

Key Human-Centered Transition Issues for Future Oceanic Air Traffic Control Systems

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ABSTRACT

Communication, navigation, surveillance, and decision support capabilities in Oceanic air traffic control are evolving significantly. It is important to consider the effect of the changes on the controller's task. In this paper the results from multi-disciplinary studies performed at MIT (Massachusetts Institute of Technology) and the University of Iceland are presented. At MIT, a human-centered systems analysis was used to identify key human factors issues for the future Oceanic air traffic control environment to be experimentally investigated. At the University of Iceland, a prototype for a future air traffic control display was designed and evaluated. Both studies identified three key human factors issues that require consideration. The first is a mismatch between time and space separation restrictions imposed and information support provided, requiring the controller to cognitively resolve temporal/spatial mismatches to meet restrictions. The second issue is the effects of mixed communication and surveillance equipment, which complicates the control task and requires the controller to cognitively integrate asynchronous information. The final is the importance of cultivating controller trust and understanding issues of complacency and automation disuse when implementing highly automated conflict probes that are being considered in the future Oceanic environments.

Keywords

Air traffic control, oceanic, human factors, time, space, temporal, spatial, projection, trust, mixed equipment

INTRODUCTION

Oceanic air traffic is growing; the FAA 2003 forecast predicts an annual growth rate of 4.2% for Oceanic passenger traffic and 6.3% for Oceanic cargo traffic for 2005-2014 [1]. The desire for increased fuel efficiencies encourages a reduction of separation minima and more efficient routing. However, there is also a need to maintain the high level of safety present in the current Oceanic system. These objectives are driving the integration of enhanced communication, navigation, and surveillance (CNS) technologies, causing the Oceanic air traffic control environment to evolve significantly over the next decade.

The new era of Oceanic air transportation will significantly influence the tasks of the controller. Therefore, during this time of transition human-centered issues need to be identified and addressed to guide the design of future Oceanic air transportation systems. This approach would ensure reasonable controller workload while maximizing use of the capabilities afforded by human controllers.

METHODS

As part of a collaborative effort, research programs have been conducted in MIT's Aeronautics and Astronautics Department and the University of Iceland's Computer Science Department. At MIT, issues for future systems have been identified through a top-down, human-centered systems analysis. An initial controller cognitive model was created based on operating procedures and job task analyses [2,3]. The cognitive model, shown in Figure 1, is partly based on work by Endsley and Pawlak [4,5]. Focused field studies at Reykjavik Center in Iceland, New York Center, Oakland Center and Shanwick Center in Scotland were conducted to refine the cognitive model and develop further analysis. During these field studies the cognitive model was used to guide the observations and interviews. The information flow, shown in Figure 2 was developed and used as a basis for the human-centered systems analysis. The next step is to perform a series of experiments to study these issues further.

At the University of Iceland, the research focus was in the context of air traffic control at Reykjavik Center. Standard HCI methods and analyses were applied for the development of a user interface, to be implemented in the near-term. Preliminary abstract Unified Modeling Language (UML) models were created and refined through site visits at Reykjavik Center [6]. Then a bottom-up analysis of the current user interface was developed in order to extract information from the user interfaces and identify discrepancies in use of concept. Next a heuristic evaluation, based on Gerhardt-Powals' Cognitive Engineering Principles, was used to identify errors in the current set of user interfaces [7]. Claims analysis, to discover positive and negative consequences of features or design issues, was then used to evaluate different approaches for a new interface [8]. Based on the results a new interface was prototyped. User testing

