

ROLE OF THE CONTROLLER IN AN INTEGRATED PILOT-CONTROLLER STUDY FOR PARALLEL APPROACHES

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Abstract

Closely spaced parallel runway operations have been found to increase capacity within the National Airspace System but poor visibility conditions reduce the use of these operations [1]. Previous research examined the concepts and procedures related to parallel runways [2][4][5]. However, there has been no investigation of the procedures associated with the strategic and tactical pairing of aircraft for these operations. This study developed and examined the pilot's and controller's procedures and information requirements for creating aircraft pairs for closely spaced parallel runway operations. The goal was to achieve aircraft pairing with a temporal separation of 15s (+/- 10s error) at a 'coupling point' that was 12 nmi from the runway threshold. In this paper, the role of the controller, as examined in an integrated study of controllers and pilots, is presented. The controllers utilized a pairing scheduler and new pairing interfaces to help create and maintain aircraft pairs, in a high-fidelity, human-in-the loop simulation experiment. Results show that the controllers worked as a team to achieve pairing between aircraft and the level of inter-controller coordination increased when the aircraft in the pair belonged to different sectors. Controller feedback did not reveal over reliance on the automation nor complacency with the pairing automation or pairing procedures.

Introduction

Reduction in air traffic capacity is the biggest challenge that airports must address with closely spaced parallel runways when visual approaches are not possible due to poor visibility [1]. The FAA's NextGen program aims to maintain visual capacities under all weather conditions at airports with closely spaced parallel runways.

Previous concepts investigated safety issues related to parallel runway operations but did not examine the information and procedures for pairing aircraft. The authors have conducted high fidelity flight simulation studies to investigate the safety issues associated with parallel approaches that may require aircraft to perform breakout maneuvers due to hazardous conditions [2,3] such as the wake of lead aircraft drifting towards the follower or the lead aircraft blundering towards the follower. In addition, the role of air traffic control in aircraft pairing for simultaneous approaches was explored [4], including the examination of controller responsibilities and communication tasks. The next logical step is to investigate the integrated role of the controller and pilot in pairing aircraft for simultaneous approaches, which was the intent of the current study.

This high fidelity human-in-the-loop simulation investigates the integrated dynamic role of controllers and pilots for pairing aircraft to parallel runways for simultaneous approaches. This paper will focus on only the controller's role specifically in terms of team performance, communication, and potential automation induced complacency. The results of the measures pertaining to both the controller and pilot have been published elsewhere [5]. Hence, the objective of this paper is to describe the automation, procedures, information requirements, and other subjective data for controllers only, when pairing aircraft for simultaneous approaches in an integrated study of controllers and pilots.

Background

The FAA has successfully conducted independent approaches to parallel runways for over forty years using the Instrument Landing System (ILS) navigation and terminal radar monitoring [1]. Some airports, like San Francisco International (SFO), can support approximately 60 landings per

hour on two parallel runways that are 750 ft apart using visual approaches, and approximately 45 landings under Simultaneous Offset Instrument Approaches (SOIA) under limited cloud ceiling-visual meteorological conditions (VMC). As visibility degrades further, the current navigation and surveillance system, as well as the existing procedures, cannot support SOIA approaches, dramatically reducing the landing rate [6].

Previous human-in-the-loop studies have explored Very Closely Spaced Parallel Runways (VCSPR) operations from the flight-deck perspective. One study examined pilot responses to VCSPR operations using the Airborne Information for Lateral Spacing (AILS) concept [7]. This concept requires technologies that enable the use of precise navigation and surveillance data, as well as technology for the detection of blunders. Further simulations have been conducted by NASA to examine pilot procedures for paired approaches on runways that are 750 ft apart in instrument meteorological conditions (IMC) [2]. Enhanced cockpit displays that depict both traffic and wake information were provided to the flight crew for these operations. The results from these investigations revealed that even in the blunder cases, no loss of separation was observed and the breakout trajectory was flown accurately. Also, pilot workload was manageable, and an adequate level of situation awareness (SA) was maintained.

