PROJECTING THE EFFECT OF CPDLC ON NAS CAPACITY

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Abstract

The Federal Aviation Administration (FAA) in conjunction with MITRE's Center for Advanced Aviation System Development (CAASD) is developing operational concepts and working with stakeholders throughout the aviation community to build the business case for investment in air/ground data communications capabilities. These capabilities are needed to respond to the high demand on the National Airspace System (NAS) currently and in the foreseeable future, resulting from the increased demand for access to airspace and the need to increase the operational efficiency of NAS infrastructure.

The FAA Air Traffic Organization (ATO) is analyzing the benefits of potentially implementing a subset of air/ground data communications in the domestic En Route domain focused on the Controller-Pilot Data Link Communications (CPDLC) application. The air/ground data communications functionality provided by CPDLC is inherently coupled with the flight data processing functions of the NAS. The ATO is in the process of replacing these functions as part of the En Route Automation Modernization (ERAM) program. Any potential introduction of CPDLC functionality would occur subsequent to the implementation of ERAM in the NAS.

This paper presents a quantitative estimate of the operational effects of implementing a CPDLC capability in the En Route domain. The economic implications of this estimate of operational effects were presented in [MITRE CAASD, 2004].

Introduction

By virtue of the joint nature of the controller-pilot data link communication (CPDLC) investment decision-making process, the key quality of any benefit-cost analysis product is that all costs, benefits, actions, and timing considerations attributed to each stakeholder fundamentally must reflect the intent of that stakeholder. Naturally, the stakeholder dependencies in such an investment analysis are critical. In such circumstances, a valid final result can best be obtained through a cycle of dialogues, wherein stakeholders trade off costs and benefits iteratively.

A key element of the business case is an understanding of the operational effects of an investment in a capability such as CPDLC. Several studies have been conducted by the FAA and EUROCONTROL that have measured those operational effects. This paper synthesizes the results of those prior studies and proposes a means whereby those results may be applied to in the development of the CPDLC business case.

Dr. Clark Shingledecker conducted the analysis of the prior studies and developed the synthesized results. Stephen Giles developed the business case analysis model within which the results were applied. Joseph P. Pino sponsored this work and provided overall management guidance. Evan Darby and Timothy Hancock provided expert guidance and review.

Background

This paper builds upon the contributions of several sources whose work underpins this offering:

Dr. Russell Chew, Chief Operating Officer of the FAA's Air Traffic Organization (ATO), published a seminal paper during his tenure at American Airlines on Preserving Airline Opportunities that set forth the premise that airborne and ground-based investments in CNS/ATM were interdependent and needed to be synchronized.

The Communications, Navigation, Surveillance / Air Traffic Management (CNS/ATM) Focused Team (C/AFT), chaired by Dr. Chew, conducted a series of assessments that built a methodology for assessing the operational and economic consequences of joint investments.

EUROCONTROL's LINK2000+ program has furthered the work of the C/AFT through a series of operational and economic modeling activities.

Full references are provided at the end of this paper.

CPDLC and Productivity

CPDLC is aimed directly at changing the basic process by which air traffic capacity is produced. In any production process, there is an economically optimal mix of equipment (usually referred to in economics discussions as "capital") and people (or "labor") that is necessary to perform the work. Approaching that optimal mix is the key objective in managing the cost of production.

CPDLC changes the labor and capital mix in air traffic services by substituting automation for routine air traffic control processes that are currently accomplished through controller-to-pilot voice communications. It can also provide a means to provide services that are currently impractical (i.e. too complex) to be delivered via voice. By reducing controller workload, CPDLC enables the ATO to accommodate higher levels of en route traffic without adding sectors. By avoiding the addition of new sectors, the ATO will avoid the costs associated with increased labor and equipment. The increase in productivity—more capacity handled by the same staffing and facilities—leads to a decrease in the unit cost of providing air traffic services. More capacity can be produced for a lower unit cost.

Previous CPDLC Benefits Efforts

In order to meet the objectives of this paper to present a brief review of past efforts to elucidate a case for the benefits of En Route CPDLC; a preliminary basis for estimating the impact of CPDLC equipage rates on airspace capacity in the NAS is examined.

