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Collocation of User Request Evaluation Tool, Traffic Management Advisor, and Controller Pilot Data Link Communications: An Initial Human Factors Evaluation

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16. Abstract

This study was a human factors evaluation of collocating User Request Evaluation Tool (URET), Core Capability Limited Deployment, Traffic Management Advisor, and Controller Pilot Data Link Communications (CPDLC), formerly Build 1A. Human Factors Specialists conducted the evaluation in two phases: a “paper and pencil” study - Phase 1 and a modified cognitive walkthrough - Phase 2. They examined the tools from existing documentation and system design in the context of human factors best practices. Four primary human factors issues emerged from this analysis: 1) Computer-Human Interface (CHI) inconsistencies; 2) Radar Associate (RA)-side collocation and timely access to information; 3) Communication of information between the RA-side and Radar-side controllers; and 4) National Airspace System updates from the different tools. Results include recommendations for human factors engineering for integrating the URET, CPDLC, and Computer Readout Display information on the RA-side, as well as working toward improving CHI consistencies.

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As a final note, Parimal Kopardekar, Ph.D., served as the Titan Systems Project Manager on this project and subsequently moved to the FAA office (formerly ACB-100). For purposes of this report, he is noted as the Titan Systems Human Factors Manager.

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Executive Summary

This study was a human factors evaluation of collocating User Request Evaluation Tool (URET), Core Capability Limited Deployment (CCLD), Traffic Management Advisor (TMA), and Controller Pilot Data Link Communications (CPDLC), Build 1A. Human Factors Specialists and Subject Matter Experts (SMEs) from the National Airspace System (NAS) Human Factors Group (ATO-P), and Titan Systems Corporation conducted the study. The Free Flight Program Office Integration Division (AOZ-40) sponsored the project, and the Human Factors Division (AAR-100) provided funding.

We planned two phases for the human factors evaluation. In Phase 1, we examined the tools using existing documentation on system design. First, we determined what tasks would be supported by each system and assessed the potential for concurrent use of the tools. Second, we examined the information required to perform the major controller tasks, identifying the sources of the information on each system. Third, we applied guidelines to identify any human factors issues. We planned Phase 2 to investigate how controllers would use these systems together. We used a modified cognitive walkthrough in which we asked controllers familiar with one of the three systems to systematically think through frequent Air Traffic Control (ATC) events using all three tools.

We systematically examined the data from Phase 1 and 2 human factors evaluations within six categories of issues important to the ATC environment: Concept of Use, Computer-Human Interface (CHI), Information Flow, Integration/Collocation, Coordination, and Procedural Considerations.

We found four primary human factors issues during the analyses:

- The data blocks on URET and CPDLC presented different information in lines 0 and 4 and provided different methods of interaction. These CHI inconsistencies could lead to controller error.
- Because URET and CPDLC will both be located on the Radar Associate (RA)-side controller's monitor, there may be issues related to clutter. That is, it may be a challenge to provide timely information to the controller within the limited display space available.
- Some pieces of information, such as the conflict alerts on URET, are available only to one controller position. This will require increased coordination and communications, which in turn, will necessitate having good procedures in place that delegate roles and responsibilities to the Radar- and RA-side controllers.
- The three tools may update the NAS database simultaneously and with conflicting information. This will require further examination to ensure that all updates are consistent and that all three tools are using the most current information.

The researchers concluded that additional human factors engineering is required in the following areas:

- **RA-side display:** The findings from an assessment of which tasks the tools would support suggested that controllers would use URET and CPDLC together most frequently. Therefore, these two tools would probably benefit most from human factors engineering. Kerns (2001) anticipated this problem in her paper on collocation. As designers add windows for CPDLC, the chance of obscuring important information on URET, or visa versa, increases. Better engineering of this single aspect could possibly have the most important positive impact for controllers. The SMEs recommended integrating CPDLC and URET functionality into one display. We recommend integrating CPDLC information into the URET aircraft list. We would also support an effort to integrate these two systems.

- **Controller communication:** The current procedures for Air Traffic Management do not provide any guidance as to how controllers should operate in the presence of these new tools. Because the tools may provide conflicting information and may simultaneously update the NAS, we suggest developing new procedures to avoid potential problems related to this issue.

- **Tools and concept of use:** Desenti, Gross, and Toma (2000) identified an emergent operational concept, which is the use of URET to trial-plan metering times. Our SMEs also identified this and raised additional questions about whether the URET algorithms could make the correct calculations to handle aircraft that controllers are holding or vectoring. These issues will need to be examined in simulations using functional versions of the tools.

This study presented the first systematic human factors evaluation that explored the human factors issues related to collocating all three systems in one sector. We applied standard human factors guidelines as well as principles and methods from cognitive psychology to our analysis. We verified and extended the findings of the three prior studies, which examined collocating two of the three systems. By use of the cognitive walkthrough methodology, we identified more subtle issues related to the simultaneous use of the three tools.

A primary limitation of this study, however, was that it did not examine any functional systems. Therefore, SMEs more familiar with the specific systems and human-in-the-loop simulations should validate these findings. Through these steps, the Federal Aviation Administration can address the potential issues from this report in the course of the Free Flight Program's spiral development plans.

This study served as the foundation for a series of human-in-the-loop simulations which provided some of the answers to the questions generated here, see Sollenberger, Della Rocco, Koros and Truitt (2004, in press) for the data and conclusions.

1. INTRODUCTION

In this pilot study, researchers examined the human factors issues of collocating three en route Air Traffic Control (ATC) automation systems: 1) User Request Evaluation Tool (URET), Core Capability Limited Deployment (CCLD); 2) Traffic Management Advisor (TMA); and 3) Controller Pilot Data Link Communications (CPDLC) Build 1A[1]. To identify the collocation issues, a research team comprised of Human Factors Specialists (HFSs) and Subject Matter Experts (SMEs) from the Federal Aviation Administration (FAA) National Airspace System (NAS) Human Factors Group (ATO-P), and Titan Systems Corporation conducted the evaluation. We applied human factors guidelines as well as principles and methods from research in cognitive psychology. For this report, we only examined issues that involved the use of two or more systems. The Free Flight Program Office (AOZ-40) sponsored the project; the Human Factors Division (AAR-100) provided the funding.

We planned to complete this human factors evaluation in two phases. Phase 1 was an engineering analysis in which we examined system collocation issues using basic human factors guidelines. Phase 2 was a cognitive walkthrough in which Air Traffic Control Specialists (ATCSs) familiar with one of the three systems conducted a “mental simulation” of using the systems together. Due to reprogramming in the Data Link Program, sponsors asked us to postpone the formal cognitive walkthrough data collection. We were able, however, to test the methodology with local SME participants familiar with the systems.

In both phases of this project, we assessed collocation issues from the perspective of a sector staffed with 1) both a radar (R)-side controller and a radar associate (RA)-side controller and 2) an R-side controller only. In addition, we explored whether collocation issues might differ when controllers used the three tools in a high altitude, en route sector versus a lower altitude, transition or approach sector. We included these two factors, sector staffing and sector type, because tool usage may be different in these unique contexts.

We summarized the findings from both phases of the study using six categories important to ATC: Concept of Use; Computer-Human Interface (CHI); Information Flow; Integration/Collocation; Coordination; and Procedural considerations. The concepts of use for the systems were already defined, but it was possible that new concepts of use could emerge from collocating the tools. Therefore, we addressed this as a specific issue. The CHI considerations identified in this report were a focus of the project, whereas the other five categories are important within the ATC context. This study, however, could only explore issues related to information flow, integration procedures, and coordination. Likewise, the present methods could not address the important psychological issues of workload and situational awareness (SA).

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[1] At the time of this study, CPDLC Build 1A was planned with the nine services described in this report. Subsequently, the Build 1A program was cancelled in April 2003. No information was available about the CPDLC Build 1A functions on the RA-side, so we made certain assumptions about the interface based upon Build 1 displays and R-side Build 1A designs.

The goals of the Free Flight Office are to achieve early benefits for aviation by deploying low-risk technology while maintaining or exceeding current levels of safety through evolutionary development of systems. Our goal was to assist the deployment of these three systems by a systematic examination of potential human factors issues that could be addressed early.

1.1 Background

The FAA is deploying new automation systems for use by ATCSs under the Free Flight Program Phases 1 and 2 (FFP1 and FFP2). Most of the systems (including URET, TMA, and CPDLC) were developed independently. Deploying these as standalone systems meets the Free Flight Program's goal of achieving early benefits for aviation with low-risk technologies. However, concurrent deployment of the systems may result in both benefits and human factors issues for ATCSs. The collocation of URET, TMA, and CPDLC at a single sector presents more information in different forms than is currently available to controllers. Issues of changing controller workload and decreasing SA are prime concerns. The en route controller's job relies on accurate, timely, and easily understood and accessed information. Collocating systems with inconsistent information or functionality in which a controller must spend time searching for critical data may negatively affect workload and SA. If we identify and understand collocation issues by applying human factors principles, we can minimize any potential consequences and maximize any potential benefits. A wealth of knowledge exists in the cognitive psychology and human factors literature that can guide such efforts. The following sections summarize relevant human factors and cognitive research.

1.1.1 Human Factors Guidelines and Cognitive Principles

There are guidelines that specify general human factors principles specific to ATC systems. The research team used two primary sets of guidelines in this study: the revised Chapter 8 of the Human Factors Design Guide (Ahlstrom & Longo, 2001) and Human Factors in the Design and Evaluation of Air Traffic Control Systems (Cardosi & Murphy, 1995). These guidelines provide general principles on how to create information displays for ATC. These include principles such as how information should be organized, which colors should be used to indicate critical information, and whether colors, symbols, or both should be used as indicators in a display. The authors developed these principles based upon what we know about human perception and cognition. When creating any new system for use in ATC, it is imperative that designers consider these factors because of the potential consequences of errors made by controllers. Research should apply these principles when evaluating how collocating URET, TMA, and CPDLC will affect ATCS performance. Applying these principles allows researchers to identify any inconsistencies in information display or other CHI issues, which, in turn, will allow the tool developers or the FAA to integrate improvements into the spiral development process. Cardosi and Hannon (1999) present a number of these guidelines (see Table 1).

Table 1. General Guidelines for ATC Displays

1. Displays must be designed for the tasks they need to support and the environment in which they will be used.
2. Whenever color is used to code critical information, it must be used along with another method of coding.
3. When color is used for the purposes of assigning a specific meaning to specific colors (i.e., red for emergencies and green for aircraft under my control), it is imperative that no more than six colors be used.
4. Care must be taken to ensure adequate contrast of all color-coded text and symbols.
5. Cultural conventions (i.e., red for danger and yellow for warning) should not be violated.
6. Pure blue should not be used for text, small symbols, other fine detail, or as a background color.
7. Bright, highly saturated colors should be used sparingly.
8. Use of color needs to be consistent across all of the displays that a single controller will use.
9. The specific colors that are chosen for a display must take into account the ambient environment and the capabilities of the specific monitor.
10. The entire set of displays that a controller will use must be designed and evaluated as a whole and not as a combination of parts. Any implementation of color needs to be tested in the context of the tasks it is designed to support and the environment in which it is intended to be used.

Cardosi and Hannon, 1999

1.1.2 Other Psychological Issues in Integrating Systems

Because the controller’s job relies so heavily on cognitive processes, we also explored the cognitive psychology literature for issues related to collocating three systems. The current plan for collocating the three separate systems requires the controllers to integrate information that each of the three tools present independently. If controllers are required to integrate this information, then potential errors could occur because of the limitations of human cognition.

Humans are, in fact, information processors. As we go about the world and encounter visual stimuli, we absorb these stimuli and process them, giving them meaning. However, our capacity to process information is limited in a number of ways, and the tools we use must be designed with this in mind. For example, humans have limited attentional resources (Kahneman, 1973; Sanders & McCormick, 1993; Wickens, 1984). We can only attend to so many things in our environment at once. As we divide our attention among an increasing number of stimuli, the amount of attention that can be allocated to a given stimulus is decreased. As a result of adding more systems to workstations, there are additional cognitive loads placed on the controller. This load may exceed the controllers' attentional capacity and lead to a loss of SA, known in ATC as "losing the picture."

It is also likely that as more systems are added to a display, search time will increase. This can be inferred from research, which demonstrates that the search time to find a target increases as the number of non-targets on a display increases (Neisser, 1963; Sobel & Cave, 1999). Therefore, we need to examine the effect of this increased information on response time and explore ways to reduce clutter, where possible. Another attentional issue is feature congruence and feature redundancy. Feature congruence is a human factors principle that similar types of information be represented by the same features (Cardosi & Murphy, 1995). This can reduce the search time for certain information. However, it is also true, according to studies done on feature redundancy, that if too many items on a display share the same feature, search time can increase (Sobel & Cave). Therefore, we need to assess the impact of

- the redundant use of features (i.e., color), and
- the increased number of items on the display (due to the collocation of the tools) on the search time and the reaction time of controllers.

In this research, we also address how increased information associated with each tool as well as the additional intra-sector communication might affect performance. With the collocation of URET, TMA, and CPDLC, a wealth of new information and capabilities will be available for the controller (e.g., trial planning, conflict detection, arrival metering, and pilot downlink requests). In addition, for example, with the inclusion of URET and CPDLC on the RA-side controller, the R-side and RA-side controller will be engaging in increased communication. Verbal and non-verbal communication will increase between both controllers and, possibly, between controllers and pilots. This increase in communication may have a significant impact on SA and prospective memory (Cardosi & Murphy, 1995). Prospective memory is defined as memory for actions that the controller has identified that need to be performed in the future. It is one of the keys to SA, which involves building a mental model about an event and projecting that event into the future (Endsley, 1988, 1995). However, for controllers, it is not sufficient for them to project an event. They must remember to act upon that event in the future. Endsley and Rodgers (1997) hypothesized that many operational errors that occurred in a study on SA were due to controllers being unaware of whether an aircraft had received clearances. This was clearly a result of forgetting to track this clearance after controllers had given it. Although there is evidence that automation actually enhances prospective memory and planning (Vortac, Edwards, Fuller, & Manning, 1994), other recent work (Harris, Cummings, & Menzies, 2000) indicates that when people need to divide their attention among different tasks, prospective memory decreases. Because these tools will increase task automation and provide external memory cues at the same time that it increases communication between controllers and pilots, it is unclear whether the addition of URET, TMA, and CPDLC will lead to any enhancement or decrement in prospective memory performance.

The visual system itself imposes processing limits. For instance, we fixate on what we process most accurately (Cardosi & Murphy, 1995; Rayner, 1998; Rayner & Pollatsek, 1989; Wickens, 1992). The information on which we fixate corresponds to what lies in the foveal region of the visual field. This implies that controllers will most effectively be processing the information that lies at the center of the visual field. If critical information is displayed at too great an angle from the focal point, people will not process it as well as information placed centrally. This is not to say that we cannot attend to items in the non-foveal region of the visual field. However, as designers add new tools to the periphery of a display, we need to be cognizant of this processing limitation. They may need to provide enhanced visual cues to prompt controllers to move their eyes to the relevant portion of the display, for example.

Studies have shown that non-foveal, pre-attentive cueing can reduce the amount of time it takes to make a saccade (eye movement) to a target (Posner, Nissen, & Ogden, 1978). Cardosi and Hannon (1999) point out that a blinking target is a much better "attention grabber" than color. Cardosi and Murphy (1995), however, correctly point out that visual cueing may not be sufficient to capture attention. When it is critical to capture attention, designers might provide auditory cues along with the visual cues. Cardosi and Murphy note that controllers develop strategies to distribute attention among systems as they are required to divide attention among tasks. Therefore, along with whatever cueing system they use, it is important that there also be some indication of criticality to assist controllers in allocating attention to the most important items on the display.

As designers add more tools to the controllers' displays, it is also important to examine whether the methods used to interact with tools are consistent. This will avoid "negative transfer" (Cardosi & Murphy, 1995; Wickens, 1992). Negative transfer has been shown to occur in cases where the interaction methods differ across tools. For instance, if your parking brake lies between the driver seat and the passenger seat, you will automatically reach for the parking brake there. However, if you sometimes drive another car, and this car has a parking brake that is set with your foot, you may initially try to reach for the parking brake between the seats. Your habit for putting on the parking brake has transferred from one car to the next. The brake is now in a new position, therefore, the transferred skill is no longer a benefit (or positive) but, instead, becomes a hindrance (or negative), thus the term "negative transfer." In addition, you will have to continue to remember both parking brake locations and be able to determine which car has which location each time you drive one of them.

This is not to say that additional tools cannot be added to the Display System Replacement (DSR) or to the RA-side controller. In fact, it is understood in cognitive psychology that as tasks become more automatized through practice, the number of cognitive resources needed to perform that task decreases dramatically (LaBerge & Samuels, 1974; Posner & Snyder, 1975; Wickens, 1992). Thus, controllers might initially take longer to use the new tools together, however, it will become easier the more they work with them. Another cognitive tool that might assist controllers to reduce the amount of attention needed to process visual input is "chunking." Research on chunking has shown that to process information more efficiently, people will impose a hierarchical structure on it (Cardosi & Murphy, 1995; Chase & Ericsson, 1982; Chase & Simon, 1973). As we add more tools to the controller's display, they will most likely use chunking to accommodate the increased amount of information they encounter.

These principles imply that controllers should be pre-trained on the tools to the point where their interaction with the tool becomes semi-automatized (Ericsson, Krampe, & Tesch-Romer, 1993). This training is critical to allow controllers to have a chance to construct an appropriate cognitive map or mental model of the tool (Carroll & Olson, 1988; Harwood, Mogford, Murphy, & Roske-Hofstrand, 1991; Mogford, 1990) prior to using it in the field.

Although pre-training is important, it should not take very long to complete. Research indicates that controllers have a specialized expertise. This expertise should produce superior abilities to remember problems that fall into their domain of expertise (De Groot, 1965, 1966; Means, Mumaw, Roth, Schlager, McWilliams, & Gagne, 1988). This should reduce the time it takes to transfer their skills to the new tools, which will reduce, in turn, cognitive workload. One way to maximize any potential benefit derived from expertise is to be sure that information in URET, TMA, and CPDLC is organized to conform to the pre-existing representation used by controllers (Chi, Feltovich, & Glaser, 1981; De Keyser, 1986).

1.1.3 System Capabilities

Several reports describe the three systems in detail and will not be repeated here. However, this project addressed specific versions of each system, and we discuss a few relevant points. A potential confounding factor in this assessment was that a new DSR CHI was scheduled to be deployed concurrently with the CPDLC Build 1A. The FAA and the National Air Traffic Controllers Association (NATCA) signed the CHI Upgrades to the “DSR” Memorandum of Understanding, dated June 16, 1998, creating the Air Traffic DSR Evolution Team (ATDET). This team is responsible for providing NATCA and FAA agreement upon CHI upgrades to the DSR system. As a result of their work, a new CPDLC/DSR R-side interface was developed and scheduled for deployment concurrently with Build 1A of CPDLC (Mike Tarka, Lockheed Martin personal communication, June 2001). The interface included, among other features, flyout menus off the data blocks as well as the added interactive functionality of altitude, heading, and speed from the menu text window. This is a substantial change in the DSR environment. We used this CHI for our assessments. The CPDLC RA-side interface had not yet been designed.

URET CCLD uses track data, flight plan data, adapted preferred routes, terminal configurations, weather data, and aircraft characteristics to model each aircraft’s trajectories (FAA, 1999). These trajectories project conflicts between aircraft as well as between aircraft and airspace. It is in these computations that some potential human factors issues arise (e.g., aircraft performance characteristic models among the tools). Because several of the tools update the NAS independently, resulting computations may be incorrect.

1.1.4 Previous Collocation Assessments

Three reports have addressed the collocation of at least two of the systems. In April 2001, Dr. Karol Kerns, MITRE Center for Advanced Aviation System Development (CAASD), examined potential operational and human factors issues associated with collocating CPDLC and

URET in the FFP2 timeframe (Kerns, 2001). Her report concluded that the RA-side controller's tasking would increase substantially with the addition of the two tools and that the success of using the tools as they were intended was critically dependent on the design of the RA-side CHI and the sector procedures. As with our project, the RA-side CHI for Build 1A was not available.