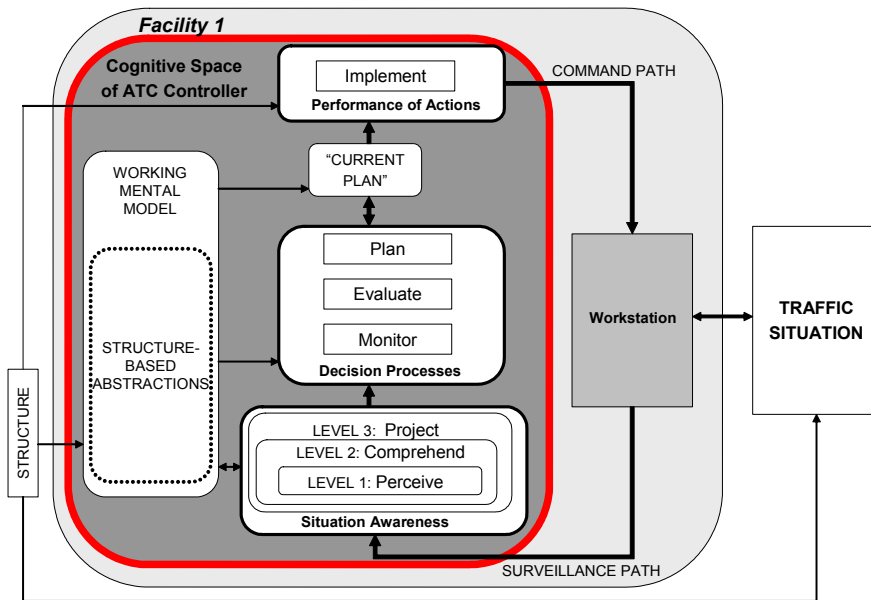


Figure 1: Controller cognitive model used to guide observations.

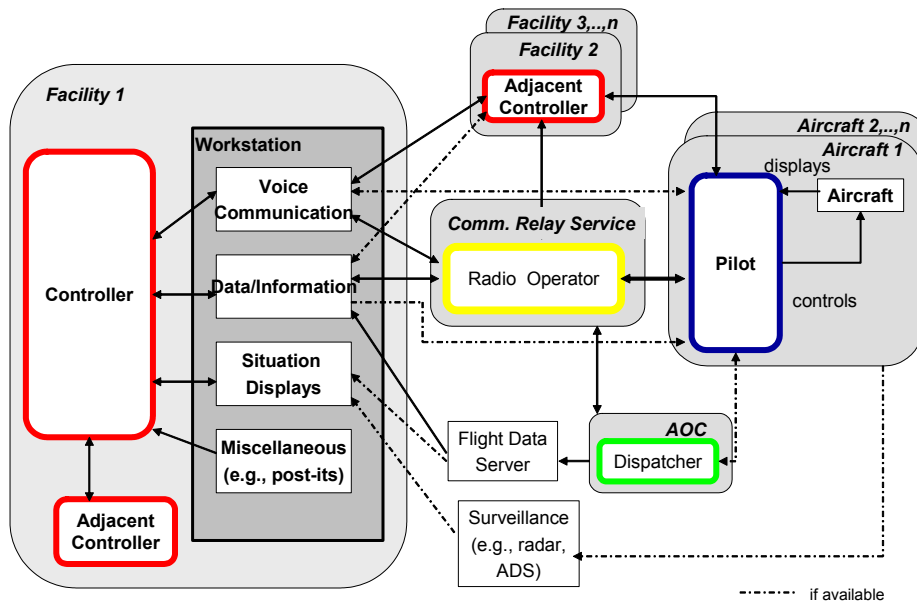


Figure 2: Generalizeable information flow for Oceanic ATC facilities, developed from site visit results.

was conducted on this paper prototype to incorporate feedback from the Reykjavik controllers. During the user testing the prototype was presented to six full performance controllers. The controllers were asked questions about different aspects of the prototype, answers and comments were collected and used for further development of the prototype. For example, the controllers were asked whether conducting flight commanding on a spatial display would increase their performance and what they thought about the colors used in the display. The next section explains the results from both of the studies and the following sections discuss the issues further. Based on the research studies at MIT and the University of Iceland, three common issues for

future Oceanic air traffic control systems have emerged; cognitive projection, mixed and variable equipage, and trust in future technologies.