Previous research has also examined the role of the controller in parallel runway operations. Under SOIA, the controller has positive control over the aircraft until the pilot breaks through the clouds and the follower aircraft has visual contact with the leading aircraft [6]. Under AILS, the final approach controller has positive control over the aircraft pair until the trailing aircraft is given a clearance for the AILS approach [8]. Previous studies by the authors have explored procedures for controllers to pair aircraft under different levels of automation [4]. Different levels of pairing automation were examined with respect to workload, situation awareness and various operational factors. The study found the most favorable controller feedback when they were given more flexibility, i.e., to either select pairs offered to them by the pairing scheduler or to create their own pairs.

Another VCSPR concept known as Terminal Area Capacity Enhancing Concept (TACEC) [9] was

collaboratively developed by Raytheon and NASA Ames Research Center. TACEC defines a set of automation-assisted procedures that can be used for conducting simultaneous instrument approaches to two or even three closely spaced parallel runways that are 750 ft apart. The concept defines a safe zone behind the leader aircraft where the trailing aircraft is protected from the wake of the leader. The suggested safe trailing distance for the follower aircraft is in a window of 5s to 25s behind the lead aircraft, with 15s representing the optimal temporal distance and +/- 10s representing the tolerance [10]. The goal for both controllers and pilots is to bring the aircraft in this wake-safe window at the “coupling point.” The coupling point is defined as a point in airspace 12nmi from the runway threshold, where the aircraft achieve the desired wake-safe temporal spacing, as described above. Pilot procedures and information requirements for TACEC were explored in several studies, and controller procedures were examined in a separate investigation [4].

The previous work provided the framework for the current study, which investigates VCSPR operations with both pilot and controller procedures integrated into the same human-in-the-loop simulation experiment. The remainder of the paper will discuss the methods and results for the controller participants in this simulation.

Method

Participants

The participants were three teams of retired controllers from the Northern California Terminal Radar Approach Control (TRACON) facility. Each controller team participated with two glass-cockpit qualified flight crews. The total of number controllers and flight crews were nine and six respectively. Each controller team consisted of three controllers and each flight crew consisted of a Captain and a First Officer. All participants had at least 10 years of experience in their respective fields. The study was run for two days per flight crew with each ATC team participating for four days. The pairing procedures were developed with the assistance of pilot and air traffic control subject matter experts. The closely spaced parallel runway operations on 28L and 28R in use at SFO were simulated. Participants were briefed and trained on the pairing concept, the new displays, and their automation tools. Pseudo pilots controlled

other aircraft targets in the scenarios to add realism. The data of the pseudo pilots' aircraft were not included in the analyses. The piloted crews always flew as the following aircraft, so there was always an opportunity to pair with another aircraft. All participants completed questionnaires and took part in a debrief session at the end of the study. During the trials, observers were positioned to watch the controllers' operations, and assessed the teamwork behavior ratings (described in the results section), took notes of controllers' verbal communication with each other, and recorded any other observations.

Airspace

Only arrival traffic was simulated in this study. Two arrivals flows from the east, Yosemite and Modesto, one flow from the north, Point Reyes, one from the south, Big Sur, and one from the west, Oceanic, were simulated (Figure 1). The arrival flows were similar to those used in the current airspace, except every arrival flow split allowing the aircraft to land its pre-specified runway, either 28R or 28L. The simulation used an arrival rate of 60 aircraft per hour. The parallel runways 28L and 28R were separated by 750ft, and were used for arrivals. The visibility was assumed to be low, runway visual range of 2nmi at 400ft in all the traffic scenarios. Two comparable traffic scenarios were exercised during eight data collection runs with a Visual Flight Rules (VFR) level of traffic. The scenarios were scripted to simulate an upstream scheduler that metered traffic into the terminal area.