URET will show the Aircraft List. The RA-side display will also need to accommodate CPDLC information and the RA-side Computer Readout Display (CRD). Kerns stressed that the CPDLC information (e.g., aircraft eligibility and connection status, uplink and downlink message status, and history) must be available to the RA-side controller. In accommodating these requirements, the RA-side display clutter becomes a potentially important issue. She also examined the roles and responsibilities of the R- and RA-side controllers and discussed possible changes in their duties. In terms of existing duties, she noted that URET's Aircraft List information would replace the paper flight progress strips. Thus, both the R- and RA-side controllers would have decreased responsibility for strip marking and management. She identified a few new responsibilities associated with the addition of the new tools, however. These involved monitoring the new systems, using the tools (URET by the RA-side controller and CPDLC by the R-side controller and the RA-side controller as assistance to the R-side controller), communicating with each other, and, finally, ensuring that they had completed the CPDLC clearances. She recommended additional work to optimize the RA-side CHI and the procedures at the sector.

Two studies addressed the collocation of URET and TMA. Desenti, Gross, and Toma (2000) conducted an analysis of Atlanta Air Route Traffic Control Center (ARTCC) (ZTL) operations for arrivals into Atlanta-Hartsfield International Airport (ATL). The authors identified a list of collocation issues. These included questions about conflict notifications between two arriving aircraft at their TMA-scheduled times or among multiple aircrafts being vectored within a sector to meet the metering times. They raised questions about the use of URET's trial planning capability to assist in meeting TMA's metering times (an unintended use of URET). A key human factors issue was that TMA and URET use different algorithms to compute an aircraft's future location, which may result in controllers receiving incongruent information. These authors identified that URET's estimated times of arrival (ETAs) at the meter fix tended to be longer and more variable than TMA's ETAs. They observed that URET uses NAS preferred routing (NPR) in calculating ETAs over a fix, whereas TMA assumed a direct-to-the-meter routing. The NPRs may be longer. The authors reported that tool designers had changed TMA to use the NPR; however, they noted continued differences in the ETAs over the meter fix. This is a good example of the possible incongruent information that can result from the concurrent use of these two different tools.

The William J. Hughes Technical Center (WJHTC) NAS Advanced Concepts Branch (2001) conducted a simulation study on collocating URET CCLD and TMA at ZTL. The study used two sectors from ZTL airspace, which fed arrivals into ATL. In addition to the ZTL controllers, the study included participants who were familiar with one of the tools (Memphis ARTCC for URET and Denver, Ft. Worth, and Minneapolis ARTCCs for TMA). The researchers trained the controllers on the airspace and both tools. They then participated in simulations at the Integration and Interoperability Facility at the WJHTC in which they ran scenarios using both TMA and URET. After each simulation, the researchers conducted a structured debriefing to assess R-side and RA-side controller interactions, between sector interactions, and tool-specific issues and operational considerations. The most important collocation finding was that the aircraft sequence on TMA was different from the URET list sequence. The participant consensus from this study, however, was that URET and TMA were quite independent tools. They concluded that the collocation posed no potential negative impact on safety. However, the primary focus of the researchers in this study was on safety-related issues and not on issues related to continuous controller operation of the tools.

In summary, collocating URET and TMA raises the possibility that incongruent information may be presented to the controller as a result of different algorithms being used to compute key information. In addition, as stated previously, Kerns (2001) identified another substantial concern for collocating these three tools—human factors issues on the RA-side. Both of these issues raise concerns as to how they will impact workload, SA, and communication between the R- and RA-side controllers. As Kerns notes, the adequate resolution of these issues has implications for whether the controllers will use the tools as designers intended and whether the expected benefits will be realized. Finally, Desenti, Gross, and Toma (2000) raised the possibility of emergent issues, such as URET being used to trial plan TMA metering times. These three studies examined the collocation of only two of the three tools we examined. In addition, only one actually simulated the concurrent use of the two tools using only qualitative assessment methods. The collocation of three systems may compound the situation. The TMA/URET collocation study provided a positive suggestion that at least URET and TMA were independent and may not cause substantial collocation issues (NAS Advanced Concepts Branch, 2001).

1.2 Assumptions

For this report, we assumed the following:

- It would be the current DSR environment with the ATDET CHI and the addition of the CCLD flat panel display on the RA-side. Controllers would use this to display CPDLC information, the RA-side CRD, and the URET windows.
- The systems would not have direct communication with the other tools but would communicate to and from the Host computer.
- Controllers would procedurally use CPDLC only for non-time critical communications and clearances, and the tool would be available at both the R- and RA-side positions.
- The RA-side CPDLC CHI would provide at least the same capability as Build 1. Specifically, the RA-side could interact with CPDLC through text-based commands in the CRD as well as “hot keys” on the RA-side keyboard.
- The RA-side would have additional CPDLC windows on the CCLD monitor similar to the R-side CPDLC windows. These would be the Message In, Message Out, Menu Text, and History windows with the same interactive capability in these windows allowed on the R-side.

- In the current deployments at Memphis and Indianapolis ARTCCs, the URET Aircraft List has replaced paper flight progress strips (FAA, 1999). We assumed that this trend would continue with CCLD.
- There would not be interactive data block capability for the RA-side CPDLC.

1.3 Problem Statement

The addition of new ATC systems, although necessary for the continuous improvement in the efficiency of the NAS, may increase the potential for controller error. This is due to the change in the method of operation and work practices. It is imperative that designers of these systems, take into consideration existing human factors guidelines. The collocation of URET, TMA, and CPDLC onto an en route controller's DSR screen is a change that may affect ATCS performance. In addition, safety is the prime concern of the FAA, and the controller plays a vital role in the safe operation of the NAS. Therefore, it is necessary to identify the effect of the collocation of these tools on controller performance. The human factors guidelines, if used for evaluation, will aid the researchers in identifying issues in areas of concern to the FAA. These human factors issues can be best summarized using the following categories:

- inconsistencies in information display,
- CHI issues,
- impact of procedural changes,
- inconsistency in interaction with the tools, and
- impact on controller workload and SA.

The current study builds on aviation research that examines human performance. In the process, we will attempt to validate these categories of performance as appropriate measures for studying the collocation of these tools. The study outcome will allow the FAA to integrate improvements into the spiral development process of these tools.

2. METHOD

2.1 Evaluation Support

2.1.1 The Research Team

The research team consisted of multidisciplinary members from the NAS Human Factors Group (ATO-P), and Titan Systems. Two FAA Ph.D. scientists, together with a Titan Systems Human Factors Manager, provided the project management. Three additional HFSs from Titan Systems participated in all phases of the project, from planning and data collection to writing. Finally, a Titan Systems Controller served as the SME for the day-to-day operation of the project. He had the unique experience of serving on the Air Traffic AERA Concepts Team (a precursor to URET) workgroups.

We conducted the human factors collocation evaluation in two phases. Table 2 describes the study design. We planned a Phase 2 cognitive walkthrough to identify any issues related to dynamically using the systems together that we could not address in Phase 1. Due to changes in the CPDLC program, the sponsor asked us to postpone the formal cognitive walkthrough. Instead, we conducted a pilot test of the methodology with local WJHTC personnel who had some familiarity with the systems. We included the findings because they identified a number of factors worth discussing.

We assessed the collocation issues from two sets of perspectives that could have implications for the human factors issues. First, we assessed the issues from the perspective of a sector staffed with an R- and an RA-side and an R-side only. We also examined when tools were collocated in high altitude sectors versus low altitude, transition sectors to explore possible differences in the usage profiles of the tools.

Table 2. Study Design

Phase		**Deliverable**	**Purpose/Activity**	**Benefit**
1	Paper Review	Task by Tool Matrix	Match tools to controller tasks the tools would support.	Identify tasks that necessitate the use of more than one tool simultaneously.
		Task by Information Matrix	Identify the type and source of information required for tasks where more than one tool is used.	Help identify conflicts in information display, if any, of the tools.
		Human Factors Evaluation Matrix	Evaluate information elements and tool functions in the context of human factors principles.	Categorize consistency in color, symbology, and function.
2	Cognitive Walkthrough/ SME Interview	Flow Diagrams	Map the information and communication flow between various elements of the ATC System (tools, Host, and controllers).	Identify the communication modes for various tasks and gaps or issues with information transfer across the system.
		Issues	List the potential issues with respect to the categories.	Identify the interoperability issues.

We focused on issues related to collocating the three systems at one en route sector. Although each system may have human factors issues, for purposes of this report, we only identified those human factors issues that involve the use of two or more systems.

2.1.2 Participants

Participants in the pilot study of the cognitive walkthrough were SMEs located at the WJHTC who had some familiarity with at least one of the tools in the study. Within this group, we had some expertise in a URET Prototype, URET CCLD, and CPDLC Build 1A.

Three of the SMEs were current or former FAA controllers. The fourth had a military ATC background, and worked with the URET CCLD program. The FAA SMEs had an average of 33.7 years (*SD* = 3.0) experience working air traffic. All four SMEs had been ATCSs for an average of 30.2 years (*SD* = 7.4). They were full performance level/Certified Professional Controllers for an average of 23.5 years (*SD* = 9.8). All four had military ATC experience for an average of 8.8 years (*SD* = 7.8).

2.2 Equipment

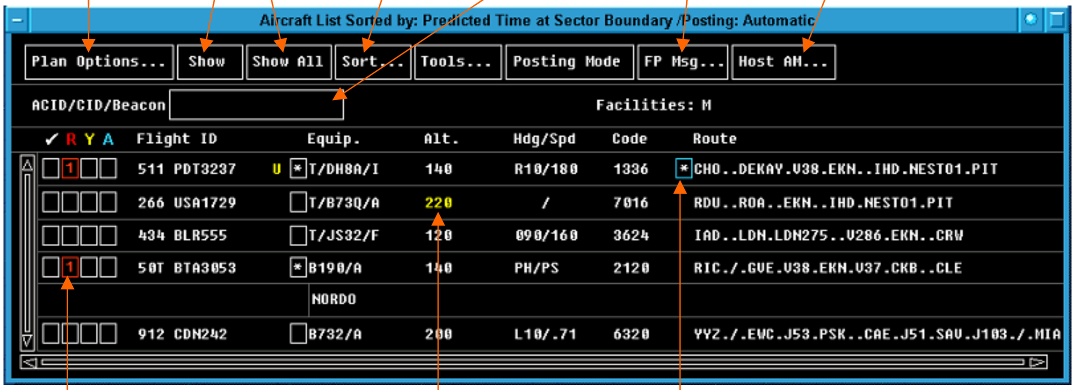
2.2.1 User Request Evaluation Tool, Core Capability Limited Deployment

MITRE CAASD originally developed a prototype of URET. CCLD is an incremental step in the spiral development process under the FFP1 Program (FAA, 1999). URET CCLD will provide the following key capabilities considered in this report:

- Trajectory modeling
- Conformance monitoring and reconformance
- Current plan and trial plan processing
- Automated conflict detection
- Inter-sector coordination and routing changes
- Interfaces with the Host and external data sources

The CCLD version of URET provides a new flat-panel display mounted on an articulated arm positioned on the RA-side of a sector workstation. This is in addition to the Data-side CRD. The design of the articulated arm facilitates the access to URET information by a single R-side sector-staffing configuration. Controllers access URET through the RA-side keyboard and trackball. The CCLD evolution integrated two keyboards into one on the RA-side (FAA, 1999). In the single R-side staffing configuration, the controller must still access the system through the RA-side keyboard. URET updates its information from the NAS. If a trial plan is accepted, it updates the NAS.

URET is a window-based environment. It provides three main display windows: the Aircraft List, the Plans Display, and the Graphic Plan Display. Figures 1 through 3 present examples of each of these windows.



Trial Plan Options

To display graphic view

To sort list by options

To search by beacon code

To view flight plan

To enter flight plan amendment

ACID/CID/Beacon

Facilities: M

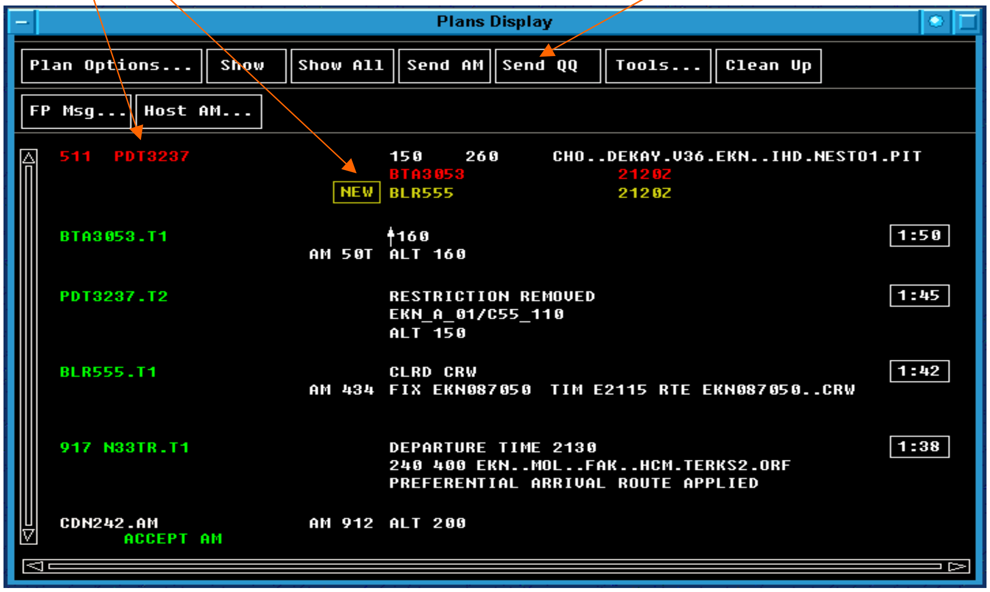
✓ R Y A	Flight ID		Equip.	Alt.	Hdg/Spd	Code	Route
☐ 1 ☐ ☐	511 PDT3237	U	☒ T/DH8A/I	140	R10/180	1336	☒ CHO..DEKAY.V38.EKN..IHD.NESTO1.PIT
☐ ☐ ☐ ☐	266 USA1729		☐ T/B73Q/A	220	/	7016	RDU..ROA..EKN..IHD.NESTO1.PIT
☐ ☐ ☐ ☐	434 BLR555		☐ T/JS32/F	120	090/160	3624	IAD..LDN.LDN275..V286.EKN..CRW
☐ 1 ☐ ☐	50T BTA3053		☒ B190/A	140	PH/PS	2120	RIC./.GVE.V38.EKN.V37.CKB..CLE
			NORDO				
☐ ☐ ☐ ☐	912 CDN242		☐ B732/A	200	L10/.71	6320	YYZ./.EWC.J53.PSK..CAE.J51.SAV.J103./.MIA

Conflict Alert

Wrong altitude for direction of flight indicator

Controller note Indication

Figure 1. URET aircraft list window.

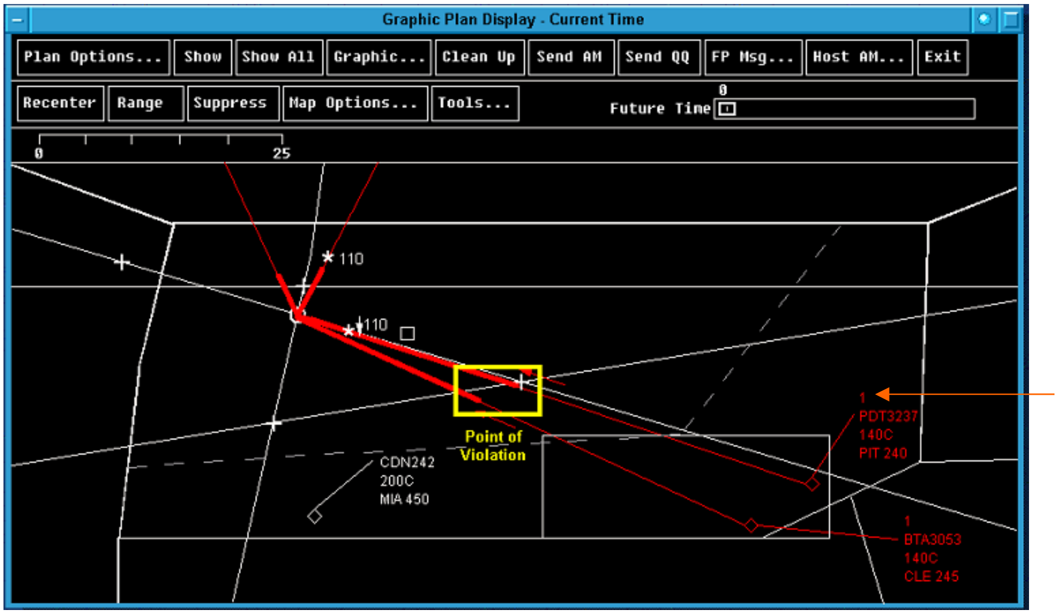


Alerts (Red, Yellow, and Blue)

To send amendments

```
511  PDT3237                    150   260    CHO..DEKAY.V36.EKN..IHD.NESTO1.PIT
                                BTA3053            2120Z
                          NEW   BLR555             2120Z

BTA3053.T1                      ↕160                                       1:50
                         AM 50T ALT 160

PDT3237.T2                      RESTRICTION REMOVED                        1:45
                                EKN_A_01/C55_110
                                ALT 150

BLR555.T1                       CLRD CRW                                   1:42
                         AM 434 FIX EKN087050  TIM E2115 RTE EKN087050..CRW

917 N33TR.T1                    DEPARTURE TIME 2130                        1:38
                                240 400 EKN..MOL..FAK..HCM.TERKS2.ORF
                                PREFERENTIAL ARRIVAL ROUTE APPLIED

CDN242.AM                AM 912 ALT 200
   ACCEPT AM
```

Figure 2. URET plans display window.



Conflict Alert

Figure 3. URET graphic plan display window.

2.2.2 Traffic Management Advisor

TMA is one of the tools in the Center-Terminal Radar Approach Control (TRACON) Automation System (CTAS) developed by the National Aeronautics and Space Administration, Ames Research Center (NASA, 2001). Designers intended TMA to assist the Traffic Management Coordinators (TMCs) and ATCSs in sequencing and spacing arrivals. TMA provides an arrival-scheduling plan (meter list) for an airport. It computes the undelayed ETA to the outer meter arc, the meter fix, the final approach fix, and the runway threshold for each aircraft. It predicts upon aircraft type, filed flight plan data, weather data, and winds aloft data. It also computes the sequences and scheduled times of arrival (STAs) to the outer meter arc, the meter fix, the final approach fix, and the runway threshold for each aircraft to meet the scheduling and sequencing constraints entered by the TMC (e.g., arrival rate). Finally, it provides the sector controller with an indication of the delay (or speed up) time needed for each aircraft to meet the maximally efficient arrival rates.

For purposes of this report, we have only focused on the information presented at the sector. TMA provides many services for the Traffic Management Unit (TMU). However, at the sector level, the information and functionality is limited; that is, TMA at the sector level involves a tabular list on the R-side’s display. A basic TMA list displays the following: Aircraft ID, ETA, STA, and delay (or expedite) times to the next metering fix. There are additional options for displaying different fields. The design concept expects the controller to meet the metering times over the fix to minimize delays for arrivals into a TRACON area. The controller can swap the order of the aircraft in the meter list or resequence the order. At the time of this report, TMA had been deployed to Ft. Worth, Minneapolis, Denver, Los Angeles, and Atlanta ARTCCs.

2.2.3 Controller Pilot Data Link Communications, Build 1A

CPDLC provides data-linked communications between ATCSs and pilots as a second channel to voice. This capability will help to reduce frequency congestion. This project specifically examined CPDLC Build 1A, which was to provide the following services (FAA, 1998):

- Transfer of Communications (TOCs)
- Initial Contact
- Altimeter Setting
- Altitude Assignment
- Heading Assignment
- Speed Assignment
- Route Clearance
- Text Messaging (Menu Text)
- Altitude Request (Downlink from the Pilot)

At the time of this writing, CPDLC Build 1 was being installed at Miami ARTCC. The FAA planned procedures for CPDLC use dictates that data link communications may be used only for messages that are not time critical. In addition, at the time of this analysis, only supervisors input messages from the menu text service supervisors. Thus, there would be no free text communication between the sector controller and the pilot. However, broadcast messages were envisioned for such things as impending weather, expecting crossing restrictions, and such. It was scheduled for shakedown in February 2002 and to become operational in June 2002.

The ATDET CHI for CPDLC provided a substantial redesign of the CPDLC CHI from Build 1. This CHI features data block functionality as well as windows, command line CRD entries, and hot keys for CPDLC entries. A small triangle to the right or left of the aircraft ID on the data block identifies eligibility, established session, and controller communications with aircraft. A box around the aircraft ID signifies uplinked messages. The CHI adds information in line 0 and line 4 of the data block. Line 0 includes warnings and controller selectable abbreviated text of downlinks and uplinks. Line 4 adds fields for speed and heading. The ATDET CHI also employs interactive data blocks. Controllers can click on the altitude, speed, or heading fields and produce “flyout” menus to assign values. An uplink button on the menu allows the controller to uplink messages or update the NAS if the aircraft is not CPDLC equipped. It is important to note that the NAS is updated immediately upon entry of altitude or route clearance messages. A menu text window and CPDLC message status for the aircraft is available from the data block, also.