RESULTS

Current Oceanic Control

Currently the primary means of communication between pilot and controller is High Frequency (HF) radio through a communication relay service, illustrated in the information flow in Figure 2. This communication loop was observed to be approximately three to five minutes, depending on the workload of the controller, radio operator, and pilot. Since

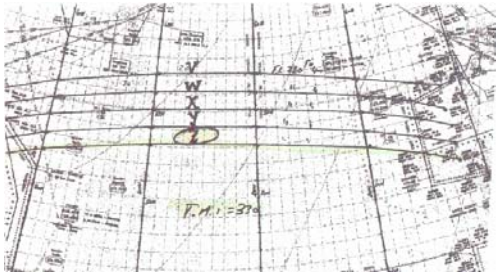


Figure 3: Eastbound North Atlantic tracks for November 25, 2003 provide procedural structure to the airspace to reduce the controller complexity.

most Oceanic traffic is out of radar coverage, surveillance is conducted through position reports, communicated by the pilot to the controller approximately every hour.

Most of the North Atlantic and part of the Pacific traffic follows the Oceanic Track Structure. The tracks are negotiated by the Centers daily based on wind information and forecast traffic. An example of one day's eastbound tracks across the North Atlantic is shown in Figure 3. This airspace structure, which reduces the continuous 4-D traffic problem to a longitudinal time-based sequencing task, is a manifestation of the surveillance limits of the current system.

The current Oceanic workstations at Oakland Center, New York Center (North Atlantic only), and Reykjavik Center consist of flight strips and a spatial situation display, examples are shown in Figures 4 and 5 respectively. The primary difference between the U.S. and Reykjavik Centers is the medium of the flight strips. At Oakland and New York Center paper flight strips are still used. Reykjavik Center transitioned to electronic flight strips in April 2002, which removed the administrative task of manually updating each flight strip as changes are made. Electronic flight strips also enable information from the strips to be displayed on the situation display.

Shanwick Center controllers rely on electronic flight strip information alone.

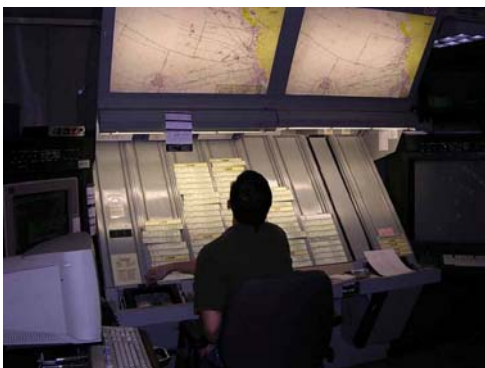


Figure 4: At this U.S. Oceanic workstation (implemented in Oakland and New York Centers), the controller is comparing paper flight strips with the sector map. The spatial situation display (right) is also available for confirming that separation standards are met.



Figure 5: The Reykjavik controller workstation consists of electronic flight strips, in front of the controller and a situation display, to the left of the controller.

organization, which varies between the facilities. Shanwick and Reykjavik Centers' strips are organized by altitude groupings, as shown in Figure 6. Within these groupings strips are arranged by time, with the first flight to leave the sector on the bottom. Horizontally, each strip shows the longitudinal progress through the airspace at the discrete position reporting points. The strips are copied to the affected altitude groupings when a flight makes a vertical maneuver. In contrast, New York Center and Oakland Center group aircraft into columns by longitudinal waypoints and other points where complex interactions take place. In each of these columns there is a copy of the strip for each aircraft that passes through this point according to the approved flightplan as illustrated in Figure 7. Vertically, the strips are arranged first by time and then by altitude.

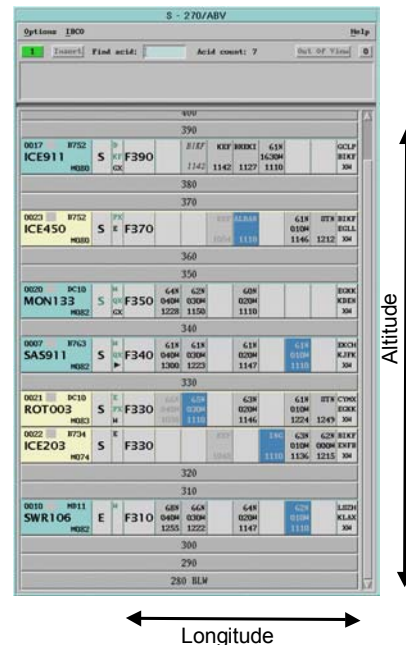


Figure 6: Electronic flight strips used at Reykjavik Center are organized into a position matrix. Vertically they are grouped by altitude and horizontally the longitudinal waypoint information is given.

