CONTROLLER – PILOT COMMUNICATIONS IN THE PRESENCE OF ASYNCHRONOUS UAS RADAR SURVEILLANCE DATA

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Integrating Unmanned Aircraft Systems (UAS) into controlled airspace will create challenges for the pilots and controllers who need information about the UAS. This paper presents a preliminary study of the effect of differential time delays, or asynchrony, in the distribution of UAS surveillance information to controllers and pilots. Effects on controller-pilot communication were observed through 6 distinct measures of both objective performance and subjective self-evaluation. Larger time delays had an observable impact on all of the observed measures; comparison of pilot and controller results showed that the operator with the most updated information consistently experiences less frustration and feels the communication were more effective.

Driven by the huge profit opportunities in the Unmanned Aircraft Systems (UAS) market, the use of UAS is gradually shifting from exclusively military applications to civil applications. The expanded use of UAS will require integration of their operations into airspace actively managed by an air traffic controller (“controlled airspace”). Recent news stories highlight the concern generated by the integration, planned or ad hoc, of UAS into controlled airspace (Hurtado, 2013). Incidents reported to NASA’s Aviation Safety Reporting System highlight concerns about the different knowledge/information of nearby UAS to pilots and/or controllers (NASA, 2013). In addition, new surveillance capabilities provide opportunities to collect and distribute data on smaller and/or non-cooperating UAS to both pilots and controllers.

The ability to more widely distribute radar surveillance data on UAS and other objects to both controllers and pilots raises a number of Human Factors challenges. Yuan et al. (2012) identified three important challenges. Differences in how the information is distributed to pilots and controllers can create differential time delays; this can result in pilots and controllers collaborating while viewing information that is a different “age” despite coming from a common source. The potential difference in the “time age” of shared information has been labeled as Information Asynchrony (Yuan et al., 2012). While there has been significant previous work on controller-pilot collaboration, there does not appear to be much data available on how differential time delays in a common information source affect the communication and collaboration between pilots and controllers.

This paper presents a preliminary study of the effect of asynchronous information on pilots and air traffic controllers’ communication. The paper first reviews related work on the impact of time-delays on controller-pilot communications, briefly describes the design of the experiment, and presents the results of the study.

Background

Ambiguity, errors, and miscommunications between pilots and controllers are all potential causes of accidents (Morrow, Lee, & Rodvold, 1993). An important factor affecting communications is the presence of time delays (Morrow et al., 1993). Rantanen, McCarley and Xu (2004) have investigated the effect of systemic audio delay (AD) and variable pilot delay (PD) on controller performance and workload. Asynchronous information already creates challenges around communicating location of convective weather and confusion generated by the presence of time delays has prompted the National Transportation Safety Board to issue safety alerts about the use of NEXRAD mosaic image by pilots (NTSB, 2012). Day et al. (1999) studied the effects of delayed visual feedback and found that it produced oscillations in control movements and targeting exercises. Outside of the air traffic control domain, Kraut, Gergle and Fussell (2002) have examined the effect of time delays in a contrived jigsaw puzzle collaboration task with a shared visual display. Introducing a delay of as little as 3 seconds in the task was reported to impact performance and “in many cases rendered the shared visual space useless” (Gergle, Kraut, & Fussell, 2006).
Controller-pilot communications are important for maintaining consistent and accurate mental models of the traffic situation for both the pilot and the controller (Mogford, 1997). The shared mental model between pilots and controllers will include weather, traffic, intent and affective states (Farley & Hansman, 1999). Farley and Hansman (1999) experimentally studied the effects of increased sharing of weather and traffic data between pilots and controllers; however, this previous work assumed that information sharing would be instantaneous and did not examine the effects of differing time delays in access to shared information.