Windows for uplinked and downlinked messages, as well as message history and menu text can be individually selected by the controller. The menu text windows also feature interactive flyout features for altitude, speed, and heading (see Figures 4 and 5).

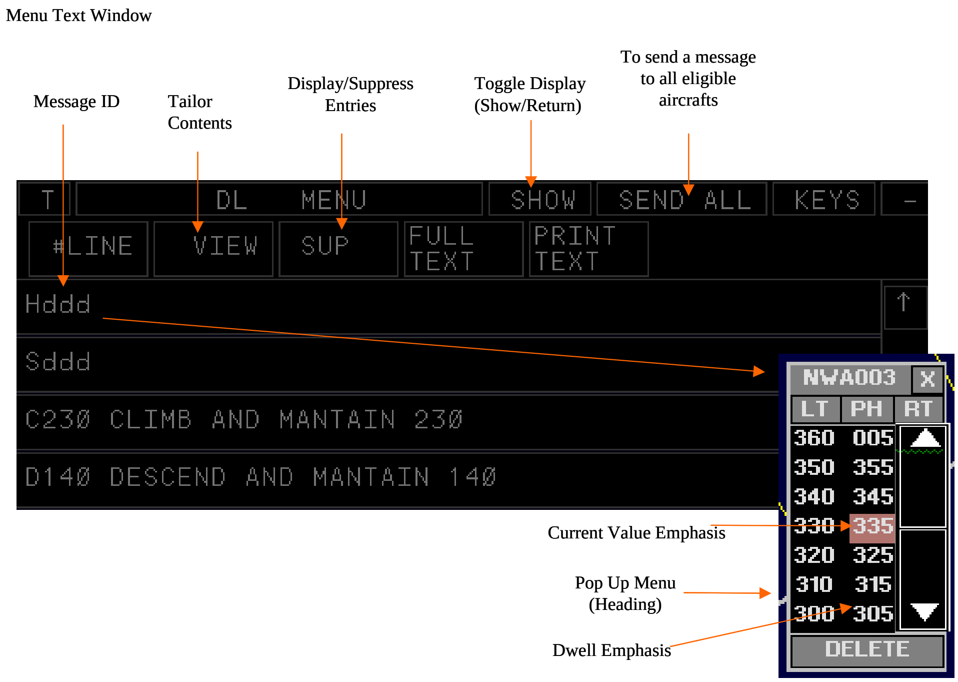


Figure 4. CPDLC menu text window.

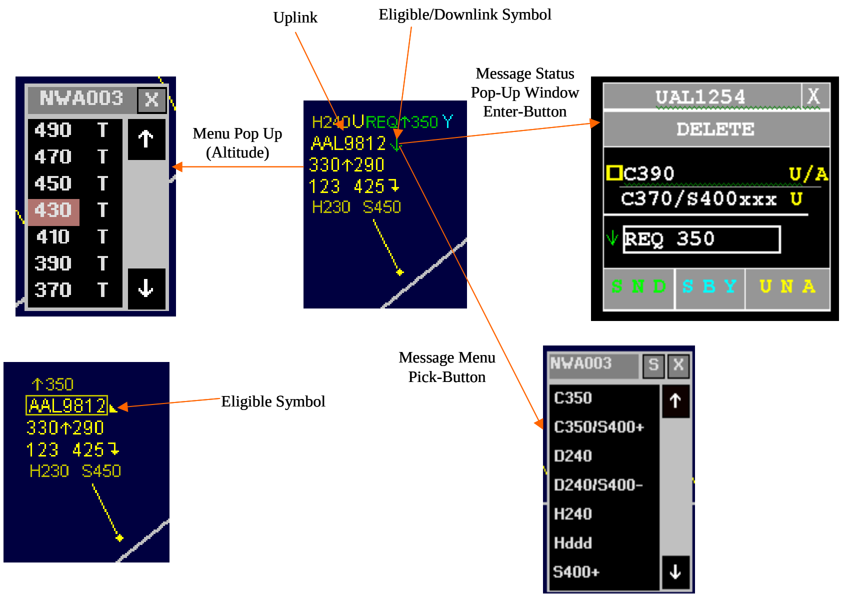


Figure 5. CPDLC data block.

2.3 Procedures

2.3.1 Phase 1 – Paper and Pencil Analyses

We designed Phase 1 to analyze the existing documentation and the design of each system, and the analyses addressed three main questions:

1. To what extent might the three tools be used together?

   To address this question, we mapped the tools to the tasks they would support. We then examined the number and types of tasks supported by multiple tools. Based on this exercise, we selected the specific events to use in Phase 2 - Modified Cognitive Walkthrough.

2. Where, within each tool, do controllers obtain information to complete typical controller tasks?

   To address this question, we examined the CHIs and their functionality. This allowed us to examine consistencies and inconsistencies across the tools in the type and location of information accessed by controllers.

3. What human factors issues exist when controllers move from one tool to another?

   To address this question, we performed an assessment of human factors issues across tools. We systematically examined the different CHIs to identify how interactions with the CHIs differed across each tool.

2.3.1.1 Familiarization

The research team examined basic documentation on each of the systems. AOZ provided briefing presentations on URET CCLD and TMA. FAA Computer-Based Instruction lessons were available for URET CCLD and CPDLC Build 1 (not 1A). We had access to the URET Prototype (a version of URET prior to CCLD) in the Research Development and Human Factors Laboratory. In addition, ATO-P, in collaboration with the R&D Labs Group (ACB-840), had developed the only functional simulation of the ATDET CHI for CPDLC Build 1A. A separate project sponsored by AUA-200 built this and performed the simulation in collaboration with the AOZ, CPDLC, NATCA, and FAA SMEs. Finally, one of the lead human factors researchers traveled to Memphis and Minneapolis ARTCCs to observe URET and TMA in daily use.

2.3.1.2 Matrix Development

2.3.1.2.1 Task by Tool Matrix

To understand the extent to which the three tools would support controller tasks and the overlap of the use of tools for specific tasks, we developed a matrix to examine which tool would support each task. The primary resource for this phase was an en route ATC task list that originated from CTA, Inc. (1990) and was modified by Rodgers and Drechsler (1993). The CTA task list was a detailed task analysis of the en route controller's job. CTA decomposed ATC functions into their smallest elements. This task analysis focused on controller's operational functions irrespective of the design of a particular piece of equipment. For this study, we used the list as reduced to what Rodgers and Drechsler termed the "task level."

The first column of the matrix in Appendix A contains the ATC task statements from the activity (Roman Numerals), subactivity (A, B, etc.), and task levels (1, 2, etc.) (Rodgers & Drechsler, 1993). The subsequent column headings include major headings for each of the three tools and subheadings for both R- and RA-side positions. The research team gave the list to the four SMEs who participated in the cognitive walkthrough with instructions on how to fill out the table. We told them to think about each subactivity and task in the context of using URET, TMA, and CPDLC. Specifically, we asked them to determine which, if any, of the tools they would use to support performing each task and whether an R- or RA-side controller would use those tools. If they designated a tool to support a specific task, we asked the SMEs to put a mark in the appropriate column. They could mark more than one tool for any task. We instructed them to be liberal in marking the tasks. SMEs completed the list independently and then met to go through the list once as a group. After they reached a final consensus as to which tools they would use for which tasks, we constructed an integrated matrix based on the results of this collaborative effort. From this matrix, the research team identified activities, subactivities, and tasks in which a controller might use two or more tools, thus, raising the possibility of interoperability issues. Appendix A presents this Task by Tool matrix.

2.3.1.2.2 Task by Information Elements Matrix

After completing the first matrix, which identified the activities, subactivities, and tasks that might involve the use of two or more tools, the research team examined the information items and sources required to accomplish those tasks. We assessed the consistency of information displayed across the tools that directly supported controller tasks. When constructing this second matrix, researchers first extrapolated a list of high-level controller subactivities from the first matrix (Rodgers & Drechsler, 1993) and then specified the type of information required to perform each specific subactivity. The matrix also identified whether there was more than one source for a specific information type on the display. Different sources could come from various views of a single tool or from either two or more of the tools. We present this matrix in Appendix B.

2.3.1.2.3 Human Factors Evaluation Matrix

The research team developed a third matrix (Appendix C) to systematically evaluate the consistencies of the common information presentation across tools. This matrix presents each type of information and identifies its source(s) within the tools and across tools. The next two columns contain the type of symbology used to represent a particular bit of information and the color used to display it. Comparison across columns helped to identify any issues with the consistency of the information. Column 7 presented the results on examination for consistencies. Inconsistencies include visual, procedural, and system communication inconsistencies. After we identified potential inconsistencies, we constructed a final column identifying any human factors principles that were violated (column 8) based on the CHI guidelines contained in the revision to Chapter 8 of the Human Factors Design Guide (Ahlstrom & Longo, 2001). This matrix identified all potential issues without regard to the criticality or potential adverse effect.

2.3.2 Phase 2 – Modified Cognitive Walkthrough

The construction of the matrices in the first phase helped researchers identify the extent to which controllers might use the tools together and, therefore, the extent to which they might present interoperability human factors issues. Phase 1 also identified potential human factors issues related to information presentation. The second phase investigated the operational consistency and interoperability of the tools. Phase 2 also attempted to determine whether the issues identified in the first phase would be genuine problems for the SMEs.

In Phase 2, researchers conducted a pilot test of our modified version of the cognitive walkthrough. Four SMEs and the researchers identified issues related to how the tools might actually function together by thinking about how controllers would use the tools together to perform specific controller tasks. The final product of the modified cognitive walkthrough includes a list of all human factors issues identified by the operational SMEs during this walkthrough (Appendices D and E). It is important to note this was a mental simulation, and SMEs were not able to assess these issues via direct interaction with the tools. Therefore, we could not objectively assess 1) the boundary conditions for defining each issue, 2) the criticality or impact an issue might have operationally, or 3) the effect of collocation on a controller's workload or SA. A human-in-the-loop simulation would be required to address these issues.

2.3.2.1 Modified Cognitive Walkthrough

A "Cognitive Walkthrough" (Nielsen, 1994) is an experimental methodology that explores system interfaces without having to perform an actual simulation. Nielsen's cognitive walkthrough methodology introduces potential, but naïve, users to a single new interface. Researchers systematically question participants about usability issues as they interact with one of the new tools. In a more recent version of the cognitive walkthrough procedure (Wharton, Reiman, Lewis, & Polson, 1994), researchers identified specific problem areas before asking the participants to examine an interface. The researchers used these issues to guide the interface inspection. Other variations of the method exist (Karat, Campbell, & Fiegel, 1992; Nielsen & Molich, 1990; Sears, 1997). We modified the cognitive walkthrough methodology to examine how experienced users would use three tools concurrently to accomplish typical ATC tasks.

Four SMEs participated in the walkthrough, but first, we familiarized them with all of the tools. Only one of the SMEs required training. This SME was familiar with URET CCLD but was not familiar with either CPDLC or TMA. The other three SMEs had some familiarity with all three tools, as well as research protocols. We then briefed the SMEs on the main goals of this study. We informed them that this study was an attempt to identify problems and/or benefits related to the collocation of URET, CPDLC, and TMA.

Researchers provided the SMEs with a packet containing all of the relevant documentation for the walkthrough. This packet contained a brief, written introduction to the study; a list of the core capabilities of the three tools; a list of information types that the tools display (i.e., altitude, beacon code, speed); and a complete list of the events that were to be covered during the walkthrough. In the modified cognitive walkthrough, we chose to use events for which controllers would use more than one tool and which were most representative of common controller functions. We selected the 11 events used in this study from the events contained in the CTA en route task analysis (CTA, Inc., 1990) at the activity level. Table 3 depicts the selected list of events.

Table 3. List of Events

1. Route changes
2. Climb requests
3. Descent requests
4. Weather related deviation/re-routing
5. Responding to required TMU restrictions
6. Speed adjustments
7. Conflict alerts
8. Holding
9. Hand off in
10. Hand off out
11. Emergency situation (engine failure)

2.3.2.1.1 Flow Diagrams

The SMEs received an uncompleted flow diagram on which they were to graphically depict the information flow during an event. A moderator familiar with the walkthrough methodology then discussed the process with the SMEs as they completed final flow diagrams.

For the first diagram, the moderator began by having the SMEs step through the sequence of information flow for a climb request. The assumptions on the first pass through the flow diagram, which we explicitly presented to the SMEs, were that 1) there was an RA-side; 2) aircraft were equipped with CPDLC; and 3) SMEs should use all tools when possible for the first pass. The SMEs identified issues as they proceeded through the event list with the moderator.

A Visual Basic mock-up of the tools was available as a visual reference. If SMEs wanted to check the graphical display for one of the tools, then we projected that tool onto a screen. At the top of the page on all of the flow diagrams, we indicated the event, the sector (low or high), and the staffing (R-side alone and both R- and RA-side). Therefore, for each event, there were potentially four flow diagrams to be filled out (Appendix F). However, due to time restrictions, SMEs did not complete all four for each event. As stated previously, the SMEs completed the first flow diagram assuming both R- and RA-side staffing in a high sector. If the consensus of the SMEs was that the tasks needed to perform an event did not differ when there was only

R-side staffing or when the plane was in a low sector, then they completed only one flow diagram for that event. The researchers projected the flow diagrams onto a screen (see Figure 6). At the top of the flow diagram, we presented R- and RA-side tools. The R-side, column headings included the DSR, TMA, CPDLC, Voice, and CRD. The RA-side columns included URET, CPDLC, Voice, and CRD. We asked SMEs to list the specific steps needed to respond to that event. We then entered these steps into separate rows in the flow diagram. For each step, arrows and circles indicated communication and interaction. Arrows indicated communication between controllers or controllers and pilots and circles indicated interaction with that tool. Researchers left circles unfilled if they were marking interactions where the tools would simply be observed (i.e., when reading the aircraft delay from TMA). Alternatively, if the interaction involved controllers actively using a tool (i.e., when using URET to perform a trial plan), researchers filled in the circle. In addition, at each step of the event, we asked the SMEs to think about how the tools would support these events and identify any corresponding human factors issues related to using this tool for this event. For instance, when the flow diagram indicated communication of electronic information, we asked the SMEs to think about whether that piece of information needed to be transmitted to any other tool or if any other tool redundantly transmitted the same piece of information to the NAS. We also asked them to identify any gaps in information transfer across the different tools (e.g., in the event of route change, where the controllers had to manually enter route information suggested by URET in CPDLC).

Event: **Route Change**
(High Sector) & (R- and RA-Side)

Info Type	**Pilot / Flight Deck**	**Host**	**R-Side Interface**					**RA-Side Interface**			
			DSR	**TMA**	**CPDLC**	**Voice**	**CRD**	**URET**	**CPDLC**	**Voice**	**CRD**

ID#_____

Notes:

Figure 6. Blank flow diagram for route change event.

2.3.2.1.2 Potential Issues

During the walkthrough, the researchers recorded any issues raised by SMEs. We videotaped the walkthrough itself, as a back up in case SMEs had discussed an issue but had not recorded it. Once we identified these issues, we then sorted them into the following categories:

- Concept of use considerations examined how the three tools collectively supported controller functions and whether there were any emerging or new uses of the tools when being used together.
- CHI considerations were concerned with any display problems, including those that dealt with display real estate, symbology, and coding.
- Information flow considerations dealt with information exchange, either between the tools themselves or between the tools and the controllers.
- Collocation considerations included any issues due to the controller's interactive use of the three tools as part of the sector equipment and automation suite as well as the system as a whole. It also included any changes in workload that was the result of the use of more than one tool.
- Coordination considerations were those that dealt solely with communication between controllers. This included both communication between controllers in different sectors and communication between the R- and RA-side controllers.
- Procedural considerations involved instances where controllers wanted to implement a new procedure to handle a specific situation.

We then created a list that enumerates the advantages and disadvantages related to the collocation of URET, TMA, and CPDLC. We organized this list around these six collocation categories. Lastly, we identified issues that the modified cognitive walkthrough methodology could not adequately cover. This list may serve as a guideline for any future human-in-the-loop simulation to study.

3. RESULTS

3.1 Phase 1 – Paper and Pencil Analyses

The Phase 1 engineering analyses answered three questions:

- To what extent might controllers use the three tools together?
- Where, within each tool, do controllers get information to complete those tasks?
- What human factors issues exist when controllers move from one tool to another?

3.1.1 Task by Tool Matrix

The four SMEs identified the en route controller tasks that could be supported by each of the tools. The purpose of the exercise was to provide an initial engineering assessment of the tasks where controllers might use the tools together.

CTA conducted the task analysis (CTA, Inc., 1990; Rodgers & Drechsler, 1993) in an ATC environment where controllers used a planned view display of traffic and paper flight progress strips to control traffic. Activities such as “perform situation monitoring” (Activity I) were broken down into subactivities such as “check and evaluate separation” (Subactivity I.A.). These subactivities were then further broken down to the task level such as “project an aircraft’s future position, altitude, and path” (Task I. A. 1). We asked controllers to determine if any of the new tools would support an old task. For example, URET would be marked to support the old Task I.A.2 (project mentally an aircraft’s future position, altitude, and path) because the design of URET would support and supplement the controller’s mental projection of aircraft path and position in both the trial planning and conflict probe modes. After SMEs made their marks for tasks, we performed an analysis one level up at the subactivity level to obtain a broader picture of when controllers would use individual tools. As shown in Appendix A, SMEs marked URET to support 26 of 39 or 67% of the major subactivities. These included the controller’s main separation tasks, such as check and evaluate separation (Subactivity 1.A), perform aircraft conflict resolution (Subactivity II.A), and perform airspace conflict processing (Subactivity II.C). SMEs reported that URET would be used on both the R-side and RA-side because the R-side would take over the operation of URET when there was no RA-side staffing. Controllers marked TMA to support 5 of 39 or 13% of the major subactivities. The subactivities supported by TMA included establish arrival sequences (Subactivity III.D) and respond to traffic management constraints/flow considerations (Subactivity III.A). SMEs also marked TMA for plan clearances (Subactivity IV.A) because SMEs felt that controllers may evaluate TMA information when planning clearances. CPDLC was marked to support 16 of 39 or 41% of the major subactivities. These subactivities included issuing clearances (Subactivity IV.J), performing CPDLC services (e.g., TOC, altimeter, and Mode C altitude mismatch with the assigned altitude), as well as other messaging, which controllers could accomplish using the menu text option. In addition, the SMEs noted that CPDLC could be used in novel ways to support tasks such as communicating with an aircraft that had no radio communication but which was data link-equipped.

We performed another analysis, which assessed the proportion of subactivities for which controllers might use more than one tool. Analysis at this level provided insight into when they might use three tools in close proximity in time, for example to plan a clearance. We present the SMEs’ estimate in the subactivity overlap in the Venn diagram in Figure 7. It is important to point out that this analysis only provides a count of the number of subactivities supported by multiple tools. It does not assess the relative importance of different subactivities.

Figure 7 shows that of the 39 subactivities, the SMEs estimated that only three (7.7%) would involve the use of all three tools. Because TMA’s function is narrowly focused on effectively managing arrival traffic, it is not surprising that the number of subactivities involving all three tools is small and includes 1) Responding to traffic management constraints/flow (Subactivity III.A); 2) Establishing arrival sequences (Task III.D); and 3) Planning clearances (Subactivity IV.A).