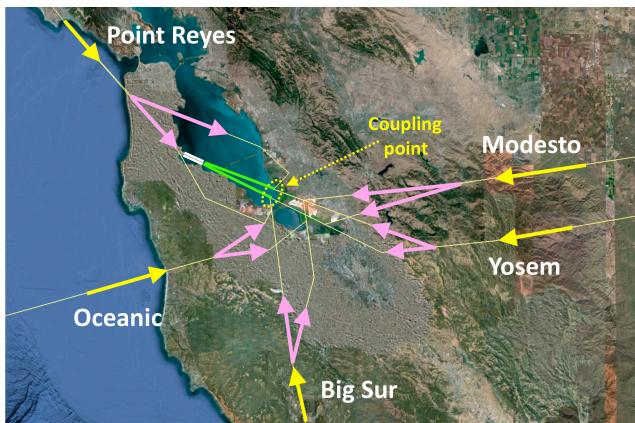


Figure 1. SFO Airspace.

Controller Procedures

Three controller positions were simulated for the study, namely, Area Coordinator, Boulder Sector and Niles Sector. The Boulder controller managed the north (Point Reyes), south (Big Sur) and west (Oceanic) traffic flows. The Niles Controller managed the arrival flows from the east, Yosemite and Modesto. The coordinator position was responsible for the creation of pairs in the two sectors, Niles and Boulder.

The goal of the pairing procedure was to have the trailing aircraft reach the coupling point at 5 to 25s behind the lead aircraft. The Area Coordinator could pair aircraft from any of the five arrival streams but not the same stream to avoid an overtake situation. The sector controllers were responsible for maintaining the pairs to the 'coupling point' (12 nmi from the runway threshold) with the desired intra-pair spacing of 5-25s. They were allowed to use speed adjustments only to achieve pairing and spacing.

The flight deck of the following aircraft had speed control algorithms that allowed the flight deck to adjust speeds automatically in order to come behind the lead aircraft in the wake-safe zone of 5-25s. The controller was not allowed to manipulate the speeds of the following aircraft, unless pairing was cancelled. However, the controllers had more direct control over the lead aircraft. The procedure to manipulate speeds on the follower required controllers to cancel the pair and then provide speed commands to the following aircraft. If they did not wish to cancel the pair, they manipulated the speeds on the lead aircraft, and eventually the speed algorithm on the follower reacted and accordingly adjusted the speeds on the follower.

Based on the findings of previous research [4], a level of automation was selected for the pairing tool, in which the automation suggested pairs of aircraft in the Pairing Table (Figure 2). The Area Coordinator then had the option of either selecting one of the suggested pairs, or manually overriding the pairs suggested by automation and selecting an alternate pair. The main goal for the coordinator was to evaluate pairs offered by the automation to ensure the two aircraft were capable of landing between 5 and 25s of each other. The coordinator used the timeline (Figure 3) to evaluate and select aircraft that appeared to be natural pairs, such that their times to the runway-thresholds were within 30-60s from each other.

To finalize a pair, the coordinator evaluated the pair suggested by the automation against the timeline. If the pair was evaluated as acceptable, the coordinator sent a data link message to the two aircraft. When the pilots of both aircraft acknowledged the pairing, the aircraft call signs turned green in the pairing table. The pairing table in the sector controller's display contained only finalized pairs.

Both aircraft in the pair were then given an approach clearance electronically by the sector controller who owned the trailing aircraft in the pair. The approach clearance was given at about 14 nmi from the threshold. It was found necessary that the two aircraft in the pair receive the approach clearance at the same time to ensure that they make the 15s temporal separation at the 'coupling point.' The approach clearance also implicitly delegated separation authority to the flight-deck. Aircraft pairs that were out of conformance could only be given approach clearances via voice. Once an approach clearance was provided, the aircraft changed color to blue in the pairing table. This color coding helped the controllers manage information about the pair. If a pair lost conformance, controllers had to perform any of the following three options – 1) re-establish the pair after making speed adjustments (if possible), 2) land the planes as singles, or 3) vector them away and return them back to the flow upstream. Any of the controller positions could cancel a pair, by highlighting the pair in the pairing table and pressing the delete button.

All the three controller positions had a pairing table, which listed all pairs in the order of their Estimated Times of Arrival (ETAs), with a continually-updated timeline (configured to show the ETAs of the aircraft to the two parallel runways), and a conformance monitoring tool (Figure 4), which displayed two bars on the following aircraft to show the leading and trailing edge of the 5-25s conformance envelope.

