THE EFFECT OF DATA LINK ON EN ROUTE CONTROLLER WORKLOAD

Ben Willems, Sehchang Hah, and Randy Phillips, Human Factors Group
Federal Aviation Administration, William J. Hughes Technical Center
Atlantic City International Airport, NJ

The projected increase in air traffic volume has forced the Federal Aviation Administration to look for ways to increase airspace capacity. Controller Pilot Data Link Communications may be one solution that has the potential to reduce controller workload. Previous studies have shown that data link reduces the number and duration of voice communications and controller workload, but did not show how that translated in increased sector capacity. In this study, we provided controllers with data link functions that included air traffic control clearances such as altitude, speed, heading, and route changes. We have shown that data link reduced the number of voice clearances and workload resulting in an increase of 25% in sector capacity.

Introduction

The RTCA projected an increase in air traffic volume of between 150 and 250% over the next two decades (RTCA, 2002). The Federal Aviation Administration (FAA) projected that the number of aircraft handled by air route traffic control centers (ARTCCs) will increase by about 35% by 2015 (Federal Aviation Administration, 2005).

One of the bottlenecks in air traffic control operations with an increase in air traffic volume is the congestion of the radio frequencies used for communication between pilots and controllers. Talotta, Shingledecker, and Reynolds (1990) showed controllers spent 45% less time on the voice channel when 70% of aircraft were equipped with Controller Pilot Data Link Communications (CPDLC). Talotta et al. thereby eliminated one of the constraints to sector capacity.

The FAA has developed the CPDLC system to enhance air-ground communications (Post & Knorr, 2003). In 2002, Miami ARTCC was the first facility to use CPDLC in domestic en route air traffic control. The initial CPDLC called CPDLC I supported four CPDLC messages that controllers and pilots routinely exchange: initial contact, transfer of control frequency, altimeter setting, and menu text. Post and Knorr expected that the FAA would implement CPDLC in three more ARTCCs by 2006. The Airline Dispatcher Federation (2001) put CPDLC in their top ten list of essential air traffic control programs that required immediate implementation. Plagued by schedule delays and cost overruns, the FAA canceled the CPDLC program in 2004 (Stefani, 2004). Many future decision processes rely heavily on the availability of CPDLC (Breunig, et al., 2003; Ehrmanntraut, Bauer, & Hally, 2002) and may suffer from the cancellation of the en route CPDLC program. The FAA still has data link programs in other domains including the Tower Data Link System (TDLS) and Advanced Technologies and Oceanic Procedures (ATOP) CPDLC (Murphy, 2004).

To investigate the ability of controllers to handle the projected increase in traffic and to develop new concepts for future en route workstations, we started a research program called Future En Route Workstation Study (FEWS). In FEWS environment controllers handle air traffic levels projected for 2015 and beyond. In addition to four messages available in CPDLC I, we added four more messages to our CPDLC called CPDLC IA: altitude, speed, heading, and route clearances. We also created an Enhanced (or FEWS-E) workstations that featured integration of automation functions and identical displays for the Radar and the Radar Associate Controller. We investigated the effect of using these two configurations and the effect of CPDLC on controller performance.

Method

Participants

The participants in this study were sixteen certified professional controllers from several ARTCCs within the continental United States. Their mean age was 41.8 (SD=5.9) years with a mean experience in ATC of 17.8 (SD=7.2) years. They were assigned to either R or D side. This led to eight groups of R and D side teams. However, we experienced computer problems for the first two groups and used the data of the next six groups.

Airspace

We used a generic ARTCC containing several sectors, fix posting areas, terminal radar approach control facilities, navigational aids, airways, standard terminal approach routes, and standard instrumented departures (Figure 1).