FAA En Route Benefits Study (1995)

Past efforts to quantify the economic benefits of implementing CPDLC in En Route airspace began with the FAA decision to conduct a large-scale, high fidelity, controller and pilot-in-the-loop simulation to assess benefits that would be accrued by airspace users [FAA, 1995]. Prior real-time simulation studies had demonstrated that CPDLC would reduce access limitations on the air-ground voice frequencies. However, the position of the air carrier industry at the time was that, in order to justify equipage costs, the mechanisms by which this increased communications capability would result in user cost savings would have to be directly and objectively demonstrated.

Retrospective consideration of the FAA En Route benefits study after nearly ten years indicates that it provided at least two important foundations for the development of contemporary benefits cases for CPDLC. It empirically demonstrated that the increase in communications channel capacity and decrease in voice frequency access limitations provided by CPDLC will provide direct benefits in terms of En Route sector productivity and efficiency with resulting reduced aircraft delays. This earlier study, and subsequent real-time simulation studies, has shown that frequency access limitations are reduced in proportion to the number of equipped aircraft. These results provide an objective basis for the assertion in benefits cases that reductions in user delays and increases in the effective capacity of En Route airspace will be positively and monotonically related to the number of aircraft equipped for CPDLC.

Another important outcome of the 1995 FAA study is that it established some of the primary mechanisms by which CPDLC provides benefits through its effects on the tasks and resulting productivity of air traffic controllers. The findings of the study show that improvements in ATC service to aircraft were attributable to several factors. First, CPDLC alleviated frequency access limitations, making the voice radio frequency more available for time-critical clearance delivery. Second, automation of some communications tasks and simplified CPDLC inputs freed the controllers to devote more time to developing and executing effective control strategies. Third, CPDLC communications could be conducted in parallel as opposed to the inherently serial nature of communications using the voice radio. Finally, optimal use of the expanded communications capability was achieved by distributing communications tasks to all members of the control teams. This permitted simultaneous voice and CPDLC messaging to different aircraft. It also allowed the controllers to act as coordinated and flexible team decision makers.

CNS/ATM Focus Team (C/AFT) U.S. Investment Analysis (1999)

The C/AFT was an international industry/air traffic service provider group headed by the airlines that was organized to facilitate CNS/ATM implementation progress by developing global airline consensus on economic issues. In 1999, C/AFT published an investment analysis [C/AFT, 1999] that examined the costs and benefits associated with equipping the airline fleet with VDL to meet Aeronautical Operational Communication (AOC) requirements and to obtain CPDLC services. The full analysis was conducted solely to assess costs and benefits to the airline industry. AOC benefits assessments were based on the need to meet the airlines' internal communications requirements with new technology aimed at resolving limitations associated with the existing Aircraft Communications Addressing and Reporting System (ACARS) system.

C/AFT European Investment Analysis (2000)

While not explicitly attributed to the earlier work, the benefits estimation methodology adopted for this analysis capitalized on the known relationship between aircraft equipage levels and reductions in voice radio frequency usage, and the extrapolation of this relationship to aircraft delays originally demonstrated in the 1995 FAA benefits study. The CPDLC benefits case was based on a combination of empirical data derived from real-time simulation and analytical findings obtained from fast-time simulation models.

The initial step in the process was a real-time simulation performed at the EUROCONTROL Experimental Centre [EUROCONTROL, 2000]. This study investigated voice radio frequency usage at three levels of traffic volume (baseline study day traffic, and 150% and 200% of the baseline volume), and at four levels of Data Link aircraft equipage (0%, 50%, 75% and 100%). Simulation limitations that confounded data regarding perceived controller workload and measures of flight efficiency prevented the use of this information in the calculation of benefits. However, a clear positive correlation was obtained between aircraft equipage level and reduction in voice frequency usage.