Existing/Planned Aircraft Pairs		
Send	Locate	Delete
LEADER		TRAILER
UAL657	-----	VRD953
EGF3188	-----	SWA410
UAL309	-----	JAL2

Figure 2: Partial view of the finalized pairs in the pairs table.

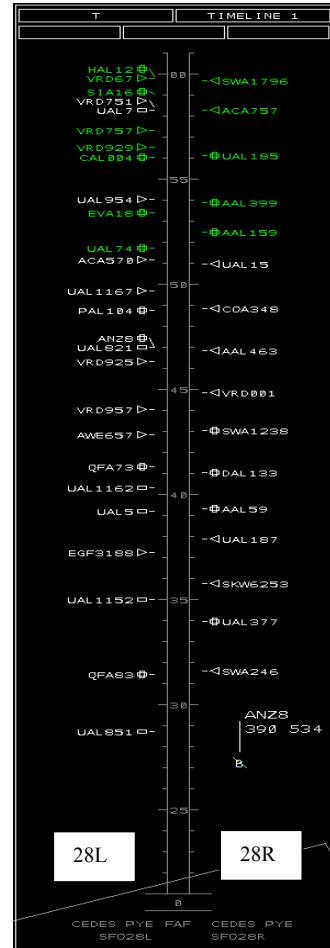


Figure 3. Timeline showing aircraft scheduled for the two runways 28L and 28R. Example of natural pair QFA83 and SWA246.



Figure 4. Conformance monitoring bars.

Results and Discussion

The study goal was to explore the dynamic and integrated role of controllers and pilots for aircraft pairing on simultaneous arrivals. Results on the metrics of throughput, controller workload and controller situation awareness have been reported elsewhere [5]. Hence, these results will only be described briefly. The remainder of this paper will focus, in greater detail, on the other metrics such as team behaviors as reported by the observers, trust in automation and other subjective feedback received by the controllers, which help to define the air traffic control information requirements and procedures. The study aims to provide results on team behavior to investigate the changes induced due to the introduction of the Area Coordinator position and the task of pairing aircraft assigned to them. Similarly, inter-controller communication is reported to explore any changes in communication brought about by the introduction of new pairing automation and procedures that involved pairing aircraft from different sectors. Potential for complacency towards the new pairing automation and procedures have also been described in this paper to assess controller's level of trust in the new automation. The metrics presented here have been averaged across the three controller positions.

Prior Results: Throughput, Workload, Situation Awareness

The controllers helped achieve the desired VFR throughput by pairing 30 aircraft and canceling only one pair (on average) in any 30 min run. Although the objective of the controller was to land as many pairs as possible, having a small number of singles or unpaired aircraft (e.g., canceled pairs) helps with efficiency, particularly in cases when an aircraft was vectored or had a go-around and had to be reintegrated back into the flow.

The ATWIT (Air Traffic Workload Input Technique) [11] was used to collect subjective controller workload assessments during the course of the simulation runs. While there were no statistically significant differences between the positions on subjective workload, overall ratings indicated a low and manageable level of controller workload, on average. However, the variability in the workload rating distribution suggested that workload was

occasionally high enough to prevent vigilance decrement.

Controller situation awareness data were collected using the Situation Awareness Rating Technique (SART) [12]. ANOVA results indicated high controller situation awareness across all the positions. No statistically significant differences were found between the positions.

Team Behavior Data

Three experiment observers used an adapted version of the Anti-air Teamwork Observation Measure (ATOM) [13] to provide an assessment of controller team behaviors. ATOM consists of 15 items that measure six dimensions of teamwork, namely, communication, monitoring, feedback, back-up, coordination, and team orientation. The authors felt the need to assess the impact of the new position-Area Coordinator required for pairing on team behavior. The adapted version of ATOM used in this study has a reduced number of questions/items in the overall scale, but collectively, all items map to the same 6 dimensions of teamwork. It is designed to be used by observers who have operational knowledge of participants' tasks. Three observers used the scale to observe the team behavior exhibited by the three controller positions. The scale is a behaviorally anchored 7-point Likert scale that is used by the observers to capture poor-team behavior on one end of the scale (1 on the scale) and good team behavior on the other end of the scale (7 on the scale).