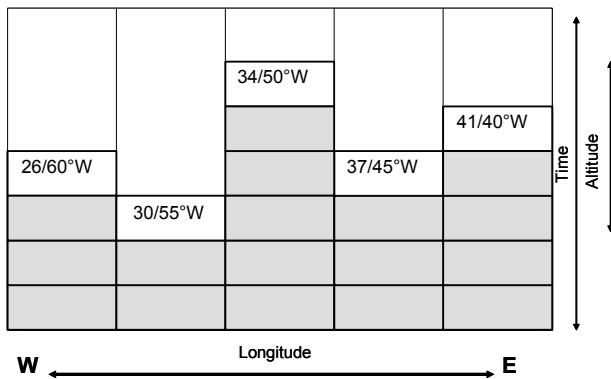


Figure 7: Paper flight strips at New York Center are organized vertically first by time and then by altitude. Horizontally there is a copy of each strip in each longitudinal position it passes through.

In all of the Oceanic facilities visited, the controllers are required, by procedure, to ensure separation using the flight strips. Consequently the controllers' mental model is trained to view the traffic situation as it is portrayed on the strips. The flight strip information and thus the controller mental model has evolved to support the controllers' task of longitudinally sequencing aircraft along the flight tracks. The primary separation requirements used in this task are temporal minute-in-trail requirements, such as 10 minutes longitudinal separation. The flight strips, providing temporal information on the arrival of the flight at a particular longitudinal position, are an appropriate form of support for the temporal sequencing task.

The spatial situation display is a graphical depiction of the continuous projected path of aircraft based on the initial flight plan, updates to the flight plan and models influencing aircraft trajectories, such as the wind model. It serves only as a secondary tool for Oceanic controllers. Since the information on the situation display is not reliably updated, the controllers often do not trust or use the spatial situation display. However, there are situations in which a spatial separation requirement must be met using temporal flight strip information in the current Oceanic environment, such as the lateral separation between the tracks and crossing traffic. In this situation at New York and Oakland Centers, the controllers manually transcribe the flight strip information onto an erasable map to determine if the spatial requirement can be met.

This is frequently seen in Oakland airspace because RNP-10 (Required Navigation Performance) has been implemented for most Pacific routes. The RNP index is a measure of aircraft navigational performance. RNP-X requires that all aircraft in the designated airspace maintain a navigational cross-track performance accuracy of X nautical miles (nm), 95 percent of the time. Lateral separation for RNP-10 aircraft in the Pacific has been reduced from 100 nm to 50 nm. Usually the track structure provides lateral separation, however in this airspace the tracks are separated by 50 nm, which is appropriate only for RNP-10 equipped aircraft. Therefore if an aircraft that is not RNP-10 certified crosses through this airspace the controller must manually ensure 100 nm lateral separation

between the unequipped aircraft and the tracks using the erasable map. The controllers reported that this increases their workload and decreases the number of pilot requests they are able to address.

In addition to improved navigation performance, improved surveillance (e.g., Automatic Dependent Surveillance (ADS)) and communication are being introduced. The frequency of future surveillance updates and communication paths will significantly increase, as shown in Figure 8. These improvements provide the opportunity for Oceanic ATC initiatives such as reduced separation. As a near-term step the programs for Reduced Vertical Separation Minima¹ (RVSM) have been implemented in the North Atlantic and the Pacific and Reduced Horizontal Separation Minima (RHSM) for RNP-10 certified aircraft is active in the Pacific, as mentioned above. In the far-term the FAA plans to move towards "Oceanic Free Flight". This concept is still being defined, but it generally entails a certain level of free routing by aircraft across the oceans and a degree of self-separation by aircraft [9].