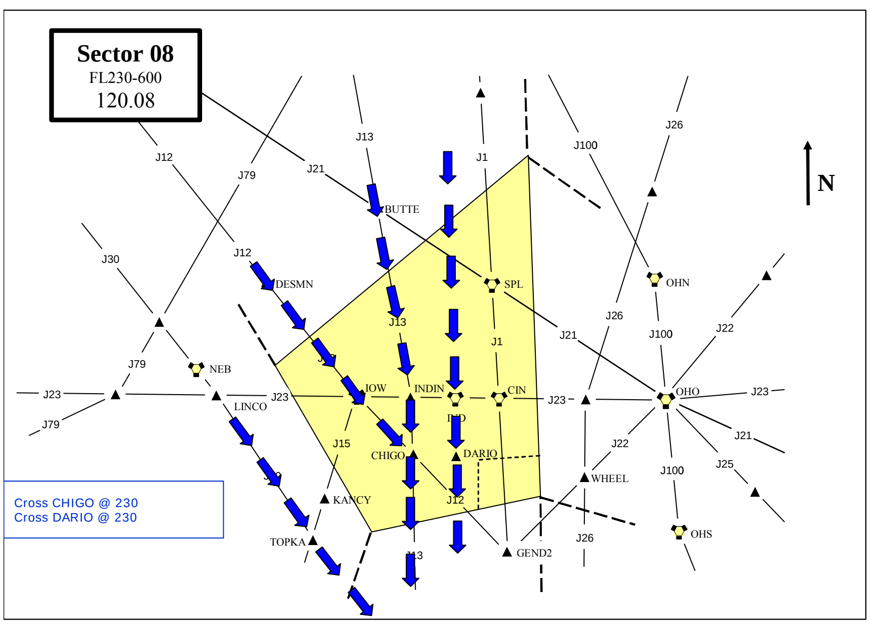

Figure 1. Air traffic flow patterns in the high altitude Sector 08.

Traffic

Controllers in Sector 08 metered traffic into Genera Airport (GEN) using two meter fixes located in Sector 18 below and south of Sector 08 (Figure 1). As a standard operating procedure, controllers handed off aircraft to Sector 18 at 23,000 feet before the aircraft left Sector 08. Controllers were also responsible to hand off aircraft with destinations to several other airports at 22,000 feet. The traffic flow required controllers to merge two flows over Chicago (CHIGO) while absorbing delays to meet arrival rates at GEN. We used scenarios that continuously had between 24 and 28 aircraft in the sector (equivalent to about 133% of the currently acceptable traffic levels). The traffic flow was mostly from north to south with some crossing aircraft.

Experimental Design and Workstation Configurations

We compared Baseline to Enhanced (or FEWS-E) workstation configurations with and without CPDLC. The Baseline workstation consisted of a high fidelity emulation of the Display System Replacement (DSR) display (Build BCC-23) including a Traffic Management Advisor (TMA) list. When this Baseline had CPDLC, the R-side display was configured with CPDLC Build 1A interface and the D-side display was configured with the computer readout device (CRD), the User Request Evaluation Tool (URET) windows, and a CPDLC Build 1A D-side interface.

In the Enhanced (or FEWS-E) configuration, R-side and the D-side displays were identical. The displays were similar to the DSR display but had additional system enhancements and interface changes. The system enhancements automated handoffs for aircraft entering the sector and also automatically changed the Full Data Block (FDB) to the limited data block with the beacon code and altitude only as the aircraft left the sector. The interface changes included an indicator in the FDB for the detection of a potential conflict. When a controller selected an FDB, the system displayed aircraft type and indicated airspeed in the FDB. We removed the TMA-list, the continuous range readout (CRR) list, and the conflict alert (CA) list. Instead, we added the information on the FDB. Finally, we also changed the interface so that controllers could scroll through values within a field such as altitude in the FDB instead of using the fly-out window. This enabled controllers to update National Airspace System (NAS) and uplink CPDLC messages from the FDB to the aircraft and receive the feedback about the up-linked messages.

Procedure

We collected participants' workload ratings every two minutes during experimental runs. Our data were based on three experimental runs with different scenarios for each team of R side and D side controllers. Each run lasted about 50 minutes. Participants were instructed to press a button from 1 to 10 rating values with the following instructions: ""At the low end of the scale (1 or 2), your workload is low - you can accomplish everything easily. As the numbers increase, your workload is getting higher. Numbers 3, 4, and 5 represent the increasing levels of moderate workload where the chance of error is still low but steadily increasing. Numbers 6, 7, and 8 reflect relatively high workload where there is some chance of making errors. At the high end of the scale are numbers 9 and 10, which represent a very high workload, where it is likely that you will have to leave some tasks unfinished."