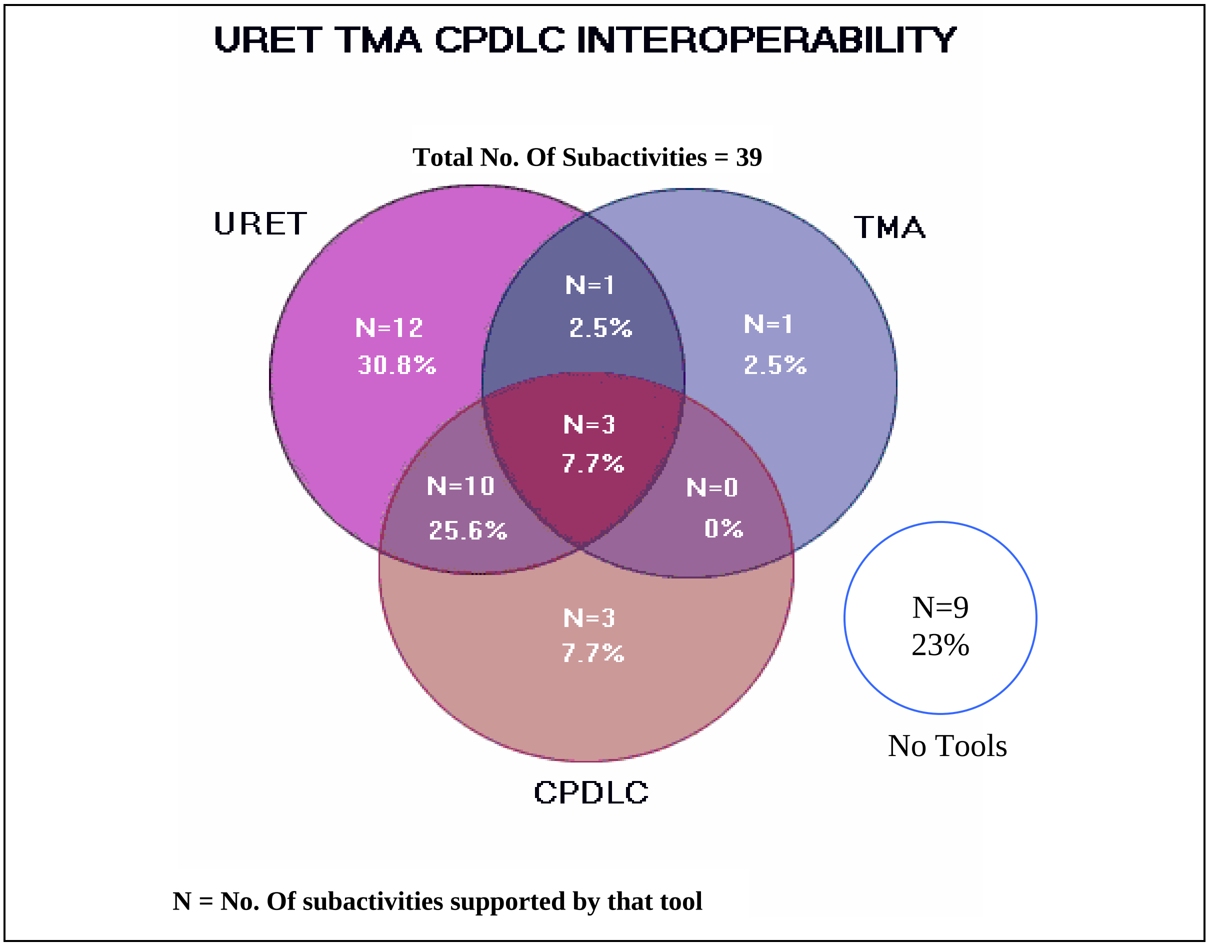


Figure 7. Venn diagram.

Only one subactivity (2%), "check and evaluate separation" (Subactivity I.A) would involve the use of URET and TMA together. However, this subactivity accounts for a large proportion of an ATCS's job. The collocation of URET and CPDLC, however, has the potential to be used together in over 25% of the subactivities. SMEs indicated that there were 10 subactivities (25.6%) where controllers could use URET and CPDLC together. These included the primary controller duties such as planning and issuing clearances. Although it is likely that the tools will be used sequentially, such that URET will be used first for planning and CPDLC used to then issue clearances, they were frequently marked together. This was because SMEs felt that controller would frequently need to assess the status of information on CPDLC when planning clearances. It should also be pointed out that for 16 (41%) of the subactivities, SMEs only marked one tool as being used, and for 9 of the 39 subactivities (23%), they did not mark any tools as being used.

To get a more detailed perspective on the specific ways in which controllers might use the tools together, we examined the Rodgers and Drechsler (1993) list at the task level to examine those cases where SMEs marked more than one tool (see Appendix A). This level of analysis provided an insight into where there might be direct interaction between the uses of the tools. SMEs did not mark any single tasks at this level of analysis for support by all three tools. Two tools supported 21 tasks (out of 400) or 5.2%. Ten of these involved using URET and TMA together, and 11 involved using URET and CPDLC together.

The analyses at both the task and subactivity level provided additional insight into how the tools might interact. The larger number of URET and TMA pairs suggested that controllers would use information from both tools during the planning stages when managing arrivals and clearances. Therefore, it is important that the controllers have the information available from these tools readily accessible, consistent, and understandable. The SMEs suggested that URET may be used to trial plan metering times (Desenti, Gross, & Toma, 2000) and therefore, marked URET and TMA for projecting traffic sequences to establish or modify approach flow to the airport (Task III.D.2) and evaluating flight projections for appropriateness (Task IV.A.8).

Finally, for 8 of the 11 URET/CPDLC pairs, the SMEs marked tasks in the responding to contingencies/emergencies task category (Task IV.B.5, 16, and 17) and in the executing backup procedures task (Task VI.C.2, 3, 6, 7, and 12). SMEs felt that controllers might use one or both in unusual situations. There were no serious collocation issues thought to be associated with carrying out these tasks. However, we also noted that SMEs marked both URET and CPDLC for record necessary flight plan data (Task III.D.9). It became apparent to us when considering this issue that both tools update NAS independently. We feel that this may create a serious problem when the two tools are used concurrently because independent updates of the NAS by two different tools can lead to things like incorrect trajectory calculations when trial planning.

3.1.2 Task by Information Matrix

We designed the second matrix to identify the sources of information controllers would use to perform each activity, subactivity, and task. By systematically identifying information that supported the tasks, we could systematically examine the presentation of the information by each tool in the Human Factors Evaluation Matrix (Appendix C) and begin to assess the impact of inconsistencies. We included DSR because it is a primary source of information, and the tools should be consistent with the DSR environment. We used this information to construct the Human Factors Evaluation Matrix.

3.1.3 Human Factors Evaluation Matrix

This section provides a systematic review of human factors guidelines and the CHI as a controller moves from one tool to the next. Specifically, we examined information presentation, application of color, symbology, some functionality for consistency, and other human factors principles. We did not assess the criticality of these issues. Thus, we identified any inconsistencies we found. Some examples are as follows:

- The most widely, inconsistently used symbol was the letter H. In the URET Aircraft List, H means a heavy aircraft. An H in line 0 of the data block with CPDLC means that a controller is handing off an aircraft to that sector and is waiting for a TOC (held TOC). Finally, in the new ATDET CHI for the R-side, H appears in the menu text windows and line 4 of the data block, indicating heading. This H precedes either an "xxx" in the menu text window or the heading value in the data block.
- We found the data block to differ between URET and the ATDET CHI with CPDLC. Lines 0 and 4 were added in the ATDET CHI. Line 0 in CPDLC carries warnings and information about downlinks and uplinks. In the URET Graphic Plan Display, it provides alerts about conflicts. Line 4 in the ATDET CHI provides heading and speed information for coordination. It is absent in URET. Finally, Line 3 in URET carries destination information; whereas, in the DSR/CPDLC data block, it presents the computer ID and timeshares handoff and aircraft ownership information.
- We identified some differences in the application of color across the three tools. For example, URET uses blue for an airspace conflict alert, but CPDLC uses blue for a "standby" message.
- Inconsistencies in coding included: 1) use of a triangle in CPDLC to mean equipped aircraft and a frozen aircraft (aircraft that has been cleared to land in that sequence and cannot alter its position now) in TMA; and 2) different placement and notation for destinations in the DSR and URET data blocks.

3.2 Phase 2 – The Modified Cognitive Walkthrough

The Phase 1 engineering assessment provided an inherently limited analysis of the functional and air traffic-related human factors issues associated with using these tools together. The research team conducted a pilot test of the modified cognitive walkthrough methodology. This provided controllers with the opportunity to systematically think through conducting air traffic tasks using the three tools together. As the controllers thought through the process of using the tools together, we asked them to identify any relevant issues. We illustrated the information flow using the flow diagrams shown in Appendix F.

When we examined the flow diagrams, one primary pattern was clearly present. With the addition of URET on the RA-side, there was much more communication between the R- and RA-side whenever they used URET. When using URET, the R-side needs to voice a request for a trial plan to the RA-side, who then needs to complete the trial plan before voicing the result of the trial plan back to the R-side. If the trial plan is acceptable, only then can the R-side voice the plan to the pilot.

Other evident issues with the flow diagram exercise were as follows:

- TMA information was not available to the RA-side controller who uses URET for trial planning, and the R-side controller would have to update him on any occurrence.
- A CPDLC response to a voice request was consistent with established practices.
- Procedures are needed for between sector coordination using URET and CPDLC. Added communications could increase the chances of potential errors.

- Some instances required the R- and RA-side controllers to look at each other's screen. This is a potential hindrance in doing their job.
- Lack of communication between URET and TMA may hamper the capability of URET.

4. CONCLUSIONS

Even though this was a pilot study using new methodology, the SMEs raised many important issues when they were filling out and discussing the flow diagrams. Table 4 summarizes our most important human factors findings from both phases categorized in the six categories. Appendix D shows a complete list of issues raised by the SMEs organized according to the six collocation category types. Appendix E presents the same list organized according to the event categories.

Table 4. Human Factors Evaluation Issues

ISSUE CATEGORY	**SUMMARY**
Concept of Use	• URET was not designed to trial plan times to TMA meter fix in arrival streams, but in combining the two systems, controllers may use URET for this purpose. • There are routine tasks in approach sectors that URET or TMA do not support very well, such as holding and vectoring.
CHI Consideration	• URET takes up a lot of real estate on the RA-side controller's radar screen, which must be shared with the CRD and CPDLC. This creates a timesharing situation in which controllers could miss critical information from one of the systems. • Inconsistencies in the CHI across the three tools include different ways of interacting with data blocks, scroll bar positioning, presentation of information, and color application. For example, data block on line 0 of URET has conflict alert information, whereas CPDLC has warnings as well as uplink/downlink information.
Information Flow	• It is not possible to move information among the tools, which is a potential source of error due to dual entry capability with different information. SMEs recommended a cut and paste capability among the tools.
Integration/ Collocation	• CPDLC updates NAS information when the controller uplinks a message without waiting until a pilot accepts the clearance. URET updates NAS when the controller accepts trial plans. This provides two sources of updating for the NAS, which can cause inconsistencies in display information. URET computations of conflict alert will be computed for the new information from CPDLC or URET, thus risking misinformation about conflict status.
Coordination Consideration	• Because the RA-side controller does URET trial planning, when there is RA-side staffing, he/she will communicate trial plans to the R-side for approval before they will be sent to the pilot. This is only one situation that will impose greater communication and coordination demands on both the R-side and RA-side controllers. This also poses workload, SA issues, as well as potential for error or misunderstanding in the information exchange.
Procedural Consideration	• The ability of the RA-side to communicate directly with the pilot via CPDLC can create certain procedural issues relating to the responsibility for communicating clearances to the pilot. A typical example is when the RA-side checks an altitude in URET. SMEs recommend having a procedure detailing who is responsible for sending information to the pilot, monitoring to make sure the correct information is sent, and monitoring to make sure the WILCO is received. Otherwise, changes made to the NAS when a controller sends a message via CPDLC to a pilot might not reflect the current status of an aircraft if a pilot "unables" the message. This has implications not only within a single sector, but when coordinating between sectors as well. SMEs also recommended having some method to flag CPDLC messages as "sent" but not "WILCOed" to ensure that these are tracked properly, with some clear indication on the R-side of changes made on the RA-side and visa versa.

4.1 Concept of Use

Two issues related to concept of use emerged. First was the use of URET to trial plan TMA metering times. The operational SMEs discussed this possibility at some length. They felt that controllers would use URET for this application. Currently, URET will not show information to indicate that a specific clearance would meet the metering time. To trial plan in URET, controllers would have to mentally calculate options and then trial plan their calculations. They could also trial plan an option and then adjust the outcome using DSR information. The SMEs felt that the controllers would have to exert extra effort with the current capabilities. They recommended upgrading URET to accommodate this need pending further review.

The second limitation is that it cannot correctly model aircraft that controllers are holding or vectoring. TMA also cannot accommodate aircraft that are in a holding pattern. However, holding and vectoring are ATC techniques that controllers will commonly use in sectors where they use URET and TMA together. The computations for aircraft that they are holding or vectoring will not be accurate for either tool. This will then shift the load to human memory, processing, and air traffic skills to accommodate the TMA recommendations, as well as all of the TMU restrictions. URET would also have reduced operational use in any metering sector where controllers were holding or vectoring aircraft.

4.2 Computer-Human Interface Issues

SMEs and the research team identified some interface inconsistency issues in Phase 1 and Phase 2. These included inconsistencies in the data block format, which we mentioned previously, including differences in both line 0 and line 4 between URET and DSR. There were also some differences in the application of color.

Some additional examples include the following:

- The way that the data block responds on URET and CPDLC is not consistent.
- The scroll bars on the fly out windows for URET and CPDLC are on different sides.
- DSR and URET note the destinations differently.
- Triangles indicate two different things in TMA and CPDLC (i.e., frozen aircraft vs. data link-equipped aircraft, respectively).

The SMEs felt that differences in interacting with the data block and scroll bars might be a source of confusion in a single R-side operation. Another important CHI issue was that the SMEs expressed concern that URET "takes up a lot of real estate," which may cause important and critical information to be covered by other tool's windows.

4.3 Information Flow

The SMEs identified information flow issues in Phases 1 and 2. The first functional issue was that both CPDLC and URET update the NAS computer when the controller enters the information. Thus, when a controller accepts a URET trial plan, the URET acceptance updates NAS. In the case of CPDLC, the NAS is updated when the controller uplinks the message. The uplink updates NAS before the pilot even gets the message. If the pilot "unables" the clearance, the controller must remember to change the NAS information or else the uplinked information will persist. This only applies to information such as altitude and routing, which is updated in the NAS. Heading and speed information can be data linked; however, NAS is not notified. There are two collocation issues that arise from this information flow issue. First, two independent sources update NAS information. This could be a source for error in data entry. Second, this has implications for URET's conflict probe and trial planning computations. URET's computations will use the new altitude or routing as soon as it becomes the NAS value. There will be a latency before the pilot receives a clearance via data link, even if the pilot responds that he/she will comply with a "WILCO" to the clearance. If the pilot "unables" the clearance, the controller must remember to change the NAS to the original value.

Another issue was that TMA and URET use different flow restriction databases. The controller must update both as restrictions change. This could also be a source for error or inconsistent information being presented to the controller.

4.4 Collocation

The collocation of these three tools will provide the controller with additional information about impending conflicts and arrival sequencing. The SMEs found all three to provide very useful information.

The collocation issues raised by the SMEs in Phase 1 and Phase 2 relate primarily to the consistency of the information presented to the controller, and we have mentioned them previously in relation to the restriction data bases used, algorithms used to compute time over a fix, and consistent use of color and formats of presentation. The RA-side collocation of these tools raised the most concern with the SMEs because the tools were not integrated. They were concerned that because different windows present so much information, a controller could miss important information. They recommended that URET and CPDLC be integrated on the RA-side as soon as possible. This would allow trial plans to be uplinked if they were accepted. In addition, they recommended a cut and paste feature that would allow for transfer of text information between tools. The SMEs thought this would be particularly useful for routing and rerouting information.

4.5 Coordination

Phase 1 and Phase 2 raised issues about the requirement for increased coordination between the R- and RA-side controllers. Take, for example, URET trial planning, which the RA-side performs when there is RA-side staffing. If no procedural changes are instituted and current practices are followed, the RA-side controller will have to communicate trial plans to the R-side for approval before he/she can send them to the pilot. This will impose greater communication and coordination demands on both the R-side and RA-side controllers. In addition, the SMEs felt that because URET has a 20-minute look ahead time, controllers may have to deal with conflicts between aircraft in their control sector and aircraft in other sectors. In this case, controllers would require multi-sector coordination in neighboring sectors if they needed to communicate about planning constraints when handling a current conflict.

4.6 Procedural Considerations

In this pilot study, SMEs identified two primary procedural issues. These issues arose from some of the previously identified information flow and coordination issues. When there are multiple ways to communicate from the R- and RA-side to pilots, to the Host, to NAS, or to another controller, there is a potential for both sides to communicate conflicting information. The SMEs recognized that there are no procedures currently in place to dictate how controllers should handle these communications. The SMEs felt that in these types of situations, it was critical that written procedures were in place. These rules would dictate responsibility for sending the communication and who should be responsible for monitoring the communication to ensure that the correct information was received and acted upon on the other end. The second procedural issue dealt with how to delegate responsibility for dealing with an alert on URET when the two conflicting aircrafts lie in different sectors. Again, SMEs felt that it would be necessary to have written procedures in place for handling this situation.

5. DISCUSSION

URET, TMA, and CPDLC are three tools that provide the controllers with the capability and the flexibility to accomplish their routine functions. At the same time, they would provide the controllers with more decision-making information than is now available. However, regardless of their potential benefits, these tools will not be deployed as standalone systems but will, instead, be used concurrently. Therefore, this pilot study's aim was to identify any potential issues that might arise when controllers use these tools together, and the SMEs helped us to explore any of these potential issues. They also assisted us in identifying those human factors issues, which, if addressed prior to concurrent deployment, could help maximize the utility and benefits of each tool.

We investigated how controllers would use these tools together by examining the specific tasks that the tools would support. We then asked our SMEs to cognitively walkthrough specific events that occur commonly in an ATC setting. The SMEs' responses revealed a concept for use of these three tools in which a controller a) would continuously monitor the displays of each tool for current information and changes in status, b) use the information from all the tools in planning clearances, and c) use CPDLC to deliver the clearance.

Because of its conflict detection and trial planning capabilities, controllers would use URET to support many of their day-to-day functions. However, because of URET's inability to handle holding and vectoring, URET would not be of much help in the arrival sector. On the other hand, TMA would be primarily involved in the arrival sequencing. Thus, they marked few tasks for support by all three tools. However, our SMEs felt that controllers would likely use information from all three tools in planning and evaluating most clearances. Therefore, it is important that we ensure that the information from the three tools is readily available, accessible, and consistent.

When evaluating the CHI issues for collocation of URET, CPDLC, and TMA, we found a number of specific violations of some important human factors design principles. These design principles stress the importance of not having

- a human operator interacting with two pieces of software that use similar symbology but with different meanings,
- scroll bars in different locations, and
- different results for interacting with the same piece of information (in this case, the data block).

One possible result of these CHI inconsistencies is that controllers may demonstrate negative transfer. For example, they may waste valuable time looking for conflict alert information on the fourth line of the data block in CPDLC when they should be looking at the URET data block for this information. Although it was not possible in this pilot study to assess the criticality of these findings, based upon best human factors practice, if these CHIs are not made as consistent as possible, there will be some impact on controller performance.

A second issue dealt with the collocation of URET, CPDLC, and the CRD all on the RA-side. The SMEs raised concerns about the amount of space required for accessing information from each of these tools. In the task analysis that resulted in the Task by Tool and Task by Information matrices, the SMEs anticipated that controllers would use URET and CPDLC together to support over 25% of the subactivities. These subactivities involved many of the main tasks of controllers, including separation and issuing clearances. Although they most likely will use URET and CPDLC sequentially and use CPDLC only for “non time-critical” clearances, the controllers anticipated that they would need to continuously monitor the status of clearances and other information on the displays for both systems. With the number of known windows required to display URET features, the CRD window, and the anticipated CPDLC information, it will be too difficult to monitor the status of URET and CPDLC at the same time. In terms of the space requirements, there is the possibility that critical information may be covered, and it may not be quickly accessible when it is needed. As designers add windows for CPDLC, the chance of obscuring important information on one system or the other escalates. This presents challenges to the RA-side controllers to manage their workload and maintain SA. With the indication from this study that controllers may frequently use URET and CPDLC together, there is a pressing need to apply human factors design principles when engineering the RA-side display. Kerns (2001) anticipated this need in her paper on collocation.

Human factors engineering could contribute significantly to the success of the deployment. In addition, it should have an important operational impact on controllers. Specific benefits would include

- maximizing the use of the limited space on the CCLD monitor,
- enhancing the accessibility of important information and decreasing the risk that important information would be missed,
- decreasing the chance of errors,
- decreasing the taskload required to monitor multiple windows, and
- improving CHI compatibility.

The SMEs recommended actually integrating CPDLC and URET functionality into one display. We support the notion that if time is available, the effort would be well spent to move to integrating these two systems. However, short of system integration, our minimum recommendation would be to integrate the display of some CPDLC status information into the URET Aircraft List. The SMEs also raised the issue of clutter on the R-side as windows are added. Because of limited attentional capacity, cluttered displays may lead to critical information being displayed outside of a controllers field of attention, particularly on the R-side DSR monitor. Controllers may not process this non-foveal information appropriately in time-critical situations, or they may respond more slowly. The ATDET CHI, in which each data block presents CPDLC status information for each aircraft, may mitigate some of the problems associated with this issue; however, the interactive data blocks may, themselves, present issues of display clutter and affect controller-scanning patterns.