New technologies, such as System Wide Information Management (SWIM) (Meserole & Moore, 2007), are creating the opportunity to more broadly share information between pilots and controllers (Ulfbratt & McConville, 2008). Yuan et al. (2012) have developed a model of future operations incorporating SWIM; the model was used to identify potential Human Factors challenges resulting from the expanded distribution of surveillance data on non-cooperative objects. A key challenge identified was the potential of pilots and controllers coordinating resolution actions while dealing with asynchronous information. This is similar to challenges in current operations with communicating about convective weather (Brown, 2007).

**Experiment Probing the Effect of Asynchronous Information on Controller-Pilot Communication**

A simple experiment was designed as an initial examination of the effect of asynchronous information on controller-pilot communication. In the experiment, participants were shown static pictures of a radar surveillance display (controller participant) and a primary navigation display (pilot participant) (Figure 1). Their tasks were to observe the displays, identify potential conflicts and communicate with each other to resolve the conflicts. Relevant data, including the communication time and subjective mental status, were collected. The experiment manipulated the amount of time delay between the information presented to the controller participant and the pilot participant between 0 and 10 minutes.

**Experimental Setup, Tasks and Scenario Design**

The task was setup to resemble current controller-pilot voice communications. A divider was placed between the two participants (Figure 2) allowing them to communicate verbally but without being able to see the other person or any gestures.

In each trial, participants were asked to evaluate their radar surveillance display/navigation display and communicate with each other in order to resolve any conflicts presented. Controllers were notified of the general
traffic situation in their controlled sector by providing a written briefing prior to the trial. Each group of participants performed five experimental trials; each trial used a scenario randomly selected from a pool of previously generated scenarios. A delay interval of (0, 0.5 1, 5, 10) minutes was applied to the information for either the controller or pilot display. To minimize potential learning effects, the sequence of time delays in the experimental trials was random.

Ten different scenarios were designed; these formed a pool of five takeoff scenarios and five landing scenarios. This was done to minimize any effects of the details of the traffic situation on the results, while still presenting participants with novel and engaging situations in each trial. For each scenario, the common elements shown to both participants included traditional aircraft, as well as depictions of non-cooperative objects such as birds, weather and UAS. One or more impending conflicts between the pilot’s aircraft and a UAS/weather condition/birds were embedded in each scenario. For each trial, once a scenario was selected from the pool, the required time delay was applied to the non-cooperative objects in the selected scenario.

Participants and training

Access to trained professionals was not possible; instead, students from a local university were recruited as participants. Consequently, the participants were expected to be not as familiar with air traffic control and piloting operations. However, for the purpose of the intended task, it was felt that the core goal of communicating to negotiate a coordinated resolution to a conflict did not require specialized knowledge. Since the participants were naïve, multiple training trials were provided to make sure that the participants were capable of reading the display, analyzing potential conflicts and communicating with each other. In the display training, participants were taught to recognize the legends (aircraft icon, non-cooperative objects icon, etc.) and understand the information presented on the displays. Training on how to communicate was provided; 4 static displays were used to illustrate to participants how to communicate regarding potential conflicts.

Participants were comprised of 12 groups (12 female and 12 male participants) with an average age of 29.5 years old. Participants were assigned to the pilot and controller roles randomly at the start of the experiment. And participants did not previously know each other. In addition, in order to eliminate the effect of gender, there were three “male – male” groups, three “female – female” groups and six “female – male” groups.

Data Collection

Both objective and self-reported data was collected. At the end of each experimental trial, the participants completed a post-trial questionnaire with four 10-point Likert scales asking participants to rate their self-assessed performance, communication effectiveness, frustration level and trial difficulty. As well, the experimental trials were audio recorded for the purpose of analyzing communication time and clarification information.

Results

Objective Data

Communication time. Communication time refers to the time from the beginning of the trial until the participants reached an agreement on a resolution action. Figure 3 (a) presents the average communication time observed for each time delay interval. Error bars in the figure represent the standard error. The general trend indicates that the communication time increases when someone has more updated information (either the pilot or the controller). A repeated measures ANOVA analysis was also performed. $F (4, 36) = 2.54, p = .057 > .05$ which indicates that there is no significant relationship between communication time and the delay interval.