Results

The duration of our voice communication events itself did not differ between conditions with and without CPDLC and was approximately 3.5 seconds. However, the number of communication events was significantly lower when CPDLC was available than when it was not available (Λ=.095, $F(1,6)=56.960$, $p<.05$). The average number of communication events was 50% less when CPDLC was available than when controllers used voice only (Figure2). When we assume that the number and duration of pilot communication events to be equal to that of the controllers, this is equivalent to approximately 70% vs. 35% occupancy of the voice channel, respectively.

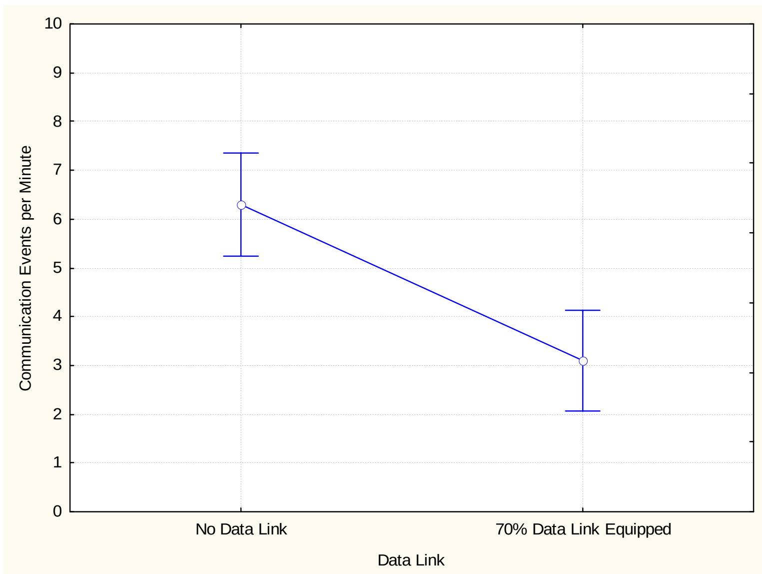

Figure 2. Number of communication events per minute.

We considered the duty position (R and D sides) as a nested independent variable. Large inter-individual differences for both R and D sides resulted in a three-way interaction between the presence of CPDLC, workstation design, and controller position as well as between the presence of CPDLC, workstation design, and controller team for both R and D sides, $F(6,258)$.= 14.59 and $F(5,258) = 53.04$, respectively, both at $p<.05$. As shown in Figure 3, the R-side controllers perceived a higher workload than the D-side controllers, and CPDLC reduced workload ratings for both controllers. Important to note, however, is that without CPDLC several of our R-side controllers indicated they perceived workload that would put them at risk of making errors (Note: The workload rating instructions specified that ratings between 6 and 8 reflected an increased risk of making errors.).