In order to achieve the operational benefits of these initiatives aircraft must meet CNS equipage requirements. However, the high cost to meet aircraft equipment requirements introduces a barrier to entry and not all aircraft will initially choose to levels of equipage performance introduces new operational factors. The controller must now be aware of the aircraft equipage and determine which procedures to apply based on this new attribute.

One approach, which is currently used to simplify the mixed equipage airspace for the controller, is to segregate airspace for equipped and unequipped aircraft. For example since most aircraft that fly over the ocean are RVSM certified, flight levels 290-410, which includes the most preferred airspace, are reserved for RVSM equipped aircraft. Aircraft that are not equipped for RVSM are restricted to the airspace below or

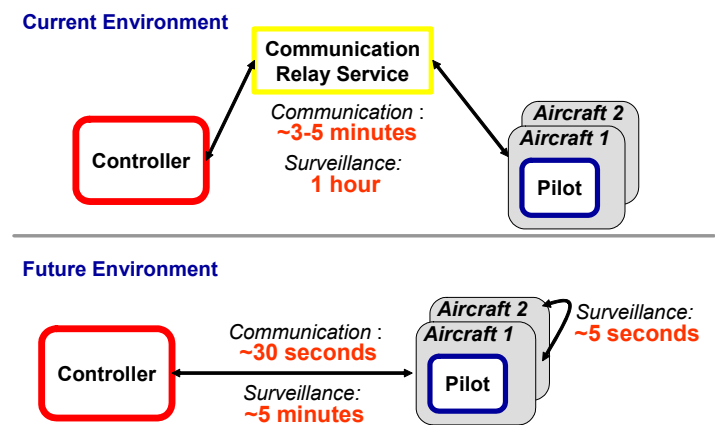


Figure 8: Controller and pilot surveillance and communication paths in the current and future environment. Surveillance and communication frequency will drastically increase in the future environment.

¹ For RVSM, vertical separation is reduced from 2000 ft. to 1000 ft.

above these flight levels. Currently aircraft equipage information is displayed on the flight strip in the United States and Iceland as a letter designator. In an environment with more complex variations in aircraft equipage this current method will not allow the controller to handle the interactions of aircraft with different levels of equipage.

The increase in complexity due to the mixed equipage environment is expected to lead to controllers to simplify the control task by applying the procedures appropriate to the lowest level of equipage to all aircraft, i.e. the lowest common denominator. Therefore, the advantage of these initiatives would not be achieved unless the ATC systems adapt to the future environment. For example, Reykjavik Center mixed radar and Oceanic workstations are not equipped to integrate radar and pilot position report information. One spatial display shows the aircraft in radar coverage only and another shows the extrapolation of all the aircraft paths within the sector based on the flight strip information. The controller must cognitively integrate the information from the two spatial displays, as well as the flight strips.

Reykjavik Prototype

The design of a future Reykjavik workstation is being investigated by the University of Iceland. The prototype design, illustrated in Figure 9, is a spatial display without flight strips. The controllers were presented with three approaches for a user interface, before they were shown the new prototype. The three approaches were: 1) flight strips only, 2) a spatial situation display only, and 3) a display with synchronization between the flight strips and the spatial situation display. They were asked to choose which approach they preferred. The majority (four out of six) of the controllers chose the spatial situation display only. The controllers preferred having all the information they need on an intuitive display. However, they expressed concerns about losing key elements that the strips provide. Specifically, they reported that the time sequence information and the altitude groupings of the flight strips are important to performing their control tasks. This is an apparent indication of the impact that the flight strip structure has on the controller mental model.

Another attribute of the prototype is the integration of different surveillance sources. In the prototype, the surveillance sources are all integrated into one display and distinguished by using different aircraft icons, as shown in Figure 10. During user testing of this prototype the controllers reported that they did not feel that they would be able to distinguish between the symbols for the different surveillance sources (small diamonds and circles). This is being addressed in the second phase of prototyping.