Table 1 shows the average team behavior across all positions. Overall the observers rated the team at mid-point to above mid-point level on team behavior. In the absence of other data on team behavior in similar air traffic management setting, it is difficult to interpret the mid-point range as being average or not. The items 'Providing Guidance', 'Error Correction' and 'Providing & Requesting Backup' were found to be relatively low. The item 'Stating Priorities' was found to be the lowest rated item amongst all the ratings. These items particularly depict the roles and responsibilities that the controllers assumed while performing the pairing task. This could mean that the controller-participants did not regard stating priorities or providing guidance for another controller as their job unless they are in a supervisor position. We found that the Area Coordinator position sometimes took that role, or sometimes, the expert in the group assumed that role. More insight into inter-controller

communication data is provided in the following section.

Table 1: Means and Standard Deviations of Team Behavior Ratings

	Mean	SD
Seeking Sources	4.00	0.89
Passing Information	4.10	0.87
Situation Update	4.20	0.87
Using Proper Phraseology	4.80	0.51
Providing Guidance	3.80	0.97
Stating Priorities	3.10	1.13
Completeness of Reports	4.60	0.64
Brevity	4.40	0.94
Clarity	4.80	0.50
Error Correction	3.70	0.93
Providing & Requesting Backup	3.70	0.87

Inter-Controller Communications

The Adaptive Architectures for Command and Control (A2C2) technique [14] was used to assess semantic and quantitative aspects of inter-controller verbal communications. All inter-controller communication was recorded by the observers stationed at every controller position. These communications were then categorized as ‘Requests’ or ‘Transfers’ using the form shown in Figure 5. The number of transfers and requests assesses the push and pull of information within the team. Push refers to information being proactively offered and pull refers to information requested or actively sought. Within the ‘Request’ and ‘Transfer’ category the items were further categorized for information, action, and coordination. Since the categories ‘action’ and ‘coordination’ were hard to separate in the terminal environment, they were merged as ‘coordination’ only. Thus the current investigation used only four of the communication categories provided by the A2C2, namely, information requests, information transfers, coordination requests, and coordination transfers.

Quantitative communication analysis through the A2C2 technique involves an anticipation ratio. The anticipation ratio measures efficiency of communication for effective team performance [14]. The ratio is the number of communication transfers to number of communication requests. A ratio greater than one indicates that more information is being sent than asked for and information needs are anticipated before requests occur. A higher ratio indicates more information is being provided than has been requested. The ratios help understand the nature of the communication that is being proactively used to achieve the goals of the tasks.

Team Id _____	Run _____	Date _____	Observer _____
Type and Content			
Request	Information		
	Action & task		
	Resource Utilization		
	Coordination		
Transfers	Information		
	Action & task		
	Resource Utilization		
	Coordination		
Acknowledgements			

Figure 5. Example of Matrix used to capture Verbal Communication

Most of the communication instances were directed towards coordination (Table 2), which led to an anticipation ratio for coordination to be 4.14, which is almost double the anticipation ratio for information (2.18). It is difficult to interpret what an anticipation ratio of 4.14 means. However, it’s safe to say that the level of coordination in this study was double that of level of information proactively provided by the controller. The conditions under which the overall number of communication increased involved an aircraft pair going out of conformance or the necessity to vector aircraft out of approach routes and merge it back into the arrival flow. Also, higher levels of coordination were

required to handle inter-pair spacing when the lead and following aircraft were in different sectors.

Chi-square analyses yielded no significant differences between the positions or the scenarios on the various categories of communication.