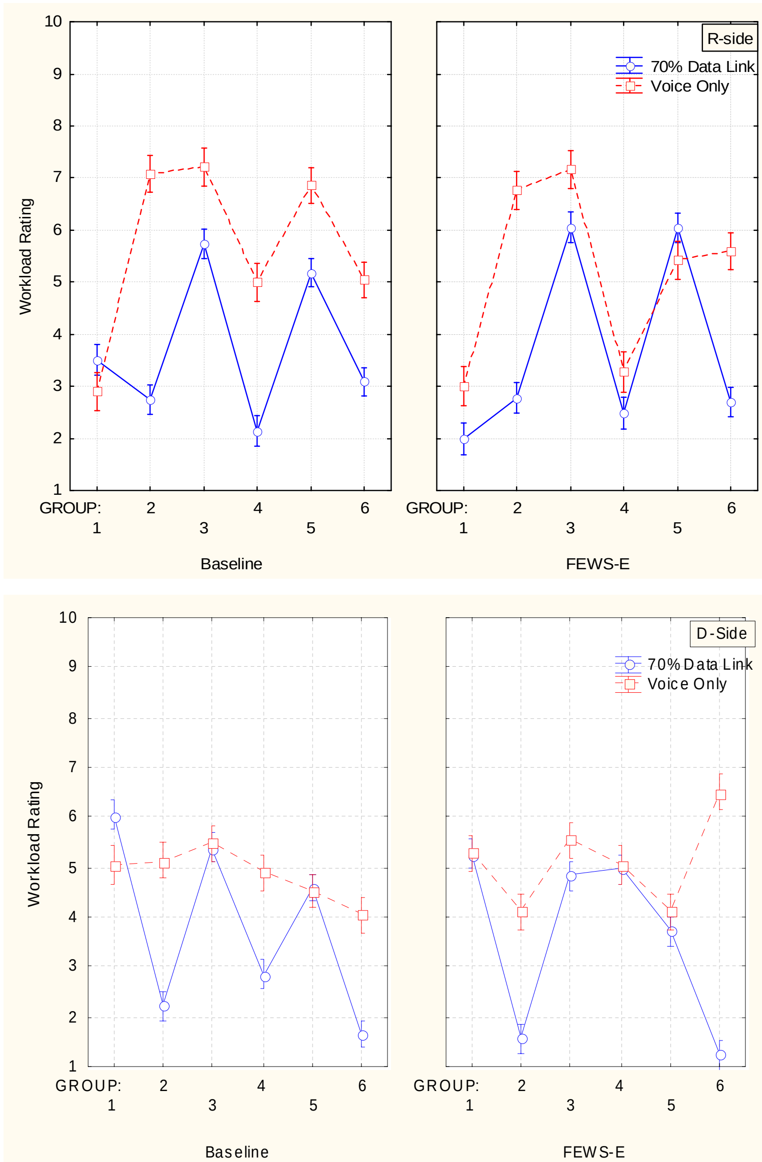

Figure 3. Workload rating as a function of CPDLC presence, workstation design, and controller position nested within group. Top figures are for R Side and bottom figures are for D Side.

For workload ratings we instructed controllers that for Levels between 6 and 8, controllers would be more likely to make mistakes. We therefore considered Level 6 as the maximum workload level where the likelihood that controllers will make mistake is still acceptable. As shown in Figure 3, more R-side controllers rated higher than Level 6 without CPDLC than with CPDLC.

In the experiment we had also tested the effect of traffic level on controller performance and behavior when 70% CPDLC was available. By pooling the data for all traffic levels with CPDLC in the Baseline condition we had a wide range of the number of aircraft (x axis) in the sector as shown in Figure 4. This enabled us to predict the number of aircraft at which controllers reached the workload threshold. A regression of the number of aircraft under control to workload in the Baseline condition with CPDLC showed that controllers would not reach Level 6 until they had 31 aircraft. (See the regression line in Figure 4.)

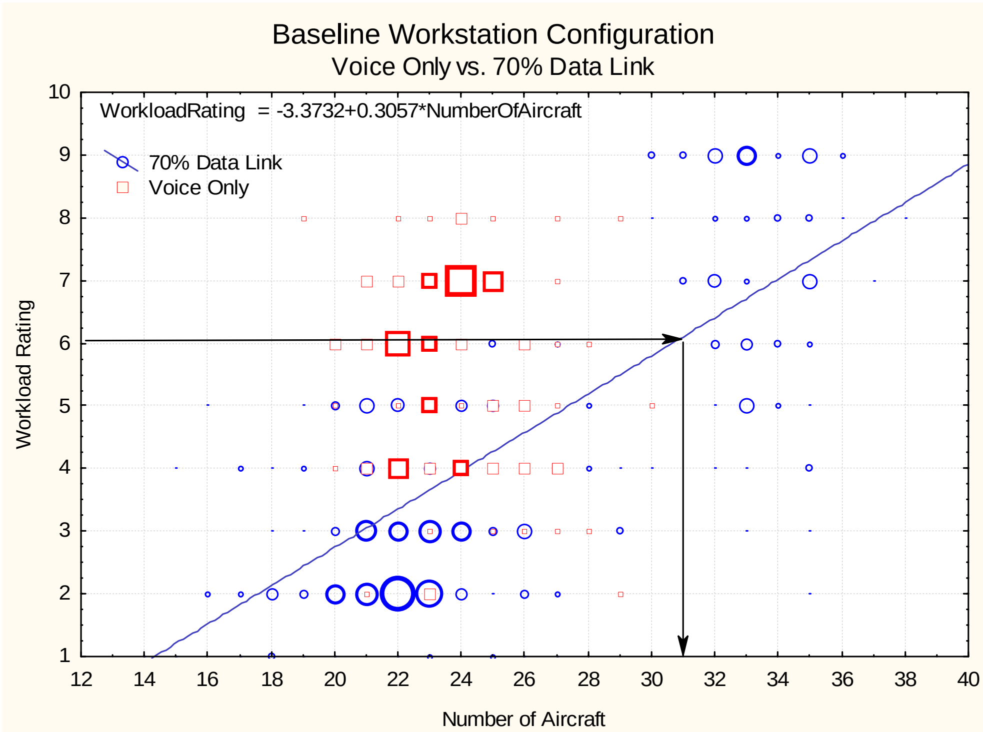

Figure 4. Workload ratings in the baseline condition as a function of the number of aircraft under control with and without CPDLC.