Working with these data, EUROCONTROL used previous non-data link study findings from National Air Traffic Services (NATS), in the United Kingdom (U.K.) and Centre d'Études de la Navigation Aérienne (CENA), France to estimate reductions in total sector workload associated with communications under current voice-only conditions. These earlier results indicated that communications normally constitute 35% to 50% of total sector workload. Based on the reductions in frequency usage identified in the real-time simulation, EUROCONTROL researchers calculated total sector workload reduction associated with CPDLC for each level of data link equipage using the conservative estimate of communications workload (35%). It should be noted that the estimates of total sector workload reduction were exclusively based on the observed reductions in voice radio usage. They did not account for the potential contribution of the CPDLC tasks to sector workload.

The link between sector workload and airspace capacity was estimated using prior results obtained with the ATC Capacity Analyser (CAPAN) tool. Work with this controller task-based fast-time simulation tool suggested that proportional sector capacity increases are approximately one-half of the amount of workload reduction achieved in a sector. The results of the workload and capacity calculations performed by EUROCONTROL [EUROCONTROL, 1999] are presented in Table 1Estimated Capacity Gain as a Function of CPDLC Equipage.

Table 1Estimated Capacity Gain as a Function of CPDLC Equipage

Percent Aircraft Equipage	Workload Reduction	Capacity Gain
0%	0%	0%
50%	16%	8%
75%	22%	11%
100%	29%	14%

Two additional steps were performed to validate the estimated capacity increases afforded by CPDLC and to extrapolate the capacity increases to aircraft delay reductions of direct interest to airspace users. A fast-time CAPAN simulation was conducted to determine the correspondence between the original estimate of CPDLC effects and a detailed assessment of the specific controller tasking changes associated with CPDLC on sector capacity [EUROCONTROL, 1999].

The CAPAN tool models airspace and traffic and records controller workload generated by the passage of traffic through each sector. The workload assessments are based on task execution times. Controller tasks modeled include flight data management, coordination, conflict search, and voice radio communications. For the CPDLC analysis, workload variations were introduced by substituting CPDLC communications task times for the voice radio task times that could be eliminated using the available message set. The criterion used for maximum controller workload was defined as the point where the sum of sector task execution times exceeded 70% of the available time. Sector capacity differences between baseline and CPDLC conditions were determined by the number of aircraft operating within the sector when the maximum workload levels were met.

As shown in Table 2 CPDLC CAPAN Model Results, the results of the CAPAN simulation, which was based on an explicit consideration of controller task execution times, are remarkably similar to those based on the estimates calculated from the real-time simulation data.

Table 2 CPDLC CAPAN Model Results

Percent Aircraft Equipage	Workload Reduction	Capacity Gain
0%	0%	0%
25%	7%	3.4%
50%	15%	7.8%
75%	22%	11.2%
100%	29%	15.9%

Extrapolation of the capacity increases to the delay reductions of interest to airspace users was achieved using the Common Simulator to Assess ATFM Concepts (COSAAC). COSAAC [EUROCONTROL, 2004] was developed by EUROCONTROL to investigate the impact of traffic and capacity variations on Air Traffic Flow Management (ATFM) delays in the European environment. The traffic sample and airspace used for the delay calculations were identical to those used in the real-time simulation baseline. Results of the COSAAC simulation are shown in Table 3 Delay Reduction as a Function of CPDLC Equipage below.

Table 3 Delay Reduction as a Function of CPDLC Equipage

Percent Aircraft Equipage	ATFM Delay Reduction	Overall Delay Reduction
0%	0%	0%
25%	10%	2.5%
50%	31%	8%
75%	44%	11%
100%	53%	13%

It should be noted that ATFM delays in EUROCONTROL airspace historically constitute 25% of all delays experienced by aircraft. The third column of the table reflects the reduction in total delays attributed to CPDLC.

Preliminary Estimation of Capacity Benefits

As suggested in the analysis of prior CPDLC benefits cases above, future efforts should endeavor to identify and quantify benefits that will be gained not only by airspace users, but also by ATSPs. As in the case of delay reductions, these ATSP benefits flow directly from the increase in sector productivity (controller workload capacity) associated with the use of CPDLC, but are realized as an alternative means to increase airspace capacity.