Table 2. Frequencies and Anticipation Ratios for Inter Controller Communications (Mean values and Standard Deviations)

CATEGORY	MEAN	SD
Number of information transfers	73.00	35.50
Number of information requests	40.50	24.90
<i>Information anticipation ratio</i>	2.18	1.02
Number of coordination transfers	95.00	53.70
Number of coordination requests	26.50	18.40
<i>Coordination Anticipation ratio</i>	4.14	1.17
Total number of transfers	168.00	87.90
Total number of requests	66.80	42.60
<i>Anticipation ratio for all communications</i>	2.90	1.04

Controller Feedback on Communications

The controllers provided feedback on levels of communication and coordination during the debrief sessions. They indicated that coordination was used quite frequently when the lead and following aircraft were in different sectors. Controllers reported that radio communication between controllers and pilots increased when an aircraft pair had to be canceled and vectored. Those situations were often marked as high workload for the controllers. Approach clearances were sent via data link, which had the effect of reducing radio communication. However, the procedures required

one controller to give approach clearances for two aircraft and sometimes, they were in different sectors. In this situation, there was increased verbal coordination with the other sector controller because the aircraft being cleared for approach was not owned by the same controller. Some controllers mentioned that they still preferred to give the approach clearance verbally instead of using datalink, despite the increase in workload. The verbal clearance issuance would provide the controllers the assurance that the pilots are aware of their responsibility for self-spacing from the aircraft in front of them. The controller participants agreed that although the level of overall radio communication was reduced between the controllers and the pilots, some of the verbal communications between the controllers increased.

Complacency Potential Factor in Pairing Automation

A Complacency Potential Rating Scale was used to collect data on automation-induced complacency [15]. Wiener [16] defined complacency as “a psychological state characterized by a low index of suspicion.” Automation is often identified as a significant factor that induces complacency. Procedures, roles and responsibilities are also potential factors that induce complacency. According to Wickens [17], reliability in automation engenders excessive trust and over-reliance in pilots. Singh et. al. [15] identified four factors that may be related to over-trust or complacency in automation. These are confidence, reliance, trust, and safety in automation. Some examples of scale items that measure different constructs are shown in Table 3 below.

The Complacency Potential Rating Scale was adapted and used to collect data for all the three controller positions. The adapted scale for the four dimensions is provided in the Appendix. The scale uses a 5 point Likert scale that ranges from ‘strongly disagree’ to ‘strongly agree’. For some of the questions in the rating scale are reversed to ensure reliability in the responses. The scale was adapted to ask questions about the pairing automation and procedures that the controllers used.

It was found that the controllers reported trust and confidence about the pairing automation (Figure 7). The controllers also rated the pairing procedures and conformance bars as highly safe. However, the controllers did not rate the pairing

automation as highly on the *Reliance* scale. This provides some insight into the way the automation was used by the controllers. In general they believed that pairing automation was better than manually pairing aircraft or monitoring aircraft for conformance. The pairing automation suggested pairs to the controller, which they could manually override at any time. Since they had little experience with the pairing automation, they did not assume that the automation always selected the best aircraft pairs. Rather, they evaluated every pair against the timeline before finalizing the pairs for simultaneous arrivals.

Table 3. Examples for Complacency Potential rating Scale

<i>Confidence</i>	“The conformance monitoring function is reliable”
	“The conformance monitoring automation is safe compared to monitoring aircraft manually.”
<i>Reliance</i>	“How many safeguards does conformance monitoring provide against error? e.g., miscalculations for the leader or follower.”
<i>Trust</i>	“Which method do you think is more likely to be correct- manually monitoring or using automation for conformance monitoring?”
<i>Safety</i>	“Given the choice between using automated conformance monitoring or manual monitoring to monitoring to ensure 15 s between aircraft, which would you use?”

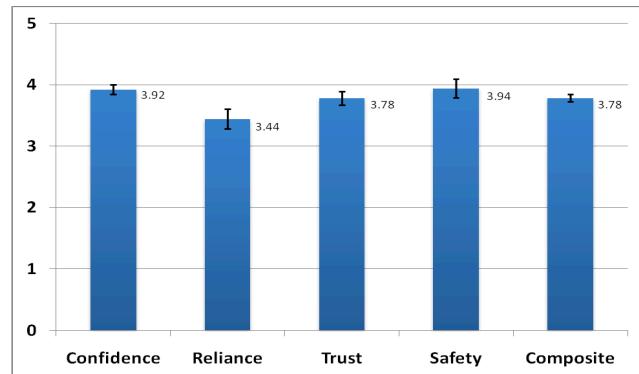


Figure 7. Complacency Potential Rating for the pairing tool and procedures

Controller Interfaces

The controllers were also asked questions on the ease with which they derived information from the displays on certain functionalities (Table 3). They rated the questions on a 5 point scale where 1 represented ‘very difficult’ and 5 represented ‘very easy.’ The questions on responsibility and display confusion used a reversed scale.