Discussion

In this study we have used CPDLC functions that according to Wilson (1998) only replicate standard R/T communications. The use of CPDLC, however, creates possibilities that go beyond just replacing standard R/T communications. For example, to clear an aircraft to a full 4-D trajectory by voice is not practical, but with CPDLC becomes feasible.

The presence of CPDLC capabilities makes it more likely that the tactical and the strategic controllers will distribute the workload (Crespo, et al., 2004). We have seen that in our study as well. The workload distribution is more evident with a workstation configuration that integrates the CPDLC features and provides the tactical and strategic control with similar capabilities.

An additional benefit of CPDLC is that it eliminates the need for read-back and hear-back both notoriously known as causes of operational errors. Furthermore, CPDLC is potentially a faster model of communication, because controllers do not need to wait for a pilot to confirm clearances or repeat missed clearances (Harvey & Ehrmanntraut, 1999).

The introduction of CPDLC clearly eliminates frequency congestion and consequently reduces workload as others have shown (Harvey & Ehrmanntraut, 1999). In our study, however, we have shown that the reduction in workload corresponds with an increase in the number of aircraft controllers can work. The translation of the effect on workload in operational terms related to sector capacity may support operations management in deciding in when to implement CPDLC.

References

Airline Dispatcher Federation. (2001). Airlines announce "top ten" air traffic control priorities to immediately reduce delays. *The ADF News, 11 (2)*, p. 22.

Breunig, T., Eckhause, J., Hasan, S., Hemm, R., Kostiuk, P., Leiden, K., et al. (2003). *Single-year, NAS-wide benefits assessment of DAG-TM CEs 5, 6, and 11*. Moffet Field, CA: NASA.

Crespo, I., Tabernero, M., Gayraud, B., Lanzi, P., Leone, M., Marti, P., et al.. (2004). Mediterranean free flight programme. *MFF Validation Analysis Interim Report B.* Bretigny sur Orge: Eurocontrol.

Ehrmanntraut, R., Bauer, J., & Hally, A. M. A. C. (2002). Intelligent Information and interactive systems for pilot situational awareness enabled by a federation architecture. In *Proceedings of the 21st Digital Avionics Systems Conference*. St. Louis, MO: Institute of Electrical and Electronics Engineers, Inc.

Federal Aviation Administration. (2005). Air traffic activity system. [Database]. Retrieved November 16, 2005 from the Federal Aviation Administration Web site, http://http://www.apo.data.faa.gov/main/atads.asp

Harvey, A. & Ehrmanntraut, R. (1999). *EATCHIP III Evaluation and demonstration PHASE 3 and COM - ATN - EOLIA project experiment 3B: A/G Datalink.(Final Report).* Bretigny sur Orge: Eurocontrol.

Murphy, M. (2004). Data link status in the USA. Presented at the ATN 2004 conference.

Post, J. & Knorr, D. (2003). Free flight program update. *Proceedings of the 5th Air Traffic Management R & D Seminar.* Bretigny sur Orge: Eurocontrol.

RTCA, Inc. (2002). *National Airspace System. Concept of operations and vision for the future.* Washington, DC: Author.

Stefani, A. M. (2004). *Observations on FAA's controller-pilot data link communications program* (Report Number: AV-2004-101). Washington, DC: Department of Transportation: Office of the Inspector General.

Talotta, N. J., Shingledecker, C., & Reynolds, M. (1990). *Operational evaluation of initial data link en route services, Volume I* (Rep. No. DOT/FAA/CT-90/1, I). Washington, DC: U.S. Department of Transportation, Federal Aviation Administration.

Wilson, I. A. B. (1998). Trajectory negotiation in a multi-sector environment. Brussels: Eurocontrol.