, and they often reported that this task increased their workload. Likewise, the controllers expressed many negative opinions about the Conflict Alert model, so it is not surprising that workload ratings were mostly higher for this condition. Conversely, for most of the workload categories, workload was rated lower during T-TSAFE runs where no commanded altitude entries were required and T-TSAFE runs where commanded altitudes were received via ADS-B. It seems likely that the lower workload ratings were due to the absence of required commanded altitude entries. However, it should be noted that these trends should be viewed with some caution, since the mean differences did not reach statistical significance.

4.4 Subjective data – Procedures

The controllers were asked questions about T-TSAFE and Conflict Alert procedures, which they rated on a scale of 1-to-5. These data were then analyzed using Analysis of Variance. Table 2 shows the mean ratings of the controllers' ability to maintain awareness of potential conflicts. Results indicated that the controllers found it significantly easier to maintain awareness of potential conflicts with T-TSAFE as compared to the Conflict Alert model ($F=7.99$, $df=[1,7]$, $p<0.05$). These data were validated in discussions between researchers and controllers, where controllers indicated that having the Time-to-Conflict in the first line of the data block provided them with information that helped them prioritize their tasks.

Similarly, T-TSAFE was rated easier to use than Conflict Alert, possibly due to controllers' experience with the high number of false or nuisance alerts that are routine for Conflict Alert as it is currently implemented in the field. There was a significant difference in the acceptability of the T-TSAFE procedures as compared to Conflict Alert ($F=5.73$, $df=[1,7]$, $p<0.05$). The explanation of the interface and the logic behind T-TSAFE given to the controllers might explain their levels of higher acceptability of T-TSAFE. The controllers also perceived that T-TSAFE alerts were more timely and useful than Conflict Alerts. This result is consistent with controller feedback, indicating that the duration of T-TSAFE alerts was adequate for the controllers to respond in time to prevent a loss of separation. A statistically significant difference was found for the perceived number of false alerts between T-TSAFE and Conflict Alert ($F=8.27$, $df=[1,7]$, $p<0.05$). Again, the controllers were drawing on past experience with Conflict Alert in the field.

Table 2. Mean Subjective Ratings on Procedures (*p<0.05)

	T-TSAFE	SE	Conflict Alert	SE
*Maintain Awareness of Potential Conflict (1=very easy, 5=very difficult)	1.9	0.39	3.0	0.42
Ease of Procedures (1=very easy, 5=very difficult)	1.8	0.31	2.8	0.25
*Acceptability of Procedures (1= low, 5= high)	4.0	0.38	3.1	0.37
Timeliness of Alerts (1=barely enough time, 5=adequate time)	4.1	0.26	3.2	0.38
*Number of False Alerts (1=too many, 5=none)	3.8	0.44	2.5	0.42

5 CONCLUSIONS

Terminal T-SAFE is being developed by NASA as a conflict detection tool to address the inadequacies of Conflict Alert as it is currently used in the field. The selection of the independent variables in this study was guided by previous research on T-TSAFE showing that making altitude intent information available led to a reduction in false alerts. T-TSAFE received commanded altitudes either from controllers entering commanded altitudes issued for conflict resolution or as short-term intent over ADS-B. Results showed that there was no difference in the rate of false alerts across conditions. This could possibly be explained by the fact that controllers do not make too many altitude entries that were expected to impact the rate of false alerts. Also, the duration of the alerts was not affected by the conditions, and neither was the controllers' response time to the alerts.

Subjective data included results comparing a simplified model of Conflict Alert to the three T-TSAFE conditions. The controllers reported that they experienced similar levels of workload, with a slight increase in the physical component of the workload in the condition that required the controllers to make commanded altitude entries via the keyboard. The subjective data on the procedures were favorable towards T-TSAFE over Conflict Alert. The controllers found that they maintained better awareness of potential conflicts and had adequate time to act on the alerts with T-TSAFE. They also reported the T-TSAFE procedures as more acceptable and easier than those with Conflict Alert. Further human in the loop testing of the tool with longer run durations is necessary to better understand the impact of altitude entries on the overall performance of the conflict detection and resolution tool.

5 REFERENCES

Erzberger, H. (2001). The Automated Airspace Concept, Proceedings of the Fourth USA/Europe Air Traffic management R&D Seminar, Santa Fe, New Mexico, USA, December 2001.

Federal Aviation Administration (2009). FAA Aerospace Forecast Fiscal Years 2009-2025. Washington DC, 31.

Friedman-Berg, F., Allendoerfer, K. & Pai, S. (2008). Nuisance Alerts in Operational ATC Environments: Classification and Frequencies. Proceedings of the Human Factors and Ergonomics Society 52nd Annual Meeting.

Hart, S. & Staveland, L. (1988). Development of a Multi-Dimensional Workload Rating Scale: Results of Empirical and Theoretical Research, In P. Hancock & N. Meshkati (Eds.), Human Mental Workload, Amsterdam, The Netherlands, Elsevier, 139-183.

Homola, J., Prevot, T., Mercer, J., Manini, M. & Cabrall, C. (2009). Human/Automation Response Strategies in Tactical Conflict Situations. 28th Digital Avionics System Conference, October, 2009.

Joint Development and Planning Office (2004). The Next Generation Air Transport System Integration National Plan. December 12, 2004.

Kuchar, J. & Yang, L. (2002). A Review of Conflict Detection and Resolution Modeling Methods. *IEEE Transactions on Intelligent Transportation Systems*. Vol. 1, No. 4, December 2000, 179-189.

Majumdar, A., Ochieng, W. & Polak, J. (2002). Estimation of European Airspace Capacity from a Model of Controller Workload. *The Journal of Navigation*. 55. 381-403.

Paeilli, R.A. & Erzberger, H. (2007). Design and Testing of Tactical Conflict Alerting Aid for Air Traffic Controllers.

Prevot, T., Homola, J., Mercer, J., Manini, M. & Cabrall, C. (2009). Initial Evaluation of NextGen Air/Ground Operations with Ground-Based Automated Separation Assurance. Eight USA/Europe Air Traffic management Research and Development Seminar (ATM 2009). June 2009, Napa Valley, CA, USA.

Tang, H., Robinson, J.E. & Denery, D.G. (2011). Tactical Conflict Detection in Terminal Airspace. *Journal of Guidance, Control, and Dynamics*. Vol 34, No. 2, 403-413.