The third major issue was the requirement for increased communications between the R- and RA-side controllers. The flow diagrams clearly demonstrated that for a two-person operation within a sector, there would be an increase in the communication between controllers (information exchange) as compared to the baseline condition. The added communication and the difference in the way designers present the information across tools may impose additional workload. Increased communication may also impact SA and prospective memory (Cardosi & Murphy, 1995). The research team did not intend the walkthrough methodology to measure the SA and workload changes. With the addition of information to both positions and the associated requirement to make sure that the other controller is aware of important information, it will be critical for Air Traffic Service to adopt clear procedures for information exchange, as well as clear procedures designating who is responsible for entering the data into the NAS (Kerns, 2001).

The fourth primary issue was that different systems would update the NAS. The point at which the three tools will acquire common information is at the NAS database. Each of the tools obtains values from the NAS database to display information. URET and TMA use this information as input to algorithms that controllers use in computations for conflict probe, trial planning, and arrival sequencing. However, as noted by the SMEs during the cognitive walkthrough, URET updates NAS when controllers accept a trial plan, and CPDLC updates NAS when controllers enter a clearance, potentially before the pilot attends to the clearance. The two key NAS fields that the tools may update are altitude and route. At least two potential issues arise from this situation: 1) The values that the NAS uses as input for these algorithms may, for a period of time, not reflect the accepted/actual value of the aircraft; and 2) Multiple sources of entry may lead to different values being entered for the same NAS field. There is currently no way to notify controllers that the tools entered conflicting information. Researchers were unable to assess the criticality or potential frequency of either of these issues in this project; however, we strongly recommend investigating the ramifications of these conflicts and potential mitigation strategies, possibly with a human-in-the-loop simulation. The multiple sources for data entry further increases the need for the R- and RA-side controllers to have good communications and clear procedures for using the systems.

Desenti, Gross, and Toma (2000) identified an emergent operational concept for the use of URET to trial plan metering times. Our SMEs also felt that URET may be used to trial plan metering times and raised additional questions as to whether URET algorithms would be appropriate to use in a sector in which a lot of vectoring and holding take place. They recommended that designers improve URET's algorithms to more directly support this. Researchers should examine these issues in simulations utilizing functional versions of the tools. Assuming the eventual use of URET as the trial planning tool and the use of TMA to provide time estimates of the aircraft over fixes, trial planning-aided time metering seems to be a logical next step. URET functions by evaluating the modification to the plan suggested by the controller and informs of any conflicts that the plan may cause. The SMEs anticipated a future extension to URET, Problem Analysis Resolution and Ranking, by requesting development of a "more capable URET" that used known constraints to recommend workable plans. SMEs felt that the most pressing need for this capability would be in arrival sectors, where the controllers would need to integrate constraints set forth by TMA. With multi-sector TMA, this capability, although modifying the current concept of use, could help controllers plan more optimal routes and sequences.

A major effect of collocating these three tools will be the addition of more information, which may increase the load on the controller's cognitive and attentional resources. Although a one-person operation does not involve the information exchange described previously, the SMEs observed information exchange to have its own issues. These issues arise from both the inability of the tools to integrate information and from the high memory load imposed on an individual controller. However, once again this study could not measure the extent to which this would directly affect workload, SA, or both, particularly under high traffic loads.

We examined the human factors issues within six categories for this project (i.e., concept of use, CHI, information flow, integration, coordination, and procedural issues). This expanded upon the evaluation of TMA and URET conducted by the NAS Advanced Concepts Branch (2001). The method helped us to focus on specific areas that are particularly important to air traffic. We recommend that future evaluations of decision support tools and system collocation adopt a similar strategy.

For this project, we selected the CTA en route task analysis (CTA, Inc., 1990) with the Rodgers and Drechsler (1993) revisions. We recognize that it is dated; however, it was the most complete analysis that served our purposes. We did not rewrite the task descriptions, nor did we do a new task analysis of the activities that each tool would add to the controllers' jobs. Such a task analysis was beyond the scope of this project. However, we recommend that a new job task analysis be conducted, which examines task performance when using the DSR environment and the three tools.

This study presented a systematic, human factors evaluation of collocating URET, TMA, and CPDLC. We applied standard human factors guidelines and principles of cognitive psychology to the analysis. We verified and extended the findings of the three prior studies of collocating two of the three systems. By use of the cognitive walkthrough, we identified some more subtle aspects related to the simultaneous use of the three tools. The project was limited, however, because it did not examine any functional systems. These findings should be validated both by using SMEs more familiar with the specific systems and by using human-in-the-loop simulations to answer the most pressing psychological issues, such as how collocation of the three tools would impact workload and SA. Through these steps, the FAA can address all of the potential issues from this report in the course of the Free Flight Program's spiral development plans.

6. RECOMMENDATIONS

Researchers derived several specific recommendations from this analysis, as follows:

1. The inconsistencies in the CHIs across systems should be examined, and, to the extent possible, a consistent format should be adopted.
2. The RA-side CHI should minimally integrate CPDLC information into URET's Aircraft List, and, if possible, integrate the systems into one.
3. Clear procedures should be established for anyone who enters data that reach the NAS.
4. Procedures should be established for handling two-person sector operations that help controllers prioritize and clearly communicate important information from each system.

In addition, researchers recommend obtaining more objective measures (i.e., via actual human-in-the-loop simulation) on the impact of collocating the three tools. We list the recommendations in order of importance:

1. Conduct a cognitive walkthrough with field controllers who have operational experience with one of the systems or test and evaluation experience with CPDLC. This walkthrough would check and refine issues identified in this report and potentially identify additional issues.
2. Conduct a human-in-the-loop simulation to assess the effect of collocation on controller SA, workload, and performance, with particular emphasis on the following questions:
    a. What is the effect of the increased information from all three tools?
    b. What is the effect of the increased communication requirements?
    c. What is the effect of the differences in the CHI?
    d. What is the effect of the different tools updating NAS?
    e. Is there an issue with clutter on both the RA-side and R-sides?
    f. Are there issues unique to a single R-side operation?
    g. Is there an interaction with the ATDET CHI when collocating the three tools?
3. Design and conduct a simulation of an integrated URET and CPDLC CHI for the RA-side and develop additional metrics for these assessments.

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Acronyms

AERA	Automated En Route Air Traffic Control
ARTCC	Air Route Traffic Control Center
ATC	Air Traffic Control
ATCS	Air Traffic Control Specialist
ATDET	Air Traffic DSR Evolution Team
ATL	Atlanta-Hartsfield International Airport
CAASD	Center for Advanced Aviation System Development
CCLD	Core Capability Limited Deployment
CHI	Computer-Human Interface
CPDLC	Controller Pilot Data Link Communications
CRD	Computer Readout Display
CTAS	Center Terminal Radar Approach Control Automation System
DSR	Display System Replacement
ETA	Estimated Time of Arrival
FAA	Federal Aviation Administration
FFP1	Free Flight Program Phase 1
FFP2	Free Flight Program Phase 2
HFS	Human Factors Specialist
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NATCA	National Air Traffic Controllers Association
NPR	NAS Preferred Routing
PDF	Portable Document Format
R&D	Research and Development
R	Radar
RA	Radar Associate
SA	Situational Awareness
SD	Standard Diviation
SME	Subject Matter Expert
STA	Scheduled Time of Arrival
TMA	Traffic Management Advisor
TMC	Traffic Management Coordinator
TMU	Traffic Management Unit
TOC	Transfer of Communication
TRACON	Terminal Radar Approach Control
URET	User Request Evaluation Tool
WJHTC	William J. Hughes Technical Center
ZTL	Atlanta Air Route Traffic Control Center

Appendix A

Task by Tool Matrix

Category	**URET**		**TMA**		**CPDLC**	
Position	**R-side**	**RA-side**	**R-side**	**RA-side**	**R-side**	**RA-side***
I. Perform situation monitoring. ***ACTIVITY LEVEL***						
A. Check and evaluate separation.-*SUBACTIVITY LEVEL*						
1. Review the radar display for potential violation of aircraft separation standards.- *TASK LEVEL*	X	X				
2. Project mentally an aircraft's future position, altitude, and path.	X	X				
3. Request range, bearing, and/or time message with options.						
4. Force/quick look full data block(s) to examine track information on aircraft.	X	X				
5. Determine whether aircraft may become separated by less than prescribed minima.	X	X				
6. Review the radar display for potential violation of airspace separation standards.	X	X				
7. Review the radar display for potential violation of conformance criteria.	X	X				
8. Determine whether airspace separation standards may be violated.	X	X				
9. Determine whether conformance criteria may be violated.	X	X	X			
10. Determine whether flow restrictions may be violated.			X			
11. Request display route of flight.	X	X				
12. Observe progress of an aircraft on radar display.						
13. Review flight strip bay for present and/or future aircraft separation.	X	X				

*Assumes tool will be available for this controller position.

Category	URET		TMA		CPDLC	
Position	**R-side**	**RA-side**	**R-side**	**RA-side**	**R-side**	**RA-side***
14. Review displays/records for potential violation of flow restrictions.			X			
15. Observe track velocity to project aircraft movement.	X	X				
B. Analyze initial requests for clearance.						
1. Search flight strip bay for inactive flight plan clearance request.	X	X				
2. Request flight plan readout (FR).	X	X				
3. Request pilot to file/re-file flight plan.						
C. Process departure/en route time information.						
1. Enter departure/en route time message.						
2. Initiate track manually.						
3. Observe automatic track restart.						
4. Receive departure/en route time notice.	X	X				
D. Process request for flight following.						
1. Evaluate conditions for providing flight following.	X	X				
2. Inform the pilot of alternate instructions necessary for flight following service.	X	X				
3. Receive request for flight following.						
4. Deny the flight following request.						
E. Housekeeping.						
1. Offset a data block.	X	X				

Category	**URET**		**TMA**		**CPDLC**	
Position	**R-side**	**RA-side**	**R-side**	**RA-side**	**R-side**	**RA-side***
2. Delete (remove) flight plan and track from local host system (RX).	X	X				
3. Restore data block to radar display.	X	X				
4. Obtain flight progress strip.	X	X				
5. Resequence flight progress strips.	X	X				
6. Review flight progress strip to ensure all data have been forwarded to the next controller/facility.						
7. Review flight progress strips for deadwood.	X	X				
8. Update/revise controller note.	X	X				
9. Suppress data block from radar display.	X	X				
10. Record strip marking on flight progress strip.						
11. Delete flight plan and track from ATC system.	X	X				
12. Remove flight progress strip.	X	X				
13. Delete controller note.	X	X				
14. Remove obsolete paper records or recorded data.						
II. Resolve aircraft conflicts.						
A. Perform aircraft conflict resolution.						
1. Determine validity of potential aircraft conflict notice or indication.	X	X				
2. Receive notice of potential aircraft conflict in the sector.	X	X				
3. Inform controller of potential aircraft conflict in his sector.	X	X				
4. Review the potential conflict situation for resolution.	X	X				

Category	**URET**		**TMA**		**CPDLC**	
Position	**R-side**	**RA-side**	**R-side**	**RA-side**	**R-side**	**RA-side***
5. Determine appropriate action to resolve aircraft conflict situation.	X	X				
6. Perceive potential aircraft conflict situations.	X	X				
7. Receive pilot notice of traffic in sight.						
8. Formulate safety alert content.						
9. Issue safety alert in regard to traffic proximity.						
10. Detect aircraft maneuver in response to safety alert.						
11. Inform pilot when clear of traffic.						
12. Formulate advisory content.						
13. Issue a traffic advisory in regard to traffic proximity.						
14. Detect aircraft maneuver in response to advisory.						
15. Forward notice of aircraft conflict to supervisor.						
16. Detect aircraft conflict/Mode C intruder (MCI) alert indication.						
B. Perform minimum safe altitude processing.						
1. Detect MSAW indication or alarm.						
2. Receive notice of a potential low altitude situation/MSAW in sector.						
3. Inform controller of potential low altitude situation/MSAW in his sector.						
4. Perceive potential low altitude situation.						
5. Determine validity of MSAW/ altitude notice or MSAW indication.						
6. Determine appropriate action to resolve a low altitude/MSAW situation.						

Category	URET		TMA		CPDLC	
Position	**R-side**	**RA-side**	**R-side**	**RA-side**	**R-side**	**RA-side***
7. Observe radar display for fixed obstructions/terrain that may interfere with aircraft flight.						
8. Issue safety alert in regard to low altitude situation.						
9. Forward notice of valid MSAW or flight assist to supervisor.						
C. Perform airspace conflict processing.						
1. Perceive potential airspace conflict situation.	X	X				
2. Determine appropriate action to resolve airspace conflict situation.	X	X				
3. Forward notice of potential/ actual airspace conflict to supervisor.						
4. Issue advisory in regard to special use airspace proximity.	X	X			X	X
5. Request release of special use airspace.						
6. Receive denial of use of special use airspace.						
7. Receive approval for use of special use airspace.						
8. Determine validity of airspace conflict notice.	X	X				
9. Inform controller of potential airspace conflict in his sector.	X	X				
10. Receive notice of potential airspace conflict in sector.	X	X				
D. Suppress/restore alerts.						
1. Suppress conflict alert for paired aircraft.						
2. Suppress conflict alert for group suppression.						
3. Suppress MSAW function for an aircraft.						
4. Determine validity/ appropriateness of display of an alert.	X	X				

Category	**URET**		**TMA**		**CPDLC**	
Position	**R-side**	**RA-side**	**R-side**	**RA-side**	**R-side**	**RA-side***
5. Restore specific alert function to normal.						
III. Manage air traffic sequences.						
A. Respond to traffic management constraints/flow considerations.						
1. Evaluate traffic management constraints for effect on traffic flow.	X	X	X			
2. Review options to bring aircraft into conformance with traffic management restrictions.	X	X	X			
3. Choose option to bring aircraft into conformance with traffic management restrictions.	X	X				
4. Negotiate traffic management action with pilot.					X	X
5. Receive traffic management restriction.			X			
6. Discuss discontinuance of traffic management restriction/ traffic to reroute with others.						
7. Receive metering data.			X			
8. Receive supervisor briefing on what traffic conditions to expect.						
9. Request metering list.						
10. Receive notice to hold/reroute traffic clear of contingency.	X	X	X			
11. Receive notice to implement traffic management restrictions.	X	X	X			
12. Request traffic management restriction.						
13. Request exception to traffic management restriction.						
14. Review traffic demands and traffic management restrictions with others.						

Category	URET		TMA		CPDLC	
Position	**R-side**	**RA-side**	**R-side**	**RA-side**	**R-side**	**RA-side**
15. Receive approval of request for exception to flow restriction.						
16. Receive denial of request for exception to flow restriction.						
B. Process deviations.						
1. Perceive an altitude or route deviation.	X	X				
2. Observe aircraft resuming conformance to clearance.	X	X				
3. Determine maneuver to establish/restore flight plan conformance.	X	X				
4 Detect lateral/altitude nonconformance indication.	X	X				
5. Evaluate flight data to determine future course of action.	X	X				
6. Evaluate lateral nonconformance indication for action needed.	X	X				
7. Evaluate altitude nonconformance indication for action needed.	X	X				
8. Evaluate unreasonable Mode C indication for action needed.						
9. Detect unreasonable Mode C indication.						
10. Verify altimeter setting.					X	X
11. Inform pilot to reset altimeter/ stop Mode C squawk.						
12. Request printing of flight strip(s) on flight plan.	X	X				
13. Receive controller notice of aircraft flight plan deviation.	X	X				
14. Inform controller/supervisor of aircraft flight plan deviation.	X	X				
C. Respond to special use airspace events.						
1. Inform others of airspace status change.						

Category	URET		TMA		CPDLC	
Position	**R-side**	**RA-side**	**R-side**	**RA-side**	**R-side**	**R-side**
2. Observe record of airspace status change.	X	X				
3. Receive notice of airspace status change.	X	X				
4. Determine restrictions to users necessary within released airspace.						
5. Inform others on conditions of release of special use airspace.						
6. Receive request for special use airspace.						
D. Establish arrival sequences.						
1. Determine descent time or point.	X	X				
2. Project traffic sequence to establish/modify approach flow to airport or sector.	X	X	X			
3. Observe sector metering list for metering requirements.			X			
4. Project mentally the range/ bearing between aircraft.	X	X				
5. Project mentally the arrival flow for aircraft landing in or near this sector.	X	X				
6. Issue current arrival information.					X	X
7. Observe radar target/data block of arrival aircraft.	X	X				
8. Determine approach sequence.			X			
9. Record necessary flight plan data.	X	X			X	X
10. Forward arrival sequence to tower controller.						
11. Request that aircraft be rerouted.	X	X				
E. Manage departure flows.						
1. Project traffic sequence to establish/modify departure flow.	X	X				
2. Receive notice of missed approach.						

Category	URET		TMA		CPDLC	
Position	**R-side**	**RA-side**	**R-side**	**RA-side**	**R-side**	**RA-side***
3. Receive request for release of departure aircraft from tower.						
4. Forward departure release.						
F. Monitor non-controlled objects.						
1. Observe airspace intrusion by non-controlled object (e.g., balloon, glider).						
2. Observe (monitor) a non-controlled object.						
3. Forward notice of airspace intrusion by non-controlled object.						
4. Receive notice of airspace intrusion by non-controlled object.						
5. Issue advisory in regard to non-controlled object.					X	X
6. Inform pilot when clear of non-controlled object.						
7. Record controller note.						
G. Respond to temporary release of airspace requests.						
1. Suppress map associated with temporary use airspace.	X	X				
2. Discuss release of airspace for temporary use.						
3. Select map display of adapted airspace requested for use by another controller.	X	X				
4. Evaluate feasibility of releasing airspace temporarily.	X	X				
5. Receive request temporary use of airspace.						
6. Forward approval for temporary use of airspace.						
7. Forward denial of temporary use of airspace.						
8. Receive notification of return of released airspace.	X	X				

Category	**URET**		**TMA**		**CPDLC**	
Position	**R-side**	**RA-side**	**R-side**	**RA-side**	**R-side**	**RA-side***
H. Request temporary release of airspace.						
1. Request temporary use of airspace.						
2. Receive release/use of airspace.						
3. Receive rejection of use of airspace.						
4. Forward notice of return of released airspace.						
IV. Route or flight plans.						
A. Plan clearances.						
1. Discuss Evaluate alternate suggestion for clearance/approval requested of another controller.	X	X				
2. Review potential impediments for impact on proposed clearance.	X	X				
3. Discuss clearance alternatives with pilot/relayer.	X	X				
4. Evaluate flight progress strip changes for clearance planning or future actions.	X	X				
5. Determine priority of control actions.	X	X	X			
6. Perceive the need for amended clearance.	X	X	X			
7. Formulate a plan of action for clearance generation.	X	X				
8. Evaluate a mental flight projection for appropriateness.	X	X	X			
9. Determine appropriate action for aircraft clearance.	X	X	X			
10. Receive requested flight plan changes.					X	X
11. Receive clearance request.					X	X
12. Receive controller request for clearance/approval.	X	X				
13. Forward clearance request to another controller.	X	X				

Category	**URET**		**TMA**		**CPDLC**	
Position	**R-side**	**RA-side**	**R-side**	**RA-side**	**R-side**	**RA-side***
14. Request clearance/approval from another controller.	X	X				
15. Receive clearance approval/ clearance restrictions from another controller.	X	X				
16. Receive clearance disapproval/ denial from another controller.	X	X				
B. Respond to contingencies/ emergencies.						
1. Advise supervisor of emergency.						
2. Issue instructions to NORDO aircraft for identification turn/ transponder response.					X	X
3. Detect pilot or aircraft problem (e.g., hypoxia, emergency beacon code).						
4. Inform designated emergency response personnel of aircraft having flight problems.						
5. Conduct a search for aircraft without radio contact.	X	X			X	X
6. Observe aircraft identification turn.						
7. Conduct radio/ radar search for overdue aircraft.	X	X				
8. Receive supervisor notice to conduct communications search for overdue/NORDO aircraft.						
9. Receive notice that the supervisor will conduct a communications search for overdue/NORDO aircraft.						
10. Receive pilot notice of emergency declared.	X	X				
11. Determine appropriate emergency/contingency actions.	X	X				
12. Receive termination notice/ time of emergency / contingency.						
13. Forward termination notice/						