Number of clarification times. A clarification was defined as the moment that 1) one party of the pair asks the other party to either confirm and/or describe one or more particular object(s), and/or 2) one party of the pair disagrees with the other on the description/position/information of one/more particular object(s). Therefore, if one party merely does not hear the description clearly and asks for more explanation, it was not counted as a clarification. Figure 3 (Right) demonstrates the relationship between the average number of clarifications and the delay intervals. The overall trend indicates that an increase of the time delay increases the number of the clarification times. Repeated measure analysis shows that the repeated scenarios have a significant impact on the number of clarification times ($F (1, 9) = 4.080, p = .008 < .05$).
Figure 3.
Mean value plots of the Clarification Times (Left) and Communication Time (Right).

Subjective Data

The main resource of subjective data is the self-rate measurements collected from the post-trial questionnaires. The 4 measures were performance, communication effectiveness, frustration, and trial level of difficulty. Checks were made for learning effects and the data showed that the ratings were generally consistent, independent of trial number.

Figure 4.
Mean value plots of subjective measurements for controller (Left) and pilot (Right).

Figure 4 shows two mean value plots of the 4 measures for the controllers and pilots respectively. In general, when there is no delay, both pilots’ and controllers’ self-reported performance scores (blue line) are the
highest and they feel the least difficulty (grey line) of the trial. Figure 4 also shows that when the pilots have the most up-to-date information, the controllers feel more frustration (green line), and the communication is less effective (yellow line). And vice versa.

In order to better understand this result, a further analysis were performed to compare the 4 measures on the same scale of “who is ahead” in relation with the score/level of the measurements (Figure 5). It indicates that the party, who has the most updated information, thinks the communication is the most effective and the least frustrating.

![Figure 5](image)
The relationship between “who is ahead” and communication (Left), “who is ahead” and frustration (Right).

**Discussions, Implications & Future Work**

There are several key implications from the results presented above. Delay time had a clear effect on the communication performance. Long delays on the order of 10 minutes produced increased frustration and need for clarifications, and longer conflict resolution times. While 10 minutes is an unrealistic delay time for distributing object locations, it is on the same order of the time delays that are experienced when communicating about weather in current operations. Future work could consider differential update rates as a source of the differential time delays. In this study, asynchronous information on UAS, birds, and weather were all updated at the same rate. In operations, however, the dynamics of these objects are not exactly the same and there may be advantages to having different update rates. For slow-moving objects, such as weather and broad areas of bird activity, rapid updates may be perceived as unnecessary as reducing update rate is one method of reducing costs and bandwidth requirements.

In addition, it was obvious that the operator receiving the most up-to-date information had a better communication experience. Results showed they felt less frustration and were more likely to feel the communication was effective. This result is different from our original hypothesis, which was that with an increase in the time delay, both parties would uniformly feel more frustrated and less effective at communication.

There are several limitations to the study that restrict the implications that can be drawn, particularly for shorter delay times; however, these limitations can be addressed in future studies. Effects of differential time delays at the shorter durations were not as pronounced due to the noise in the data. It is thought that the use of static pictures eliminated important time pressure factors and did not present participants with a dynamic vision of the situation. The lack of motion could have affected the participants’ ability to make precise predictions and decisions and masked differences in the effects of shorter delay times.

Future research will narrow the delay window to a smaller range that is more likely to represent the time delays that would be observed for transmitting object position data. The study will be repeated in a part-task dynamic simulation environment and it is hoped that professional controllers and pilots can be recruited.
Acknowledgements

The researchers express appreciation for the support and funding of this work jointly by the Canadian National Science and Engineering Research Council Collaborative Research and Development Grant (#CRDPJ-398768-2010) and Raytheon Canada Limited. The material presented in this paper represents the views of the authors and do not necessarily reflect the views of the funding agencies/company.

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