The user testing of the University of Iceland's prototype in Reykjavik also raised trust issues. The controllers were asked to rank their trust in the prototype on a scale of 1 to 5 with 1 meaning "Yes, very much so" and 5 meaning "Not at all". The response was 2.75 on average. It is hypothesized that controllers do not have trust in the current workstation because of data input quality and inadequate failure modes, which impacted their trust in this prototype.

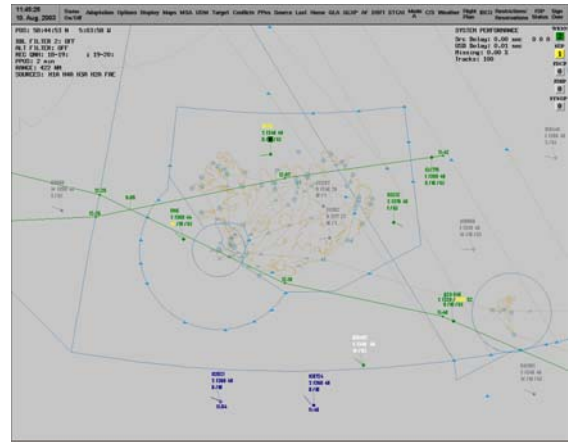


Figure 9: The University of Iceland prototype is a spatial display. The current research studies are addressing whether the controller mental model can adapt to a spatial model.



Figure 10: Aircraft icons from the University of Iceland prototype show secondary radar data (right) and secondary data reinforced with primary radar data (left).

US Prototype

The Advanced Technologies and Oceanic Procedures (ATOP), shown in Figure 11, is the future U.S. workstation. Implementation is planned at New York Center, Oakland Center, and Anchorage Center in 2004. It consists of electronic flight strips and a situation display. In this workstation, the spatial display will be used as the primary means of separation. All available radar information, ADS-A, and position report information will be integrated and displayed on the situation display. The new system will also provide the controller with more decision support tools for identifying and resolving conflicts. Since this is the first transition into a significantly different Oceanic environment in



Figure 11: Advanced Technologies and Oceanic Procedures (ATOP) is the future Oceanic workstation for the United States. Implementation at Oakland, Anchorage, and New York Center will begin in year 2004.

the U.S., it is a critical time for evaluating each of the three issues identified.

DISCUSSION

Space and Time Projection

Across the four facilities observed, there is a plan to move towards the use of spatial situation displays as the primary means of safe separation. As the Oceanic facilities proceed towards this spatial representation of the surveillance information, it is possible that controllers will be required to alter the method in which they are projecting the traffic situation.

In most of the observed Oceanic environments, a mixed spatial/temporal surveillance exists. Since most of the separation restrictions are based on time, a cognitive transformation is required between the spatial surveillance information and the projection required to determine predicted separation. The transform may change the spatial surveillance information received into temporal information, resolving the projection into comparable terms with the temporal restriction. Another option would be to change the temporal restriction to a spatial restriction, and then compare the spatial projection with the spatial restriction.

Consistent with this notion, it was observed that when spatial restrictions were provided, controllers transferred temporal information from flight strips onto a spatial map to determine if constraints were met. This observation is consistent with the concept that the temporal surveillance information was transformed into spatial format to be projected and compared against spatial separation restrictions.

When deciding whether to replace the flight strips with another means of primary surveillance, it is important to consider the effect of the changing surveillance on the cognitive method of aircraft separation and sequencing used by the controllers as well as the value that the flight strips add.

Further studies into how controller's cognitive projections can be supported in future ATC systems in Oceanic and domestic environments are ongoing at MIT. The University of Iceland also plans to incorporate the key flight strip elements into the spatial situation display of their prototype.

Mixed and Variable Equipage

As improved CNS equipment capabilities are introduced into the Oceanic environment the problem of mixed and variable equipage will become more significant and must be considered for future systems and procedures. In particular, airspace segregation strategies and controller display support should be considered.