Category	**URET**		**TMA**		**CPDLC**	
Position	**R-side**	**RA-side**	**R-side**	**RA-side**	**R-side**	**RA-side***
time of emergency / contingency.						
14. Receive notice of emergency declared and contingency plan invoked.						
15. Review contingency/ emergency checklist on static record.						
16. Declare an emergency.	X	X			X	X
17. Receive notice of a pilot or aircraft having problems (e.g., overdue, loss of radio contact).	X	X			X	X
18. Forward contingency/ emergency information to others.						
19. Request relay of instructions to NORDO aircraft for identification turn/transponder response.					X	X
20. Conduct emergency actions.						
C. Respond to special operations.						
1. Perceive presence of special operation.						
2. Receive review/notice of special operation.	X	X				
3. Forward notice of special operations to another controller/ supervisor.	X	X				
4. Conduct special operation actions.						
5. Receive notice of termination of special operation.	X	X				
6. Forward notice of termination of special operation.	X	X				
D. Review flight plans.						
1. Observe new flight progress strip.	X	X				
2. Review flight plan for completeness.	X	X				
3. Review flight progress strip for	X	X				

Category	**URET**		**TMA**		**CPDLC**	
Position	**R-side**	**RA-side**	**R-side**	**RA-side**	**R-side**	**RA-side***
flight plan errors.						
4. Receive flight plan from pilot.					X	X
5. Receive flight plan data verbally/physically and/or electronically forwarded.	X	X				
6. Question pilot about the flight plan.						
7. Forward the flight plan data.	X	X				
8. Enter stereo flight plan into the system.	X	X				
9. Record new flight plan data on flight progress strip.	X	X				
10. Enter flight plan into the system.	X	X				
11. Inform pilot/relayer of required flight plan changes.					X	X
12. Question the relayer of a flight plan.						
E. Process flight plan amendments.						
1. Enter flight plan amendment into system.	X	X				
2. Enter pilot’s position report into system.	X	X				
3. Receive flight plan amendment data that was verbally forwarded.	X	X				
4. Receive pilot’s position report.						
5. Forward flight plan amendment data.	X	X				
6. Determine the need for a flight plan amendment.	X	X				
7. Question the pilot/controller on the flight plan amendment.						
8. Forward pilot’s position report.	X	X				
9. Receive computer message of flight plan amendment.	X	X				
10. Record flight plan amendment data on flight progress strip.	X	X				
11. Flag flight progress strip for reminder action.	X	X				
12. Unflag the flight progress strip.	X	X				
13. Forward request for flight plan	X	X				

Category	URET		TMA		CPDLC	
Position	**R-side**	**RA-side**	**R-side**	**RA-side**	**R-side**	**RA-side***
amendment to other controller.						
14. Review aircraft speed/ time for amendment.	X	X				
15. Inform controller if unable to amend flight plan.	X	X				
16. Receive controller notification if unable to amend flight plan.					X	X
F. Receive transfer of control/ radar identification.						
1. Receive handoff request.					X	X
2. Accept verbal handoff.						
3. Accept automatic handoff.						
4. Determine that aircraft is entering sector.						
5. Determine response to handoff request.						
6. Receive handoff retraction.						
7. Request transfer of control.						
8. Receive control of aircraft.						
9. Deny handoff.						
G. Initiate transfer of control/ radar identification.						
1. Initiate handoff.						
2. Observe automatic initiation of handoff.						
3. Retract handoff.						
4. Receive handoff acceptance.						
5. Discuss transfer of control with other controller.						
6. Determine that aircraft is leaving sector.						
7. Detect manual handoff mode indication.						
8. Initiate transfer of flight data to another controller/ facility.						
9. Receive handoff rejection.						
10. Receive request for transfer of control.						
11. Inform controller of any conditions affecting transfer of control.						

Category	**URET**		**TMA**		**CPDLC**	
Position	**R-side**	**RA-side**	**R-side**	**RA-side**	**R-side**	**RA-side***
12. Inform controller of relinquished control of aircraft.						
H. Issue point outs.						
1. Initiate point out.						
2. Discuss point out with other controller.						
3. Receive acceptance of point out.						
4. Receive rejection of point out.						
I. Respond to points outs.						
1. Receive point out request.						
2. Suppress full data block after point out request.						
3. Determine response to point out.						
4. Accept point out.						
5. Deny point out.						
J. Issue clearances.						
1. Suggest clearance alternatives to pilot.	X	X				
2. Formulate a clearance with appropriate instructions.	X	X				
3. Issue clearance and instructions to pilot.					X	X
4. Detect read-back of issued clearance.					X	X
5. Verify aircraft compliance with clearance.	X	X			X	X
6. Question pilot/ relayer regarding conformance with clearance.						
7. Issue clearance through others for relay pilot.						
8. Approve clearance request.					X	X
9. Deny clearance request.					X	X

Category	URET		TMA		CPDLC	
Position	**R-side**	**RA-side**	**R-side**	**RA-side**	**R-side**	**RA-side***
10. Suggest alternative(s) to clearance request from controller.	X	X				
K. Establish, maintain, or terminate radio communications.						
1. Receive request to cancel air traffic services.						
2. Terminate radio communications with aircraft.						
3. Receive arrival message.3. Receive arrival message.						
4. Determine frequency in use by receiving sector.					X	X
5. Issue change of frequency to pilot.					X	X
6. Receive initial radio contact from pilot.					X	X
7. Issue altimeter setting.					X	X
8. Verify aircraft assigned altitude.					X	X
9. Validate Mode C altitude.					X	X
10. Enter reported altitude (non-radar A/C).						
L. Establish radar identification.						
1. Observe target entering radar coverage.						
2. Inform pilot that radar contact is established.						
3. Observe radar target on departing aircraft within one mile of takeoff runway.						
4. Observe beacon target change to specific code.						

Category	URET		TMA		CPDLC	
Position	**R-side**	**RA-side**	**R-side**	**RA-side**	**R-side**	**RA-side**
5. Observe radar target associated with handoff/ point out.						
6. Inform pilot to make identifying turn.						
7. Request pilot squawk ident.						
8. Observe data block ident.						
9. Request that pilot change transponder to standby.						
10. Observe loss of beacon target.						
11. Request that pilot return transponder to normal.						
12. Observe reappearance of beacon target.						
13. Inform pilot of radar position.						
14. Observe radar target corresponding to pilot report.						
15. Request beacon code for aircraft.						
16. Assign beacon code to aircraft.						
17. Reassociate data block.						
18. Observe data block not associated with target.						
19. Initiate use of radar separation standards.						
V. Assess weather impact.						
A. Respond to significant weather information.						
1. Receive weather briefing.						
2. Determine whether another controller or pilot needs weather advisory.						
3. Issue weather/ advisory/ update to others.					X	X
4. Receive weather advisory (e.g., SIGMET, AIRMET).						
5. Forward weather/ PIREP information.					X	X
6. Request weather information.						
7. Broadcast weather information.					X	X

Category	**URET**		**TMA**		**CPDLC**	
Position	**R-side**	**RA-side**	**R-side**	**RA-side**	**R-side**	**RA-side**
8. Observe radar display of weather line/ intensity/ movement.						
9. Determine weather impact on routes/ flow.	X	X				
10. Determine altitude/ route change to bypass severe weather.	X	X				
11. Evaluate the impact of a new weather condition.	X	X				
12. Receive new routing for weather avoidance.	X	X				
13. Forward urgent PIREP to others.						
14. Record PIREP.						
15. Review weather information on displays/ records.						
16. Receive PIREP on weather.						
17. Inform others of weather impact on routes/ flow.					X	X
18. Receive controller request for weather information.						
B. Process weather reports.						
1. Determine whether usable flight level has changed.						
2. Determine whether runway conditions have changed.			X			
3. Determine weather conditions in control zone for application of separation criteria.						
4. Request PIREP.						
5. Receive general NOTAM.						
6. Receive airport environmental information.						
7. Receive runway use data.						
8. Receive airport specific NOTAM.						
9. Forward runway use data.						
10. Receive weather report/ update (e.g., hourly surface observation, other reports).						

Category	**URET**		**TMA**		**CPDLC**	
Position	**R-side**	**RA-side**	**R-side**	**RA-side**	**R-side**	**RA-side**
VI. Manage sector/ position resources.						
A. Brief relieving controllers.						
1. Brief relieving controller.						
2. Verify completeness of relief briefing.						
3. Sign off at position log.						
B. Assume position responsibility.						
1. Review system status to determine currency/ update self.						
2. Verify that all required display parameters are properly set.						
3. Adjust parameters and displays/ equipment to personal preference.						
4. Check displays/ equipment for proper configuration, usability, and satisfactory status.						
5. Review briefing checklist to assure completeness of briefing coverage.						
6. Determine if ready to accept control responsibility.						
7. Receive controller relief briefing.						
8. Inhibit automatic handoff for all tracks or for designated track.						
9. Restore automatic handoff for all tracks or for designated track.						
10. Review flight progress strips and display lists for correlation.	X	X				
11. Sign on position log.						
12. Review current and projected traffic/ weather.	X	X				

Category	**URET**		**TMA**		**CPDLC**	
Position	**R-side**	**RA-side**	**R-side**	**RA-side**	**R-side**	**RA-side**
C. Execute backup procedures for processing/ peripheral equipment failures.						
1. Verify computer action during transition stages.	X	X				
2. Receive confirmation of computer action during transaction stages.	X	X			X	X
3. Detect non-acceptance of input data.	X	X			X	X
4. Receive notice of adjacent facility automation equipment status.						
5. Forward notice of equipment status.						
6. Detect failure to update flight plan data base.	X	X			X	X
7. Receive notice of equipment or operational status.	X	X			X	X
8. Revert to host/ DARC backup procedures.						
9. Revert to host reduced capability mode procedures.						
10. Detect occurrence of radar display failure.						
11. Observe data base restoration on radar display.						
12. Detect occurrence of host failure.	X	X			X	X
13. Select DARC for generation of radar display.						
14. Select host for generation of radar display.						
15. Observe posted notice of new/ changed equipment/ operational status.						
16. Request DARC be enabled.						
17. Verify flight plan database during transition.	X	X				

Category	URET		TMA		CPDLC	
Position	**R-side**	**RA-side**	**R-side**	**RA-side**	**R-side**	**RA-side**
D. Execute backup NAVAID procedures.						
1. Determine aircraft needing substitute routing.	X	X				
2. Receive notice of NAVAID status.						
3. Receive substitute routing.						
4. Discuss appropriateness with supervisor of releasing equipment to maintenance.						
5. Review need/ cancellation of substitute routing with supervisor.						
6. Receive supervisor notice of equipment released to maintenance.						
7. Record substitute routing on paper record.						
8. Review status of questionable NAVAID.						
9. Observe record of substitute routing.						
10. Forward substitute routing.						
11. Forward deletion of previous substitute routing.						
12 Forward NAVAID status.						
13. Record system status data change.						
14. Receive cancellation of substitute routing.						
15. Request report on NAVAID status.						
E. Execute backup procedures for communication failures/ transient operation.						
1. Detect communication failure or transient operation.	X	X				
2. Forward alternate communication path.					X	X
3. Receive new frequency assignment.						

Category	URET		TMA		CPDLC	
Position	**R-side**	**RA-side**	**R-side**	**RA-side**	**R-side**	**RA-side**
4. Forward notice of communication status.						
5. Receive notice of alternate communication path.						
6. Check status of personal/ console communications equipment.						
7. Receive notice of communication status.						
8. Switch to back-up air-to-ground equipment/ radio/ frequency/ BUEC.						
9. Request communication check from others.						
10. Receive communication check from others.						
11. Select original air-to-ground communications equipment/ frequency.						
12. Adjust ground-to-ground communication path to return to normal operation.						
13. Adjust ground-to-ground communication path to accommodate failure/ overload.						
14. Forward new frequency assignment.					X	X
15. Record communications status.						
F. Manage personal workload.						
1. Determine impending controller overload.						
2. Request assistance or relief.						
3. Request flow control (Reroute) be imposed or altered.						

Category	URET		TMA		CPDLC	
Position	**R-side**	**RA-side**	**R-side**	**RA-side**	**R-side**	**RA-side**
G. Perform procedures for non-radar/ degraded radar environment.						
1. Inform pilot of radar contact lost.						
2. Terminate radar service to aircraft.						
3. Initiate use of non-radar separation standards.	X	X			X	X
4. Request pilot position reports.						
5. Observe return of normal radar environment.						
6. Observe loss of radar target.					X	X
7. Receive notice of radar sensor status.						
8. Receive procedures to be used to accommodate sensor outage.						
9. Perceive tracking or transponder failure/interference.						
10. Forward notice of radar sensor status.						
11. Record pilot position report.						
H. Respond to airspace reconfigurations/ resectorizations.						
1. Receive notice to release airspace.						
2. Receive notice that adjacent facility is open.						
3. Receive notice that adjacent facility is closed.						
4. Request airspace reconfiguration.						
5. Receive notice to take over airspace.						
6. Receive notice to prepare for sector reconfigurations.						
7. Inform others of sector airspace reconfiguration.						

Rodgers & Drechsler, 1993.

Appendix B

Task by Information Matrix

Tasks	DSR	URET	TMA	CPDLC
Check and Evaluate Separation	A. Data Block 1. Speed 2. Altitude 3. Route 4. Halo	I. Aircraft List A. Rows 1. Speed 2. Altitude 3. Route 4. Numerical Alert II. Graphic Plan Display A. Data Block 1. Numerical Alerts 2. Altitude 3. Speed B. Other 1. Route Trajectory III. Plans Display A. Flight Plan 1. Route	A. Metering list 1. Metering Time	
Analyze Initial Requests for Clearance	A. Data Block 1. Speed 2. Altitude 3. Route 4. Halo B. Other 1. Traffic-Airspace Awareness 2. Weather	A. Plans Display 1.Trial Plan Responses -Accept -Cleared -Unable	A. Metering list 1. Metering Time	

Tasks	DSR	URET	TMA	CPDLC
Process departure/en route time info		A. Departure list "Automatically posted" 1. Departure time 2. Flight ID 3. A/C Type and Equipage 4. Altitude 5. Beacon Code 6. Route	A. Metering list 1. Metering Time	
Process request for flight following	Aircraft ID Aircraft Path			
Housekeeping	A. Data Block 1. Highlights Offset Data Blocks	A. Clean Up Function	A. Sent List	A. Hung up Messages

Tasks	**DSR**	**URET**	**TMA**	**CPDLC**
Perform Aircraft conflict Resolution	A. Data Block 1. Speed 2. Altitude 3. Route 4. Halo	I. Aircraft List A. Rows 1. Speed 2. Altitude 3. Route 4. Numerical Alert II. Graphic Plan Display A. Data Block 1. Numerical Alerts 2. Altitude 3. Speed B. Other 1. Route Trajectory III. Plans Display A. Flight Plan 1. Route		
Perform Minimum Safe Altitude Processing	A. Data Block 1. Altitude			

Tasks	**DSR**	**URET**	**TMA**	**CPDLC**
Perform Airspace conflict processing	A. Video Map 1. Airspace Boundaries B. Other 1. Route C. Data Block 1. Altitude 2. Heading	I. Aircraft List A. Rows 1. Speed 2. Altitude 3. Route 4. Numerical Alert 5. Status Symbol II. Graphic Plan Display A. Data Block 1. Numerical Alerts 2. Altitude 3. Speed B. Menu 1. Route Trajectory 2. Restrictions III. Plans Display A. Flight Plan 1. Route		
Suppress/Restore Alerts				

Tasks	DSR	URET	TMA	CPDLC
Respond to Traffic Mgmt Constraints/Flow Considerations	A. Data Block 1. Speed 2. Altitude 3. Route 4. Halo	I. Aircraft List A. Rows 1. Speed 2. Altitude 3. Route 4. Numerical Alert 5. Status Symbol II. Graphic Plan Display A. Data Block 1. Numerical Alerts 2. Altitude 3. Speed B. Menu 1. Route Trajectory 2. Restrictions III. Plans Display A. Flight Plan 1. Route	A. Metering list 1. Metering Time	
Process deviations	A. Data Block 1. Speed 2. Altitude 3. Route 4. Halo	I. Aircraft List A. Rows 1. Speed 2. Altitude 3. Route II. Graphic Plan Display A. Data Block 1. Altitude 2. Speed B. Menu 1. Route Trajectory III. Plans Display A. Flight Plan 1. Route	A. Metering list 1. Metering Time	

Tasks	**DSR**	**URET**	**TMA**	**CPDLC**
Respond to special use airspace events	A. Data Block 1. Speed 2. Altitude 3. Route 4. Halo	I. Aircraft List A. Rows 1. Speed 2. Altitude 3. Route II. Graphic Plan Display A. Data Block 1. Altitude 2. Speed B. Menu 1. Route Trajectory III. Plans Display A. Flight Plan 1. Route		
Establish arrival sequence	A. Data Block 1. Speed 2. Altitude 3. Route 4. Halo	I. Aircraft List A. Rows 1. Speed 2. Altitude 3. Route 4. Numerical Alert II. Graphic Plan Display A. Data Block 1. Numerical Alerts 2. Altitude 3. Speed B. Other 1. Route Trajectory III. Plans Display A. Flight Plan 1. Route	A. Metering list 1. Metering Time	A. Window 1. Uplink B. Data Block 1. Box I.D. 2. Line Zero

Tasks	**DSR**	**URET**	**TMA**	**CPDLC**
Manage departure flows	A. Data Block 1. Speed 2. Altitude 3. Route 4. Halo	I. Aircraft List A. Rows 1. Speed 2. Altitude 3. Route 4. Numerical Alert II. Graphic Plan Display A. Data Block 1. Numerical Alerts 2. Altitude 3. Speed B. Other 1. Route Trajectory III. Plans Display A. Flight Plan 1. Route	A. Metering list 1. Metering Time 2. Estimated Departure Control Times (EDCT's)	
Monitor non-controlled objects	N/A	N/A		

Tasks	DSR	URET	TMA	CPDLC
Respond to temporary release of airspace requests	A. Data Block 1. Speed 2. Altitude 3. Route 4. Halo	I. Aircraft List A. Rows 1.Speed 2. Altitude 3. Route 4. Numerical Alert II. Graphic Plan Display A. Data Block 1. Numerical Alerts 2. Altitude 3. Speed B. Other 1. Route Trajectory III. Plans Display A. Flight Plan 1. Route		A. Window 1. Uplink B. Data Block 1. Box I.D. 2. Line Zero

Tasks	**DSR**	**URET**	**TMA**	**CPDLC**
Request temporary release of airspace	A. Data Block 1. Speed 2. Altitude 3. Route 4. Halo	I. Aircraft List A. Rows 1. Speed 2. Altitude 3. Route 4. Numerical Alert II. Graphic Plan Display A. Data Block 1. Numerical Alerts 2. Altitude 3. Speed B. Other 1. Route Trajectory III. Plans Display A. Flight Plan 1. Route		

Tasks	DSR	URET	TMA	CPDLC
Plan Clearances	A. CRD 1. AircraftID 2. Callsign 3. Beacon Code 4. Route of Flight 5. Altitude	I. Aircraft List A. Rows 1. Speed 2. Altitude 3. Route 4. Numerical Alert II. Graphic Plan Display A. Data Block 1. Numerical Alerts 2. Altitude 3. Speed B. Other 1. Route Trajectory III. Plans Display A. Flight Plan 1. Route 2. Request Status		

Tasks	DSR	URET	TMA	CPDLC
Respond to contingencies/emergencies	A. CRD 1. AircraftID 2. Callsign 3. Beacon Code 4. Route of Flight 5. Altitude	I. Aircraft List A. Rows 1. Speed 2. Altitude 3. Route 4. Numerical Alert II. Graphic Plan Display A. Data Block 1. Numerical Alerts 2. Altitude 3. Speed B. Other 1. Route Trajectory III. Plans Display A. Flight Plan 1. Route 2. Request Status	A. Metering list 1. Metering Time	
Respond to special operations	N/A	N/A		
Review Flight Plans	A. CRD 1. Route of Flight	A. Plans Display 1. Plans		
Process Flight Plan Amendments		A. Plans Display 1. Amendment Message Plans (AM)	A. Metering list 1. Metering Time	
Receive transfer of control	A. Data Block 1. Altitude 2. Speed 3. Heading B. Other 1. Route	N/A	A. Metering list 1. Metering Time	