To provide a preliminary assessment of the potential magnitude of capacity increases that may be expected with CPDLC, the estimation methodology used for the European business case was applied to an extended data set derived from a combination of FAA and European controller-in-the-loop high fidelity simulations of En Route CPDLC operations during the period of 1990 to 2002. Some data points included in the set were derived from the 1995 U.S. benefits study [FAA, 1995] and the 2000 EUROCONTROL business case simulation [EUROCONTROL, 2000] described earlier. Additional data were obtained from an early FAA operational evaluation of CPDLC [FAA, 1990], a study of CPDLC implemented on a prototype ATC workstation [FAA, 1994], and a recent EUROCONTROL LINK 2000+ simulation [EUROCONTROL, 2002]. Although the controller CPDLC interfaces, airspace, and other variables differed in these studies, all produced quantifiable measures of reduction in voice radio frequency usage under one or more levels of aircraft equipage.

A total of nine assessments of equipage and reduction in frequency usage were drawn from the original FAA and EUROCONTROL reports. The scatter plot shown in Figure 1 Reduction in Voice Radio Usage as a Function of CPDLC Equipage below illustrates the somewhat remarkable agreement among the different studies. The data clearly indicate that, the larger the number of aircraft equipped to participate in ATC Data Link communications, the greater the usage of the CPDLC system and the larger the reduction in access limitations of the voice channel. Furthermore, the data suggest that this relationship holds from relatively low levels of fleet equipage (approximately 20%) up to full equipage.

Extrapolations from these empirical data to estimates of sector capacity changes were accomplished using the European methodology described earlier in this paper. The calculation of reduction in total sector workload was based on the assertion that communications workload normally represents 35% to 50% of total sector workload. The conservative value of 35% was used for LINK 2000+ and for the calculations performed for this estimate. Productivity-related capacity increases associated with these workload reductions were based on the general findings of prior simulations relating controller workload to sector capacity and validated by a controller task execution time CAPAN simulation designed specifically to study the effects of CPDLC on workload and capacity.