There are four degrees of freedom about which airspace can be segregated: vertical, lateral, longitudinal, and time. Currently airspace is segregated for RVSM aircraft along the vertical axis, allowing only equipped aircraft between flight levels 290 and 410. Lateral segregation could come in the form of designating tracks or airways to aircraft with certain performance levels. Airspace can also be segregated by This is particularly important because it is difficult to decrease the traffic load. The inefficiency of the shut-down procedures

designating lateral and longitudinal maneuvering zones, in which a higher level of performance would be required. An analogy to this type of segregation was observed at Reykjavik Center. Some Oceanic traffic crosses through areas covered by Iceland and Greenland radar. The separation minima within the radar coverage is reduced from 60 nm to 5 nm. It was observed that the controllers manage most of the crossing and climbing traffic during the radar coverage because of the increased flexibility.

Controller display support can also alleviate some of the issues associated with mixed equipage. At a minimum the display of aircraft equipage information needs to be improved upon because the current letter designator on the flight strips is not sufficient for the expected range of future equipment levels. Also, current equipage information does not provide for the display of non-nominal situations such as satellite outages or equipment failures. Therefore a transparent, dynamic equipage indicator that is standardized across the facilities is needed.

Trust

The trend for the future Oceanic ATC environment is to incorporate more automation aids for the controller to mitigate the effects of increasing operational complexity. When providing experts with decision support it is critical to ensure that the new systems are reliable and should therefore be trusted. Once that is complete a balance between misuse, defined by Parasuraman as "overreliance on automation" and disuse, defined as "underutilization of automation" must be attained for successful transition [10]. This can only be accomplished through appropriate controller trust in the automation aid.

During the field studies, certain aspects of the systems were observed to be unreliable, due primarily to data input quality and failure modes. The accuracy of the spatial situation display at New York and Oakland Centers is based on the quality of the input data. Data is integrated from cockpit datalink messages, the communication relay service electronic messages and manual controller input of verbal communications. Several mistypes received from the electronic messages were observed during the field studies and the controllers reported that these types of errors occur frequently. When controller workload is high they do not have time to resolve these discrepancies or type in updated information received through verbal communication. Therefore, the conflict alerts that appear on the situation display do not usually represent real conflicts and are often disregarded by the controllers. This inappropriate detection of conflicts by the automation is one of the four general constructs critical to developing trust identified by Dzindolet [11].

Procedures for system failures also affect controller trust. At Reykjavik Center the procedures call for the use of paper flight strips in the case of a shut-down. However, the paper flight strip system does not allow the air traffic controllers to accept the increased throughput enabled by the automation. restricted Reykjavik Center from increasing the number of aircraft each controller could handle at one time.

Another trust factor is the controllers highly trained mental model, which directly matches the current means of control. If future systems do not match this mental model the controllers will interpret the discrepancies either as the inadequacy of the automation logic or they will lose confidence in their ability to perform. This issue of self confidence was identified in the Dzindolet's experiment as a critical element to developing appropriate trust in decision support [11]. If the controllers lose confidence in self, they will rely on the automation completely, which would be a misuse. If the controllers question the performance of the automation aid, they will not use the new system at all, which would be a waste of resources and the alerts would become a nuisance to the controllers. Solutions for addressing the trust issue are difficult and highly dependent on the context.

CONCLUSIONS

As the Oceanic ATC environment enters into a new era of control with the introduction of technologies such as satellites and conflict probes, key human-centered systems issues need to be addressed during the transition period. In this paper three key issues have been identified and explored through independent studies at MIT and the University of Iceland. These fundamental issues are critical to successful transition. The mismatch between the controller mental model and the information given to him/her will lead to poor performance and controller dissatisfaction if not addressed. At the very least, it is imperative that support for the temporal sequencing task is provided as well as support for the spatial separation task. If the mixed equipage environment is not adequately addressed, controller workload will increase and equipped aircraft will not receive the full benefits of equipping. This will produce a stalemate in the evolution of the system. Controller trust is vital to the acceptance and proper use of the automation aids scheduled for implementation.

ACKNOWLEDGEMENTS

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