Tasks	DSR	URET	TMA	CPDLC
Initiate transfer of control	A. Data Block 1. Altitude 2. Speed 3. Heading B. Other 1. Route	N/A		A. Window 1. Uplink B. Data Block 1. Box I.D. 2. Line Zero
Issue of Point outs	A. Other 1. PO Sector Bidet Block 1. Altitude 2. Speed 3. Heading	N/A		
Respond to Point outs	A. Data Block 1. Altitude 2. Speed 3. Heading B. Other 1. Route			

Tasks	DSR	URET	TMA	CPDLC
Issue Clearances	A. Data Block 1. Altitude 2. Speed 3. Heading B. Other 1. Route	I. Aircraft List A. Rows 1. Speed 2. Altitude 3. Route 4. Numerical Alert II. Graphic Plan Display A. Data Block 1. Numerical Alerts 2. Altitude 3. Speed B. Other 1. Route Trajectory III. Plans Display A. Flight Plan 1. Route 2. Request Status		A. Window 1. Uplink B. Data Block 1. Box I.D. 2. Line Zero
Establish Radio Comms.	N/A	N/A		A. Window 1. Uplink B. Data Block 1. Box I.D. 2. Line Zero
Establish Radar Identification	Data Block 1. Flashing Hand-off symbol			

Tasks	**DSR**	**URET**	**TMA**	**CPDLC**
Respond to significant Weather Information	N/A	A. WindGrid Dpl. 1. Altitude 2. Temperature 3. Air pressure 4. Altimeter 5. Turbulence 6. Micro/wind shear		
Process weather reports		A. WindGrid Dpl. 1. Altitude 2. Temperature 3. Air pressure	A. CRD 1. WX APT ID	A. Altitude Change Message
Brief relieving controllers	A. Data Block 1. Speed 2. Altitude 3. Route 4. Halo	I. Aircraft List A. Rows 1. Speed 2. Altitude 3. Route 4. Numerical Alert II. Graphic Plan Display A. Data Block 1. Numerical Alerts 2. Altitude 3. Speed B. Other 1. Route Trajectory III. Plans Display A. Flight Plan 1. Route	A. Metering list 1. Metering Time	A. Window 1. Uplink B. Data Block 1. Box I.D. 2. Line Zero

Tasks	DSR	URET	TMA	CPDLC
Assume position responsibility	A. Data Block 1. Speed 2. Altitude 3. Route 4. Halo	I. Aircraft List A. Rows 1. Speed 2. Altitude 3. Route 4. Numerical Alert II. Graphic Plan Display A. Data Block 1. Numerical Alerts 2. Altitude 3. Speed B. Other 1. Route Trajectory III. Plans Display A. Flight Plan 1. Route	A. Metering list 1. Metering Time	A. Window 1. Uplink B. Data Block 1. Box I.D. 2. Line Zero
Execute backup procedures	A. Data Block 1. Speed 2. Altitude 3. Route 4. Halo			
Execute backup NAVAID procedures				
Execute backup comm. procedures				

Tasks	DSR	URET	TMA	CPDLC
Manage personal workload	A. Data Block 1. Speed 2. Altitude 3. Route 4. Halo	I. Aircraft List A. Rows 1. Speed 2. Altitude 3. Route 4. Numerical Alert II. Graphic Plan Display A. Data Block 1. Numerical Alerts 2. Altitude 3. Speed B. Other 1. Route Trajectory III. Plans Display A. Flight Plan 1. Route	A. Metering list 1. Metering Time	A. Window 1. Uplink B. Data Block 1. Box I.D. 2. Line Zero
Perform procedures for non-radar environment		I. Aircraft List A. Rows 1. Speed 2. Altitude 3. Route 4. Numerical Alert II. Graphic Plan Display A. Data Block 1. Numerical Alerts 2. Altitude 3. Speed B. Other 1. Route Trajectory III. Plans Display A. Flight Plan 1. Route		

Tasks	DSR	URET	TMA	CPDLC
Respond to airspace reconfigurations	A. Data Block 1. Speed 2. Altitude 3. Route 4. Halo	I. Aircraft List A. Rows 1.Speed 2. Altitude 3. Route 4. Numerical Alert II. Graphic Plan Display A. Data Block 1. Numerical Alerts 2. Altitude 3. Speed B. Other 1. Route Trajectory III. Plans Display A. Flight Plan 1. Route	A. Metering list 1. Metering Time	A. Window 1. Uplink B. Data Block 1. Box I.D. 2. Line Zero

Appendix C

Human Factors Evaluation Matrix

No.	Information Type	Source	Tool	Symbology	Color	Consistency	CHI Guidelines
1	Request Response	Plans Display	URET	Alphanumeric	Green, Yellow, Red, Tan, Blue	Host is updated from both URET and CPDLC. System does not check that both tools entered consistent information. Red the highest alert in URET and Yellow in CPDLC. Blue in URET means conflict with airspace whereas blue indicates Standby message in CPDLC (diff. shades of blue). This is an area of conflict that needs to be dealt with by designers when all three tools are integrated.	**8.6.1.3** colors should be used consistently within a screen, within an application, and across a set of applications. **8.6.1.4** when color is used to identify data categories, its use shall not conflict with other color-coding conventions. **8.6.1.6**. Colors shall be easily discriminable, with each color representing only one category of observed data **8.6.2.2**. When color is used to emphasize information, the brightest color should be used for the most important information **8.6.4.2** When the user community has previously established meanings for various colors, the designer shall retain those meanings. 8.6.4.3. Color coding shall conform to the following reserved meanings consistent with conventional associations for particular colors: a. red shall indicate conditions such as no-go, error, failure or malfunction c. yellow shall indicate marginal conditions, alert users to situations where caution or rechecking is necessary, or to notify users of an unexpected delay.
		Message-In Window/ Data Block	CPDLC	Alphanumeric	Green, Blue & Yellow		

No.	Information Type	Source	Tool	Symbology	Color	Consistency	CHI Guidelines
2	Full Data Block (Display)	GPD	URET	Alphanumeric	Red, Yellow, Green, Blue, Muted Red and Muted Yellow	See issues in No 1. Yellow data block (DSR) and the yellow CPDLC messages are difficult to differentiate. This is an area of conflict that needs to be dealt with by designers when all three tools are integrated.	**8.6.1.6.** Colors shall be easily discriminable, with each color representing only one category of observed data **8.6.2.5**. When similar hues are used, they should be used with only logically related information **8.6.4.1.** Each color should represent only one category of displayed data.
		DSR	CPDLC	Alphanumeric	Yellow, Green, Blue		
3	Full Data Block (Layout)	GPD	URET	Alphanumeric	Red, Yellow, Green, Blue, Muted Red and Muted Yellow	Line 0 -- Alerts in URET and messages in CPDLC. Clickable in CPLDC not in URET. Line 3 -- Destination in URET and CID in CPDLC. Line 4 -- Absent in URET.	**8.1.1.1** Information should be presented simply and in a well-organized manner. Ways to achieve simplicity include the following: b. Information should be presented in consistent, predictable locations. **8.4.1.6.** Data shall be displayed consistently, using the standards and conventions familiar to the user. **8.1.4.7**. Data display shall be consistent in word choice, format, and basic style throughout an application and related applications.
		DSR	CPDLC	Alphanumeric	Yellow, Green, Blue		

No.	Information Type	Source	Tool	Symbology	Color	Consistency	CHI Guidelines
4	Speed	A/C List	URET	Alphanumeric	Yellow	No issues.	No Issues
		Data Block	URET	Alphanumeric	Yellow		
		Data Block	DSR	Alphanumeric	Yellow		
5	Altitude	A/C List	URET	Alphanumeric	Yellow	No issues.	No Issues
		Data Block	URET	Alphanumeric	Yellow		
		Data Block	DSR	Alphanumeric	Yellow		
6	A/C Route	CRD TEXT	DSR	Alphanumeric		Blue in AC List and Plans Display if a preferential route is present.	
		A/C List	URET	Alphanumeric			
		Plans Display	URET	Alphanumeric			
		Host AM (Trial Plan)	URET	Alphanumeric			

No.	Information Type	Source	Tool	Symbology	Color	Consistency	CHI Guidelines
7	A/C Trajectory	GPD/ GPD TP Mode	URET	Graphical	White/Tan (no track Data) / Orange (planning parameter error) / Blue(SUA) / Red, Yellow and Green for aircraft conflicts	A Yellow trajectory indicates normal condition operation on the DSR scope and it indicates conflicts within 5-12 miles of an aircraft on the URET display. As stated above- color inconsistency issues need to be dealt with by designers when all three tools are integrated.	**8.6.1.3** colors should be used consistently within a screen, within an application, and across a set of applications. **8.6.1.6**. Colors shall be easily discriminable, with each color representing only one category of observed data **8.6.4.2** When the user community has previously established meanings for various colors, the designer shall retain those meanings. **8.6.4.3**. Color coding shall conform to the following reserved meanings consistent with conventional associations for particular colors: **a.** red shall indicate conditions such as no-go, error, failure or malfunction **c.** yellow shall indicate marginal conditions, alert users to situations where caution or rechecking is necessary, or to notify users of an unexpected delay.
		SCOPE	DSR	Graphical	Yellow		

No.	Information Type	Source	Tool	Symbology	Color	Consistency	CHI Guidelines
8	Delay Status (airborne A/C)	GPD	URET		Orange (Overdue)	Inconsistency between the color coding in the URET displays with that in the TMA delay list. (However URET indication is for an overdue aircraft as opposed to TMA where it is for a delayed A/C). Since these are related colors, and because the HFDG clearly states that it is ok to use related colors to convey similarity among items, this should not be an issue.	**8.6.5.6** Similar colors should be used to convey similarity among items; examples are orange/yellow and blue/violet.
		A/C List	URET	"O"	Orange		
		Metering List	TMA		Yellow		
9	Conflict Alert	A/C List	URET	Numeric	Red/Yellow/ Blue	The URET GPD shows area of conflict which contrasts to the DSR scope which gives no indication of area of conflict. Although the symbology is inconsistent over the displays, it is consistent within a tool, and hence is most likely not a major issue, since it is simply an added feature in URET GPD.	
		GPD	URET	Numeric/Graphic	Red/Yellow/ Blue		
		SCOPE	DSR	Flashing DB	Highlighted Yellow		
		Plans Display	URET	Alphanumeric	Red/Yellow/ Blue		

No.	Information Type	Source	Tool	Symbology	Color	Consistency	CHI Guidelines
10	Hand Off Alert	Scope	DSR	Line Three flashing. Sector and speed timeshare.	Yellow	No CHI issues. Need to set up procedures to deal with Manual vs. Auto Hand off issues.	
		Data Block Scope	CPDLC	Held TOC message indicator on line 0.	Yellow		
11	Heading	A/C List	URET			No CHI Issues. Heading info will go to host before pilot WILCO.	
		DSR	CPDLC	"H" on line 4 in DSR			
12	General Memory Jogger	Data Block	DSR	BCC-10 Dwell Emphasis	Highlight	Many memory joggers make it hard to learn.	
		A/C List	URET	"N", "✓", "*"			
		GPD	URET		Gray		

No.	Information Type	Source	Tool	Symbology	Color	Consistency	CHI Guidelines
13	Destination	List	TMA	Fix	See Above	Timeshares on line 3 on the DSR and is always available on line 3 on the URET GPD. It is unclear by looking at the design guidelines whether this timesharing will be an issue for A/C controllers. Controllers might try to activate the information normally timesharing on the DSR, before remembering this information is unavailable in that location in URET GPD. This could waste valuable time in an emergency and draw away critical attention from other important display information.	**8.1.1.1** Information should be presented simply and in a well-organized manner. Ways to achieve simplicity include the following: **b.** Information should be presented in consistent, predictable locations. **8.4.1.6.** Data shall be displayed consistently, using the standards and conventions familiar to the user. **8.1.4.7.** Data display shall be consistent in word choice, format, and basic style throughout an application and related applications.
		Data Block	DSR	Destination Airport	See Above		
		CRD	DSR	Full Route	See Above		
		A/C List	URET	Full Route	See Above		
		Plans Display	URET	Full Route	See Above		
		GPD	URET	Line 3 Data Block	See Above		
14	Point of Departure	CRD	DSR	See Route	See Route	No inconsistencies.	No inconsistencies
		A/C List	URET				
		Plans Display	URET				
15	Beacon Code	CRD	DSR	See Route	See Route	No inconsistencies.	No inconsistencies
		A/C List	URET				
		Limited DB	DSR				

No.	Information Type	Source	Tool	Symbology	Color	Consistency	CHI Guidelines
16	Aircraft ID	Metering List	TMA	See Data Block display and layout	See Data Block display and layout	No inconsistencies.	No inconsistencies.
		Data Block	DSR				
		CRD	DSR				
		A/C List	URET				
		GPD	URET				
17	Airspace Boundaries	Radar Scope	DSR			More options to choose various display elements in URET.	**8.3.2.1.32** Users should be provided with a means for reducing clutter without losing essential information, such as the use of filters.
		GPD	URET				
18	Restrictions	BCC-20 Radar Scope	DSR			Potential inconsistencies in representing hot/cold airspace.	
		GPD	URET				
19	Status Message "H"	A/C List	URET	Aircraft in Holding "H". Heavy a/c is equivalent to /H		Inconsistencies with multiple meaning for "H".	**8.2.5.4.1** When a system or application uses abbreviations in its user-computer interface, the abbreviations shall be unique, distinct and unambiguous so as not to confuse users. **8.7.1.6.** Coding shall be consistent throughout an application and related applications.
		Data Block	DSR	"H###" on line 4 in DSR means heading. On line Zero "H" represents held TOC.			
		Data Block	CPDLC	On line Zero "H" represents held TOC.			

No.	Information Type	Source	Tool	Symbology	Color	Consistency	CHI Guidelines
20	Flow Restrictions	Metering List	TMA			No inconsistencies.	No inconsistencies.
			URET				
21	Amendments Message	Plans Display	URET			Consistencies with multiple sources of information. Furthermore, inconsistent information updates.	
		Menu Text/Other entry formats	CPDLC				
22	Air Pressure / Altimeter	Message Out	CPDLC			No inconsistencies.	No Inconsistencies.
		WGD	URET				
		Scope	DSR				

Appendix D

Human Factors Findings by Category Type

- **Concept of Use**
    - TMA delay to meter arc, if changed to meter fix, can help absorb delay earlier in the flight.
    - URET cannot absorb delay assuming one from the TMA list. This modification would help controllers better plan (i.e., URET takes data from TMA and gives the best change which could be speed, vector, altitude etc.).
    - DSR and URET should have some indication about aircrafts frozen in TMA.
    - URET and TMA should have some indication that the aircraft is Data Link equipped and preferably be able to uplink messages from URET.
    - Need a way to let URET and TMA know that the aircraft is being kept on hold or is being vectored in order to meet the time.
    - CPDLC menu text should have messages like “hold” in them and when an A/C is sent this message, CPDLC should inform URET and TMA about the change.
    - URET could be made to be beneficial in an emergency-for example it could be used to reroute an aircraft to the closest airport.

- **CHI**
    - URET takes up a lot of space on the D-side.
    - URET should share real estate with the CRD.
    - Response of Data Block to input device on URET and CPDLC is not consistent which might affect one-person operation.
    - Scroll bar is on different sides of the flyout for URET and CPDLC. They need to comply with the ATDET team standards for all tools.
    - Multiple ways of interacting in CPDLC may cause confusion.
    - Limited real estate may cause important and critical information to be covered up by other tools windows.
    - Confusing use of triangle (Frozen in TMA and Equipped in CPDLC).
    - Destination noted differently on DSR and URET data block.
    - Multiple ways for route change amendments.

- **Information Flow**
    - URET plan acceptance information directly fed into CPDLC.
    - Increased communication between R- and D-side because URET and TMA do not communicate. Possibility of communication human error.
    - It is recommended that the changes on one side be reflected on the other side.
    - A potential conflict in URET should be displayed (probably as an interactive list) on the DSR.
    - Ability to cut and paste URET trial plans in CPDLC will be very helpful, or URET generates a held message on CPDLC for an accepted trial plan.

  - Aircraft status, if it is in another sector, should be displayed (i.e., is he frozen in the TMA list of that sector which may mean that a controller cannot run a trial plan on that aircraft).

- **Integration**
  - URET & CPDLC integration would assist in one-person operation.
  - CPDLC updates NAS before a WILCO. This may cause errors in URET trial plan. Need a way to flag that and bring to controller notice.
  - Integration should be such that one tool works if another fails.
  - Information on altitude for direction of flight is available on URET only and not on the R-side controller interface.
  - TMA does not inform URET and if there is a large delay to be generated, the controller has to trial plan to best achieve this delay.

- **Procedural**
  - Responsibility to uplink a message/advisory and follow on to make sure the change has taken place.
  - Delay to be made up should be denoted with severity (i.e., should be met or is it flexible).
  - Procedure to decide who should act on an alert (based on aircraft's current sector and the conflict sector).

- **Co-ordination**
  - Re-routing will also affect other sectors hence co-ordination with URET and also sector-to-sector CPDLC will be very helpful.
  - Absence of URET coordination may cause human communication error.

Appendix E

Human Factors Findings by Event Type

ISSUE #	ISSUE TYPE	ISSUE
EVENT: CLIMB REQUEST		
1	Information Flow (Integration)	URET should be communicating information to CPDLC (i.e., currently, if you trial plan in URET & accept plan, it sends info to NAS, but then this data needs to be manually entered into Data Link, so the human is the integrator of the information, leaving room for human error).
2	CHI Consideration	URET takes up a lot of real estate on the RA controller's display.
3	Integration/ Operational (Procedural)	If URET and CPDLC integrated, then 1 person can operate both.
4	Collocation Consideration	If you send information via CPDLC to the pilot, NAS is updated before WILCO, & so if you trial plan in URET it could lead to errors.
5	Procedural	Because RA-side has ability to communicate directly with pilot via CPDLC, then if R-side tells RA-side to check an altitude & altitude is ok, who is responsible for a) sending info to pilot & b) monitoring to make sure correct altitude is sent to pilot, and c) monitoring to make sure correct altitude is achieved by pilot (i.e., waiting for WILCO). There needs to be an explicit procedure written for how to handle this type of situation. R-side needs to be responsible for delegating to RA-side, but once responsibility delegated, RA-side assumes shared responsibility for monitoring plane for compliance.
6	Simulation Need (Issue 4)	When NAS is updated after controller sends new altitude to pilot, but prior to WILCO, there needs to be a way for the information to be flagged as a potential source of error (i.e., have the information sent to NAS with a hold or matching message needed from pilot to finalize update of NAS).
7	Collocation Consideration	Because the tools don't communicate with one another, and because URET is on the RA side, with the deployment of the three tools, communication between the R- and RA-side will increase. This may lead to communication congestion.
8	CHI Consideration	Controllers recommend having some indication on the Radar scope of the R-side as to changes made by the RA-side and visa versa.
9	CHI Consideration	On the RA-side, URET should not entirely cover up the CRD when open, but instead should share real estate.
10	Simulation Need (Issue 8)	What is the best way to indicate to R controller that change has been made on the RA-side & visa versa (i.e., color, symbology, highlighting, bolding, etc.)?

ISSUE #	ISSUE TYPE	ISSUE
11	CHI Consideration	The way that the data block responds in CPDLC and in URET (CCLD) is very different (i.e., fly out window vs. overlay). This is an issue if there is only an R-side controller, because then the same person would be operation both URET and CPDLC. Also a potential problem for any controller who is certified on both sides.
12	CHI Consideration	Scroll bar on left in URET and on right in CPDLC. There needs to be consistent compliance to ATDET team standards in all of the tools.
13	CHI Consideration	There are multiple ways to send information in different windows in CPDLC. If so, there is potential for error because you could accidentally send something incorrectly in one window, thinking you were actually in a different window, where the interaction method is different.
14	Collocation/ Simulation	If you are responsible for sending and receiving messages, and if information needed to do this is covered up by other windows, you could have a problem, so the system needs to be set up to ensure that critical information is not covered up by other windows.
15	Collocation Issue	URET & CPDLC both have capacity to update NAS and currently no way to deal with potential error due to this capacity.
16	Simulation	Need to simulate a scenario with all three tools communicating as compared to baseline condition with none of the tools communicating.
EVENT: DESCENT REQUEST (intermediate/low)/SPEED ADJUSTMENTS		
17	Concept of Use	TMA displays delay to meter arc. Recommendation by controllers that TMA show delay to fix. That way, if there is room, the sector can absorb some extra delay earlier in a flight.
18	CHI Consideration	In TMA triangle means frozen A/C and in CPDLC it means Data Link equipped.
19	Simulation	Is there a potential for problems with trial planning URET if you have two metering arcs in a sector.