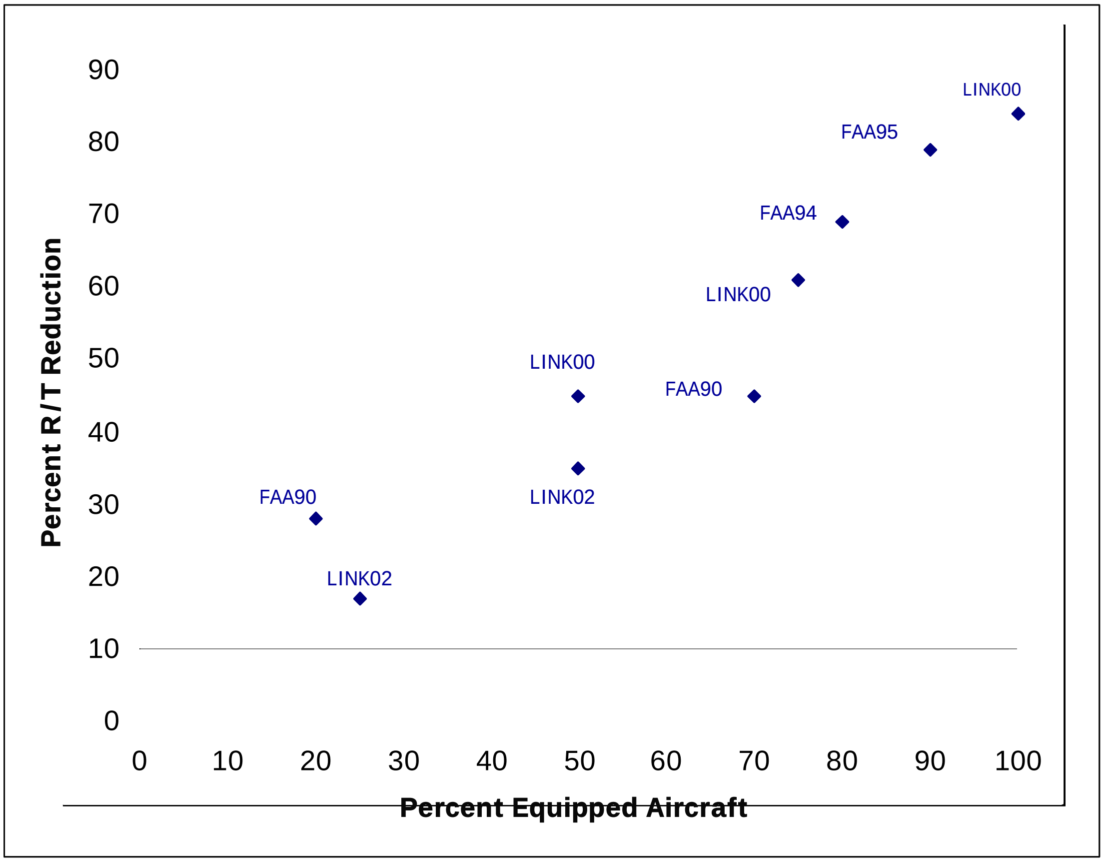

Figure 1 Reduction in Voice Radio Usage as a Function of CPDLC Equipage

The input data, their sources and results of the preliminary calculation are presented in Table 4 CPDLC Aircraft Equipage and Capacity Calculations

Table 4 CPDLC Aircraft Equipage and Capacity Calculations

Data Source	% Aircraft Equipage	% R/T Reduction	% Sector Workload Reduction	% Capacity Increase
FAA 90	20	28	10	5
LINK 02	25	17	6	3
LINK 02	50	35	12	6
LINK 00	50	45	16	8
FAA 90	70	45	16	8
LINK 00	75	61	21	10.5
FAA 94	80	69	24	12
FAA 95	90	79	28	14
LINK 00	100	84	29	14.5

A regression analysis applied to the equipage-capacity data revealed a strong linear relationship (r=.95) reflecting the original empirical correlation derived from the combined U.S. and European data. Figure 2 Estimated Capacity Increase as a Function of CPDLC Equipage shows the best linear fit to the results. Supporting descriptive statistics appear in Table 5 Parameters Associated with Capacity Estimate and Table 6 Confidence Limits.

It should be noted that variation about this estimate in terms of minimum and maximum effects of CPDLC equipage on airspace capacity can be estimated using two combined techniques. Using the European calculations, the data presented here can be considered a conservative (low) point estimate of the workload reduction and capacity increase provided by CPDLC. The high end of the range could be calculated by using 50% for the proportion of sector workload attributable to communications rather than 35%. Statistical variations about each of these extremes can be determined using the standard error of estimate for the regression equation in Figure 2 Estimated Capacity Increase as a Function of CPDLC Equipage.