Overall the controllers felt that they could easily create a pair. Sometimes they found it difficult to locate the leader, especially when the aircraft was not in their sector. A ‘locate’ button on the pairs table was provided, but it involved multiple steps, where the controller first selected the pair on the pairing table, and then pressed the locate button. The controllers reported that this function had too many steps. The controllers also reported canceling the pair, which involved similar steps as the locate function, also a cumbersome multi-step procedure. Finally, the controllers experienced little confusion over display features or roles and responsibilities amongst themselves or between air and ground.

Table 4. Ease of deriving information on different pairing function procedures (Means and Standard Deviation)

Functionality	Mean rating	SD
Creating a pair	4.70	0.50
Locating leaders	4.00	1.00
Locating trailers	4.30	0.70
Locating pairs	4.60	0.50
Conformance monitoring of your pair	4.20	1.00
Canceling a pair	3.40	1.10
Sending approach clearance	4.20	1.00
Sending handoffs	3.70	1.00
Responsibility confusion (reversed)	1.70	0.50
Display confusion (reversed)	1.90	0.60

Controller Feedback

This section describes the feedback provided by the controllers during debriefs and observations made by the observers. The controllers reported that they were able to utilize all the tools provided, e.g., the pairing table, conformance monitoring, timeline for the pairing task, etc. They did report that they used the tools in different ways at the various positions. For example, the Area Coordinator used the timeline and pairing table extensively, whereas the sector controllers used the conformance monitoring and timeline more often. The pairing table was used to issue clearances by the Niles and Boulder controllers, while the conformance bars provided support for appropriate spacing between the aircraft and meeting the goal of achieving the 15s temporal separation between the two aircraft.

As mentioned earlier, the controllers found the ‘locate’ and the ‘cancel’ features on the display very cumbersome. A different procedure for the locate function was recommended by the controllers. They suggested using a mouse-over or dwell-over on any aircraft that should highlight both aircraft in the

pair. In the experiment the dwell-over was used to bring up the conformance bars on the following aircraft. Their suggestion was to use the same dwell-over to locate the aircraft as well.

The ability to re-sequence or re-establish an aircraft pair after the pair had been canceled and the aircraft had been vectored was also found to be very difficult for the controllers. A contributing factor to this difficulty was that the timelines did not always update the vectoring aircraft accurately to allow the controller to pair the aircraft.

As for sending approach clearances via data link, it had the positive effect of reducing controller-pilot communications. This also increased the inter-controller coordination because the controller sending the clearance did not always have ownership or control over both the aircraft. The controllers also suggested that the controller owning the lead aircraft should send the clearance to both the aircraft in the pair instead of the owner of the following aircraft. This was suggested because as discussed earlier, the controller who owns the lead aircraft indirectly also has control over the speed of the following aircraft.

The controllers reported that they liked the manual override feature because it gave them flexibility and control especially when the automation offered pairs in a sequence they did not prefer. Sometimes, they reversed the sequence of the leader and follower to achieve better inter-pair spacing, for which they were still responsible. This is because making the natural leader, a follower forced the speed control on the natural follower’s flight deck to go behind the chosen leader, creating extra spacing in front of the leader.

The controllers mentioned that having aircraft pairs distributed between the two sectors made the conformance tasks extremely difficult. Often, to achieve inter-pair spacing, they had to request the controller of the lead aircraft to adjust the speed to keep the pair intact. They suggested the ability to make small speed changes on the following aircraft, without canceling the pair, would be a useful feature.