ISSUE #	ISSUE TYPE	ISSUE
20	Concept of Use	URET currently cannot, when trial planning, calculate the speed an airplane needs to be at to meet an ARC or fix (as shown on the TMA list) so controller needs to perform mental calculation. If a controller mentally underestimates the speed that the aircraft needs to be at to meet the fix or ARC then there will still be time that the aircraft needs to absorb. The controller will then have to redo the trial plan with another "guesstimated" speed to see if that is adequate to absorb or generate a delay. Speed adjustments will need to be made iteratively. (Note: Most controllers say they would trial plan once & then take off or add some speed if they haven't quite absorbed or generated the appropriate amount of delay on the first trial plan.).
21	Concept of Use/ Information Flow	There should be some way for URET to take the time that needs to be made up, integrate information from TMA, and calculate the necessary speed for an aircraft to meet those requirements (Note: EDA will have this function.) Controllers feel it would be beneficial if they had the ability to click on a plane in URET where URET would tell you the correct speed needed to meet the arc. That is, URET needs to be extended beyond its ability to handle conflicts to incorporate ability to handle metering.
22	CHI Consideration	Controllers would like to see some indication on the DSR and on URET of aircrafts that are frozen in the TMA list.
23	CHI Consideration	Controllers would like some indication in TMA & URET as to whether or not an aircraft is Data Link equipped and the ability to uplink messages directly from URET to aircraft.
24	CHI Consideration	The way that destination is displayed on the DSR (arrival center) is different than the way it is displayed in URET (airport).
25	CHI Consideration	When URET identifies a potential conflict (not a trial planned conflict), there should be some indication on the R-side of this conflict. SMEs suggest some sort of Conflict probe list (not just conflict alert list that only goes 2 minutes out). They would also like the ability to click on the item in the list & have that click bring up a screen shot inset of the two conflicting aircraft.
26	Procedural Issue	When delay to metering ARC needs to be made up, is there any flexibility or is it required (needs to be some procedural guidelines in place to address this)?

ISSUE #	ISSUE TYPE	ISSUE
27	Concept of Use	When meeting a metering ARC there are two ways a controller might handle the situation (thus using the tools differently): 1) Controller may trial plan with URET to determine new speed. 2) Controller may make a decision on speed and then trial plan the speed on URET to see if there are any conflicts.
28	Collocation Consideration	URET might have difficulties meeting TMA times if controller needs to Vector or Hold an aircraft. Then TMA times will be incorrect (controllers point out that at this point you probably won't use tools for handling this situation). Need to figure out a way to enter into URET & TMA that an aircraft is in hold or is being vectored.
EVENT: REROUTING/WEATHER RELATED DEVIATIONS/RESPONDING TO TMU RESTRICTIONS		
29	Coordination	When rerouting, R-side has to come up with route first before RA-side can trial plan the route. Potential for communication error.
30	Collocation Consideration	Controllers feel it would be beneficial if they could cut & paste information from URET trial plan into CPDLC to reduce chance for error.
31	Coordination	Because re-routing affects other sectors, there is a need for sector-to-sector CPDLC capability.
32	Collocation Consideration /Simulation Need	3 ways to enter route change amendments. Does this help or hinder performance?
33	Collocation Consideration	When systems are integrated (i.e., URET sending info to CPDLC) there needs to be safeguard, so that if one system fails it does not take down another system.
34		See climb request for other URET/CPDLC issues.
EVENT: CONFLICT DETECTION USING URET		
35	Procedural Issue	When RA controller trial plans with URET for conflict resolution a procedure needs to be in place as to who CPDLCs or voices solution to pilot.

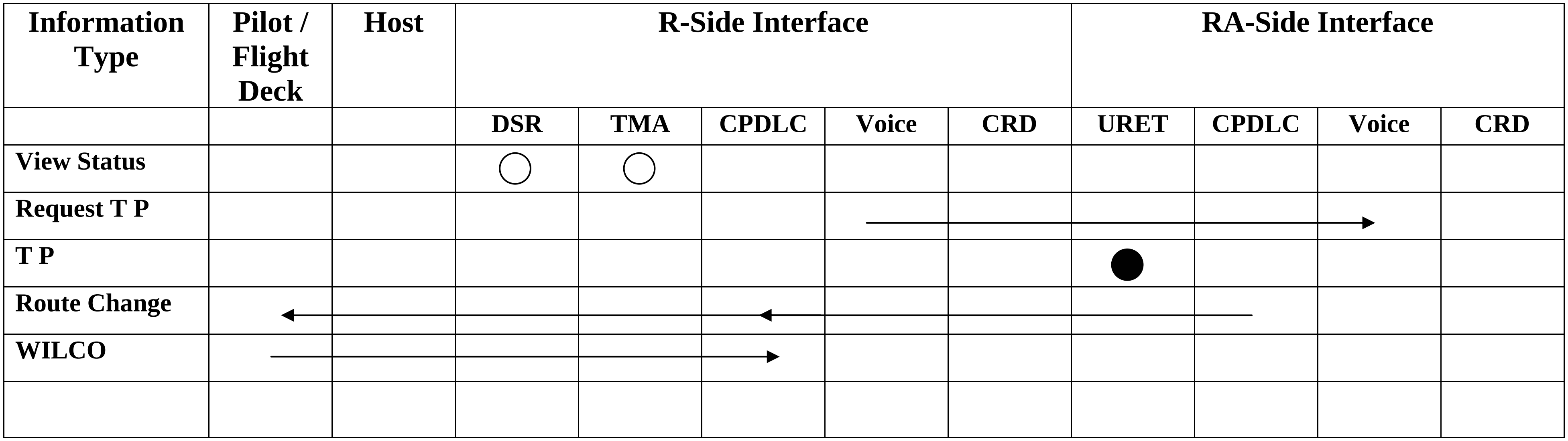
ISSUE #	ISSUE TYPE	ISSUE
36	Collocation Consideration	Controllers suggest it would be beneficial to have URET generate message on CPDLC when a trial plan is accepted, to reduce workload. (Then controller would only have to send CPDLC message).
37	Coordination Issue	When RA-side trial plans & then voices plan to R-side there is potential for communication errors.
38	Procedural Issue	Needs to be some procedure in place for assigning responsibility for trial planning when an alert comes up for a different sector, but A/C is in your sector.
39	Coordination Issue/CHI Issue	If controller in sector one created trial plan in his sector for one plane in his sector and another plane in someone else's sector, there is the potential, if the aircraft in the other sector has to be moved, for communication error. For example, the controller in sector 1 voices the plan to sector 2, because he can't use URET to send the trial plan and sector 2 makes an error in communicating message to pilot. Also, controller in sector one gets no indication on his display that other sector has taken any action.
40	Coordination	If a controller in one sector is trial planning for a conflict involving a plane in another sector that is frozen, is there any indication on the controller's TMA list that that plane is frozen? If there isn't, this could lead to errors in trial planning.
41	Coordination	If a controller in one sector is trial planning for a conflict involving a plane in another sector, but the plane in the first sector is frozen, then the controller in the first sector will have to involve the controller in the second sector which could lead to communication errors.
42	CHI Consideration /Collocation Consideration	Controllers suggest that it would be beneficial if CPDLC gave some indication that A/C is at an incorrect altitude for its direction (Would also be useful to have this in DSR). Currently URET has this capability and it could be possible to have URET communicate this information with CPDLC.
EVENT: HOLDING		
43	Collocation Consideration	Controllers suggest it would be beneficial if TMA could tell URET that there was a large amount of time to absorb so TMA would know to give a hold advisory (same for speed and vectoring.
44	Collocation Consideration	CPDLC should have canned message for hold pattern & when this message is sent to aircraft, CPDLC should send message to URET indicating A/C is being put into hold pattern.

ISSUE #	**ISSUE TYPE**	**ISSUE**
45	Benefit	URET is of benefit in an emergency (i.e., engine failure) because it will allow controller to quickly identify A/C in conflict with the troubled A/C and move them out of the way, while also tracking the fastest route to the nearest airport.
EVENT: HAND OFF IN & HAND OFF OUT		
46	No Issues	

Appendix F

Flow Diagrams

Event: **Route Change**



Information Type	Pilot / Flight Deck	Host	R-Side Interface					RA-Side Interface			
			DSR	TMA	CPDLC	Voice	CRD	URET	CPDLC	Voice	CRD
View Status			○	○							
Request T P											
T P								●			
Route Change											
WILCO											

Key:

○ - Observed Tool Only

● - Physical Interacting Tool

↔ - Communication between controllers or controllers and pilots

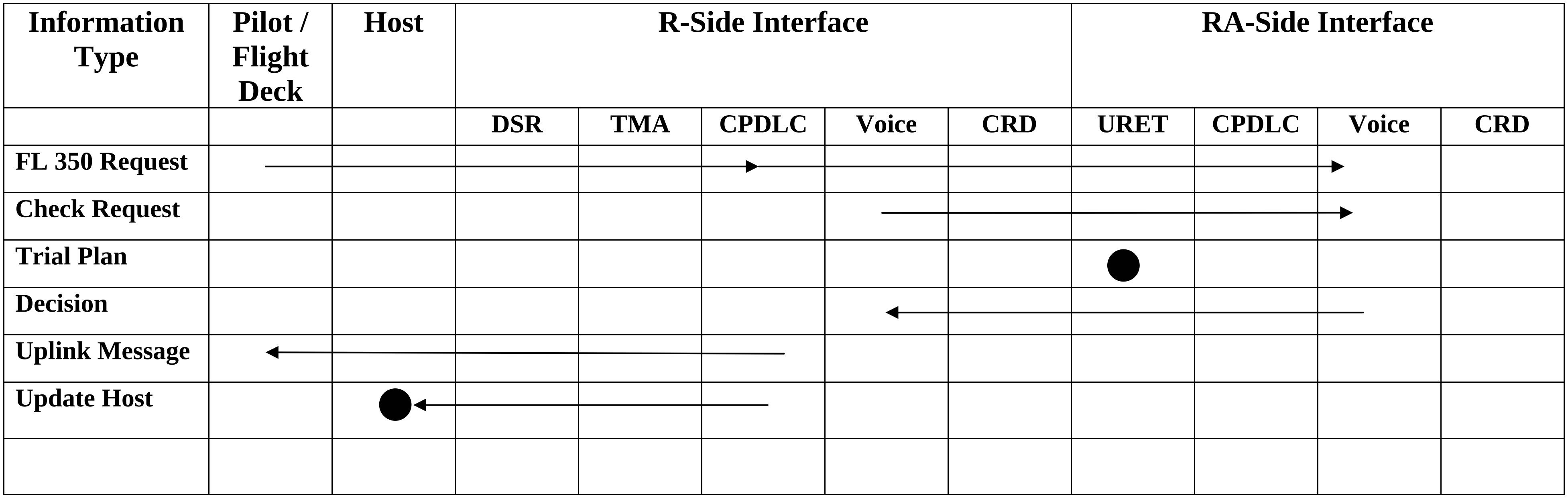
Event: **Climb Request**

Information Type	Pilot / Flight Deck	Host	R-Side Interface					RA-Side Interface			
			DSR	**TMA**	**CPDLC**	**Voice**	**CRD**	**URET**	**CPDLC**	**Voice**	**CRD**
FL 240	—	—	—	—	→	—	—	—	→		
“Check “						—	—	—	—	→	
Trial Plan								●			
“OK”						←	—	—	—	—	
Uplink FL 240	←	—	—	—	—						
WILCO											

Issues:

- Option 1: R-Side updates

Event: **Climb Request**



Information Type	Pilot / Flight Deck	Host	R-Side Interface					RA-Side Interface			
			DSR	TMA	CPDLC	Voice	CRD	URET	CPDLC	Voice	CRD
FL 350 Request											
Check Request											
Trial Plan								●			
Decision											
Uplink Message											
Update Host		●									

Issues:

- Climb request in voice and response in CPDLC.
- Climb request in CPDLC and response in CPDLC.
- Between D & R, responsibility should be decided.

Event: **Descent Clearance** (Meter Arc Sector)

Information Type	Pilot / Flight Deck	Host	R-Side Interface					RA-Side Interface			
			DSR	**TMA**	**CPDLC**	**Voice**	**CRD**	**URET**	**CPDLC**	**Voice**	**CRD**
“4 min. delay”			○	○							
Uplink Speed	◄─	─	─	─	─						
Conflict Detect								○			
Inform						◄─	─	─	─	─	
Trial Plan								●			
Send Amendment	◄─	─	─	─	─	─	─	─	─		

Event: **Conflict Alert (VOICE)**

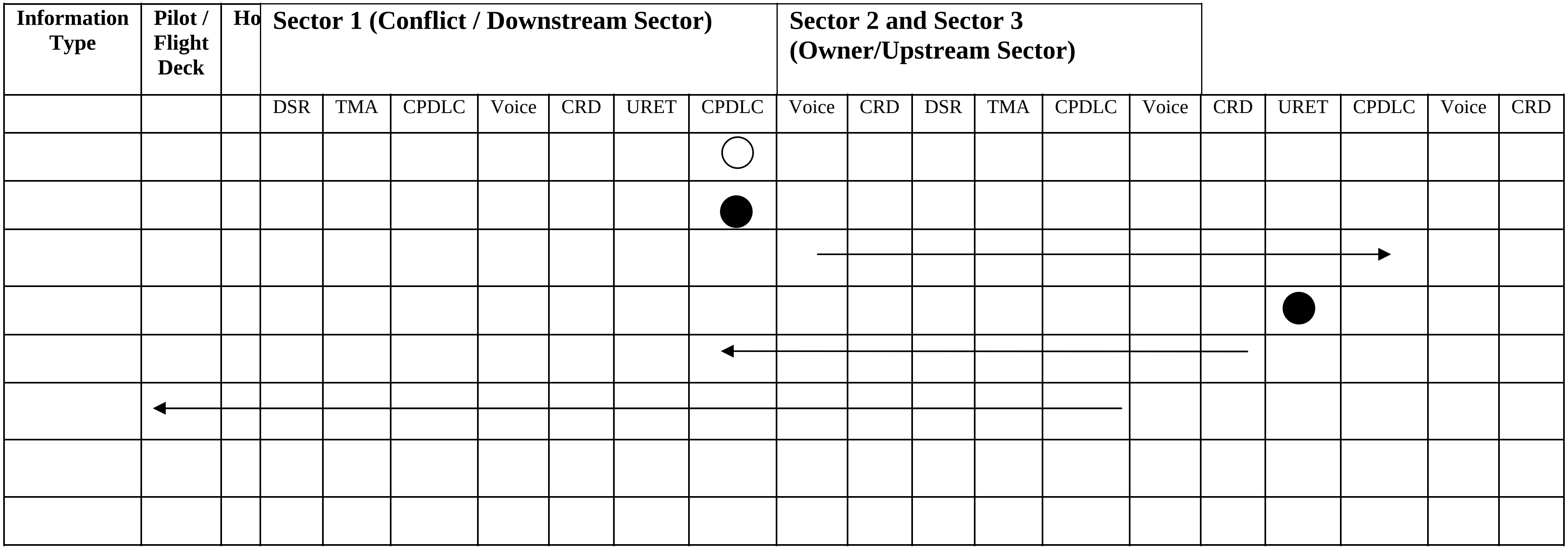
Information Type	Pilot / Flight Deck	Host	R-Side Interface					RA-Side Interface			
			DSR	TMA	CPDLC	Voice	CRD	URET	CPDLC	Voice	CRD
Receive Conflict alert.								○			
Wait for development											
TP								●			
Discuss situation and soln.						◄─	─	─	─	─►	
Send instructions	◄─	─	─	─	─	─					

Note: Used only when more than 5 min. for conflict.

Event: **Conflict Alert (CPDLC)**

Information Type	**Pilot / Flight Deck**	**Host**	**R-Side Interface**					**RA-Side Interface**			
			DSR	**TMA**	**CPDLC**	**Voice**	**CRD**	**URET**	**CPDLC**	**Voice**	**CRD**
Receive Conflict alert.								○			
TP								●			
Discuss situation and solution						◄	—	—	—	►	
Send instructions	◄	—	—	—	—	—					

Event: **Conflict Alert (CPDLC) between sectors**



Information Type	**Pilot / Flight Deck**	**Ho**	**Sector 1 (Conflict / Downstream Sector)**							**Sector 2 and Sector 3 (Owner/Upstream Sector)**										
			DSR	TMA	CPDLC	Voice	CRD	URET	CPDLC	Voice	CRD	DSR	TMA	CPDLC	Voice	CRD	URET	CPDLC	Voice	CRD
									○											
									●											
																		→		
																	●			
									←											
	←																			

Issue:

- Need a way to inform sector 1 that the amendment was accepted and acted upon.

Event: **Conflict Alert (CPDLC) between sectors**

Information Type	**Pilot / Flight Deck**	**Host**	**Sector 1 (Conflict / Sector, Owns 1 A/C)**						**Sector 2 Upstream Sector, owns 1)**											
			DSR	TMA	CPDLC	Voice	CRD	URET	CPDLC	Voice	CRD	DSR	TMA	CPDLC	Voice	CRD	URET	CPDLC	Voice	CRD
									○											
									●											
─	─	─	─	─	─	─	─	─	─▶											
																		●		
◀─	─	─	─	─	─	─	─	─	─											
◀─	─	─	─	─	─	─	─	─	─	─	─	─	─							

Assumption: Aircraft in sector 1 is frozen on TMA list, hence coordination.

Event: **Hold**

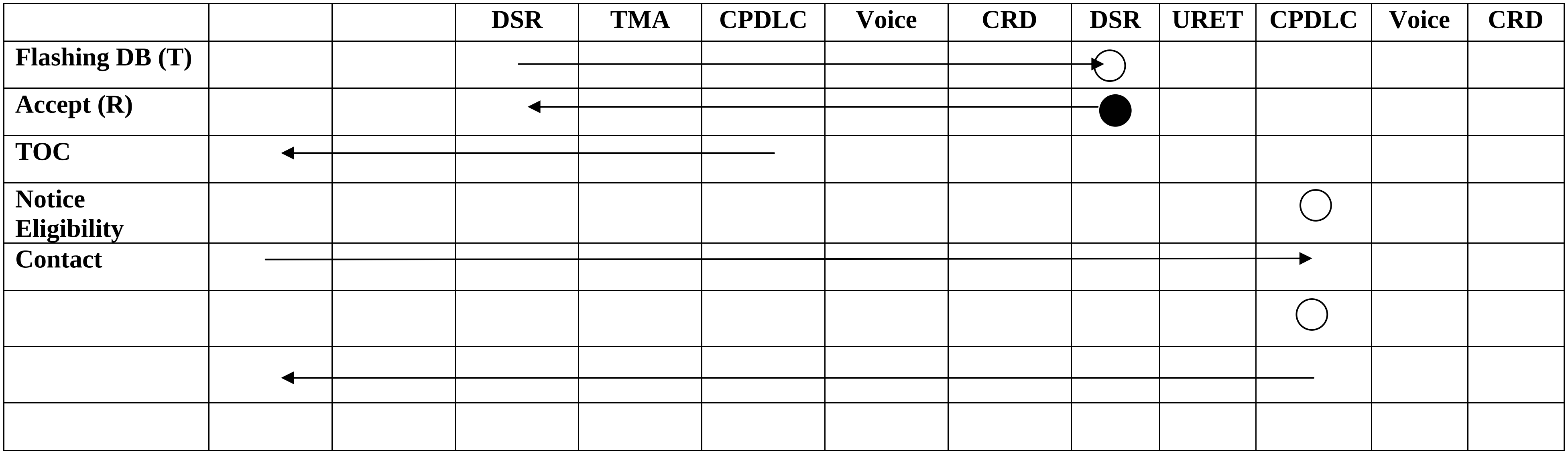
Information Type	**Pilot / Flight Deck**	**Host**	**R-Side Interface**					**RA-Side Interface**			
			DSR	**TMA**	**CPDLC**	**Voice**	**CRD**	**URET**	**CPDLC**	**Voice**	**CRD**
Delay Info.				○							
Information						←	─	─	─	→	
Expect Delay	←	─	─	─	─						
Holding Instru.	←	─	─	─	─	─					

Issue:

- URET does not probe holds.

Event: **Hand Off In**

Information Type	**Pilot / Flight Deck**	**Host**	**Sector 1 (T)**	**Sector 2 (R)**



			DSR	**TMA**	**CPDLC**	**Voice**	**CRD**	**DSR**	**URET**	**CPDLC**	**Voice**	**CRD**
Flashing DB (T)								→ ○				
Accept (R)			←					●				
TOC	←											
Notice Eligibility										○		
Contact										→		
										○		
	←											

Issue:

RA controller can accept handoff.