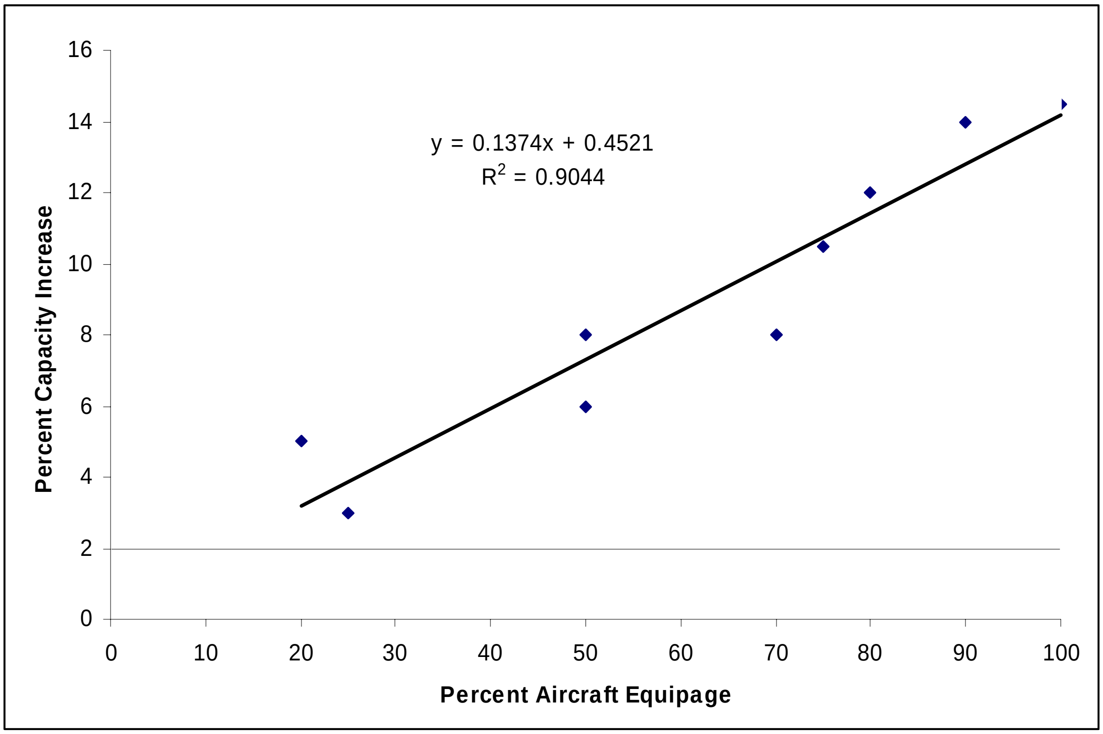

Figure 2 Estimated Capacity Increase as a Function of CPDLC Equipage

Table 5 Parameters Associated with Capacity Estimate

Estimate Parameters	Value
r	0.951
r^2	0.904
Slope	0.137
Y-Intercept	0.4521
Standard Error of Estimate	1.3302
t	8.135
df	7
Probability (one-tailed)	0.0001
Probability (two-tailed)	0.0001

Table 6 Confidence Limits

	Lower Limit	Upper Limit
0.95	0.779	0.989
0.99	0.659	0.993

Conclusions

The keys to assessing the benefits of CPDLC lie in an understanding of how CPDLC facilitates the job of air traffic controllers, and how these changes affect the effective capacity of airspace and the associated costs of sustaining a safe and efficient air traffic system and the operations costs of airspace users.

Many elements of developing the benefits case for domestic En Route CPDLC have been established in past studies and analyses that have been conducted for implementation in the U.S. and Europe. Independent of any financial estimates that were derived from the data, the original FAA Data Link benefits studies defined and recorded some of the major ways in which controller productivity is enhanced by this technology and showed how this translated to an increased ability to handle more traffic and reduced air traffic delays. These findings provided an objective foundation for the subsequent analytical studies that use aircraft equipage levels and voice frequency usage reductions to predict workload savings, capacity increases and delay savings.

The analysis presented in the previous section of this paper offers one conservative method to assess the magnitude of the capacity increases that may be achieved with CPDLC.

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CPDLC, ATN, Operational Benefits

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Evan R. Darby, Jr., is the Controller Pilot Data Link Communications (CPDLC) lead at the William J. Hughes Technical Center in Atlantic City, New Jersey. He is an En Route Air Traffic Control Specialist and was the Test Director for both the FAA's En Route and Terminal Benefit Studies (1995/1996). Mr. Darby has been apart of the En Route/Terminal CPDLC development and test team since 1989, and was part of the industry team that implemented the first operational CPDLC system at the Miami Air Route Traffic Control Center (ARTCC).

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Joseph P. Pino is the Area Manager for En Route Communications, Surveillance and Weather programs under the En Route Program Operations directorate in the FAA Air Traffic Organization (ATO). Mr. Pino received his M.B.A. summa cum laude from Monmouth University and his B.S. in electrical engineering from Drexel University. He has over 25 years of program leadership experience in the design, development and production of real time systems in both the public and private sectors. Mr. Pino was the CPDLC Program Manager that was responsible for the successful implementation of CPDLC Build 1 project at Miami.

Timothy Hancock

Timothy R. Hancock began his career with the FAA in 1984 as an Air Traffic Control Specialist at Atlanta ARTCC, where he gained experience as a radar training instructor, Airspace and Procedures Specialist, and Traffic Management Specialist. In 1989 he joined the ATC team that developed the Human-Computer Interface for CPDLC. He was a Test Director for the Data Link Benefits Studies, developed requirements, training, and procedures for the CPDLC project, and was Chairman of the government/industry/union CPDLC Integration Team partnership, that was responsible for the successful integration of the CPDLC Build 1 project in Miami. Mr. Hancock received his B.A. from Georgia State University.