The presence of automation on the flight deck to manage inter-pair spacing may also have created confusion between pilots and controllers over who had the final authority and responsibility over a pair. The controllers assumed that they would be

notified by the flight deck if pilots could not achieve the 15 s temporal spacing behind the lead aircraft. However, the pilots closely monitored their lead aircraft's speeds in order to maintain their own conformance, but also expected that the controllers might cancel their pair at any time.

Summary and Conclusions

A high fidelity human-in-the-loop simulation experiment was conducted to investigate the integrated dynamic role of controllers and pilots for pairing aircraft to closely spaced parallel runways for simultaneous approaches. Since the results of the integrated measures pertaining to both the controller and pilot have been published elsewhere [5], this paper reports the results pertaining to the controller's role in this investigation, focusing on controller team performance, controller communications, potential complacency factors and controller feedback.

Results show that the controllers were able to achieve the desired VFR-level throughput during low-visibility, low-ceiling using the pairing automation. Results also suggest that the controllers experienced manageable workload and a high level of situation awareness.

Results provide evidence as per the observers, the Area Coordinator and two sector controllers performed capably as a team, with most of the 11 team behavior analysis scales being in the mid-point and above mid-point range. Analysis of inter-controller communications indicate that the controllers may be anticipating information needs even before requests occur, and that controllers tend to spend more time communicating among controllers when pairing aircraft from different sectors or under aircraft-breakout conditions. The conformance monitoring tools such as the conformance bars aid the controllers in this proactive form of communication.

Complacency-Potential analyses show that the controllers generally report trust in the automation, although they did not assume that the automation would always select the best aircraft pair, and they would carefully evaluate each pair against the timeline before making a final selection. Results were somewhat mixed on the ease of deriving information from the automation and the displays. The controllers

made specific suggestions to increase the usability of the system (e.g., to improve the 'locate' function by simplifying the procedures).

Overall, results of this investigation show the potential promise of the air traffic control pairing automation tested, pending future research and system enhancements. While controllers were able to use the system quite capably and safely, and liked many features of the automation (e.g., the manual override in selecting aircraft pairs), they did provide suggestions for improvement. Controller feedback suggested that locate, cancel, re-sequence, pair-reassignment were found to be somewhat cumbersome to use, so it seems that careful attention is needed to address these and other issues, prior to the full implementation of the automation.

Finally, there appeared to be some confusion over who had the final authority and responsibility over the aircraft pairs, when separation conformance tasks were shared between the flight-deck and air traffic control. This issue must be fully addressed, prior to the introduction of any new automation system into the real-life milieu of air traffic control operations.

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Appendix

Complacency Potential Factor Rating Scale

(Adapted for Pairing Automation)

Confidence:

1. How reliable do you think the conformance monitoring function is?
2. How reliable do you think the pairing automation/pairs table function is?
3. Do you think the pairing automation/pairs table saved you, the controllers effort and workload?
4. Do you think the conformance monitoring saved you, the controllers, effort and workload?
5. How reliable do you think the automated paired approach procedures are compared to pilots manually flying the paired approach procedures?
6. How reliable do you think the conformance monitoring automation is compared to monitoring aircraft manually?
7. How safe do you think the conformance monitoring automation is compared to monitoring aircraft manually?
8. How safe do you think the automated paired approach procedures are compared to pilots manually flying the paired approach procedures?

Reliance:

9. How many safeguards does conformance monitoring provide against error e.g., miscalculations for the leader or follower?

10. How much easier do you think the automation for pairing/pairs table made the simultaneous approaches?

11. Do you have concerns that the paired approach automation may not work properly?

12. Do you have concerns that the conformance monitoring may not work properly?

Trust:

13. Which do you think is more reliable when you are monitoring paired approaches, automation or your own monitoring?

14. Which method do you think is more likely to be correct- manually monitoring or using automation for conformance monitoring?

15. How much safer do you think automated conformance monitoring has made simultaneous approaches?

Safety:

16. Does using automated conformance monitoring change how safe you feel about paired approaches as compared to doing your own monitoring?

17. Given the choice between using automated conformance monitoring or manual monitoring to monitor to ensure 15 s between aircraft, which would you use?

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