Data Link Investment Analysis

Prepared by

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Executive Summary

The CNS/ATM Focused Team (C/AFT) conducted a thorough economic analysis that demonstrates the costs and benefits of equipping with Very High Frequency Data Link (VDL) Mode 2 for Airline Operational Control (AOC) and Air Traffic Control (ATC) operations. The analysis was performed from an airline perspective, and focused on the value to the airlines of transitioning from Plain Old ACARS (POA) to VDL Mode 2 for AOC and ATC communication in a high-density Cruise/Terminal Transition environment of the US National Airspace System (NAS). The baseline ‘do-nothing’ scenario allows AOC frequency congestion and ATC delay to increase under status quo conditions.

Results of the analysis show that **data link is a strategic, long-term investment.** The initial investment, while significant, provides a positive return on investment and lays the foundation for future potential benefit. The value of maintaining AOC data link capability is the primary cost-avoidance driver, and provides a convincing case for forward fit equipage of airplanes. ATC delay reduction benefits will drive retrofit, although there is more uncertainty in the business case for equipping with VDL Mode 2 for the ATC delay reduction benefits only. The ATC risks are mitigated, however, by the need to preserve AOC functionality. Forward fit equipage must start as soon as possible to avoid the high retrofit costs.

C/AFT transition logic diagram and economic modeling processes were used to provide the framework for the analysis. A complete cost benefit analysis was performed for near-term operational enhancements based on reducing controller communication workload. In addition, future data link operational enhancement steps were identified, allowing industry to estimate the ‘option’ value that is provided by near-term equipage with data link. Decision analysis methodology was used as the economic modeling tool to accurately model the costs, benefits, timing, and risks associated with these investments.

The cost of AOC non-availability is a significant factor in the investment analysis. ACARS use is critical to many airlines’ performance and has grown tremendously over the past ten years. More AOC frequencies have been added to deal with the increased message traffic, but the time is fast approaching when AOC spectrum capacity will be exceeded. Many areas of the US are already experiencing congestion of en route AOC frequencies, at the same time as other non-aviation users are looking at petitioning for available spectrum. Managing AOC spectrum congestion and availability will be a growing and continuing concern for the airline industry worldwide.

The cost of delay is another significant factor in the investment analysis. American Airlines and AMR SABRE Group studied the impact of delay on airline schedule and found that airline operations will be critically constrained by the year 2005 if nothing is done to curb delay growth. American Airlines concluded that the current NAS problems are real, and that with conservative traffic growth projections, traffic delays from congestion of US domestic airspace will increase at an accelerating rate.

VDL Mode 2 has been proposed as a means of mitigating both the AOC frequency congestion and ATC delay problems. VDL Mode 2 would provide an approximate tenfold increase in communication capacity over VHF ACARS. In addition, the bit-oriented nature of VDL-2 allows messages to be transferred with fewer bits. Recent industry activities suggest that digital data link is a key enabler to reduce delay, and the FAA has funding commitments for Controller-Pilot Data Link Communication (CPDLC) Builds 1 and 1A which are based on a subset of Aeronautical Telecommunication Network (ATN) messages over VDL Mode 2.

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1. Introduction

The CNS/ATM Focused Team (C/AFT) has agreed that future system capacity is the number one driver for global airspace system changes. C/AFT is proposing to achieve capacity gains through incremental operational enhancements that can be enabled by CNS technologies. In his paper "Free Flight, Preserving Airline Opportunity" Captain Russell Chew of American Airlines presented the results of a simulation that analyzed the relationship between capacity constraints and schedule integrity. The study concluded that the airline flight schedule will be critically impacted by the year 2005, and that substantial "ATC infrastructure changes by 2005 is optimistic, however the problems can be mitigated to some extent with an incremental approach to ATC improvements."

Digital data link is a primary candidate enabler for delay reduction in congested en route and extended terminal area airspace by reducing voice frequency congestion. Future Air Navigation System (FANS-1) implementation in the South Pacific demonstrated that digital data link can be implemented in an air traffic operational environment, and was the first step in data link's evolutionary path by providing data link capability for procedural airspace. The lessons learned from FANS operation will be used to develop ATC data link for radar-controlled airspace.

The ICAO ATN Standards and Recommended Practices (SARPs) define the data link message sets, including those needed to support future radar-controlled operations. Until now, a credible business case has been missing to convince airlines and ATS service providers to equip for ATN operations. At the same time there are spectrum availability and congestion problems looming for airline AOC operations, with the potential for a large negative economic impact.

The C/AFT terms of reference include evaluating solutions and developing consensus. In order to achieve these goals C/AFT took on the task of developing an economic analysis that demonstrates to airlines and providers the costs and benefits of VDL Mode 2 data link. VDL Mode 2 data link was chosen for the analysis because the C/AFT members had better data about it than other forms of data link. The analysis has been performed from an airline point of view. This document presents the results of C/AFT's study of the costs and benefits of equipping with data link in extended terminal areas of the US NAS.

2. Scope of Analysis

This analysis evaluates the value to the airlines of transitioning from Plain Old ACARS to VDL Mode 2 for AOC and ATC communication in a high-density Cruise/Terminal Transition environment of the US NAS (AOC benefits apply to all phases of flight). Cruise/Terminal Transition is defined as from the en route transition through end of Standard Terminal Arrival Route (STAR), and from the beginning of Standard Instrument Departure (SID) through transition to en route. Both AOC and ATC benefits are considered. The baseline ‘do-nothing’ scenario allows AOC frequency congestion and ATC delay to increase under status quo conditions.

While the economic model being used by C/AFT is capable of an industry-wide analysis, it was decided that this initial data link analysis would be performed from an airline industry point-of-view only. C/AFT is an airline-led team, and was interested in determining whether or not there is a direct benefit to the airlines. The implicit assumption is that unless airlines directly benefit from an enhancement there would be little incentive for air traffic service providers to change.

It is understood that for the short term, AOC viability and delay reduction are the most important benefits. For the longer term other additional benefits are expected, such as increased flexibility. Although these additional benefit categories cannot be quantified yet, they should be mentioned for completeness.

While VDL Mode 2 data link is the only enabler investigated in this analysis, a complete investment analysis study requires evaluation of alternative technologies, including other types of data link, navigation, surveillance and air traffic management. Particular attention must be given to alternative enablers that may compete for the same benefit, with the recognition that it is seldom one or the other technology providing all of the benefit, but rather a combination of C, N, and S enablers. An alternatives analysis also assures that benefits are not 'double-counted', which can lead to inflated estimates.

3. AOC Communication Issues

Airline Communication Addressing and Reporting System (ACARS) use has grown tremendously over the past ten years. More frequencies have been added to deal with the increased message traffic, but the time is fast approaching when spectrum capacity will be exceeded. ACARS is a shared-access system based on a non-discriminatory system of FCC frequencies. There are limited numbers of VHF frequencies available and any POA expansion is doomed to be short-lived and expensive. Many areas of the US are already experiencing congestion on en route frequencies at the same time as other industries are looking at petitioning for available spectrum. In Figure 3.0-1 it can be seen that with conservative AOC traffic growth projections and maximum ACARS frequency capacity (8 frequencies) parts of the US will run out of spectrum as early as 2003. Managing spectrum congestion and availability will be a growing and continuing concern for the airline industry.

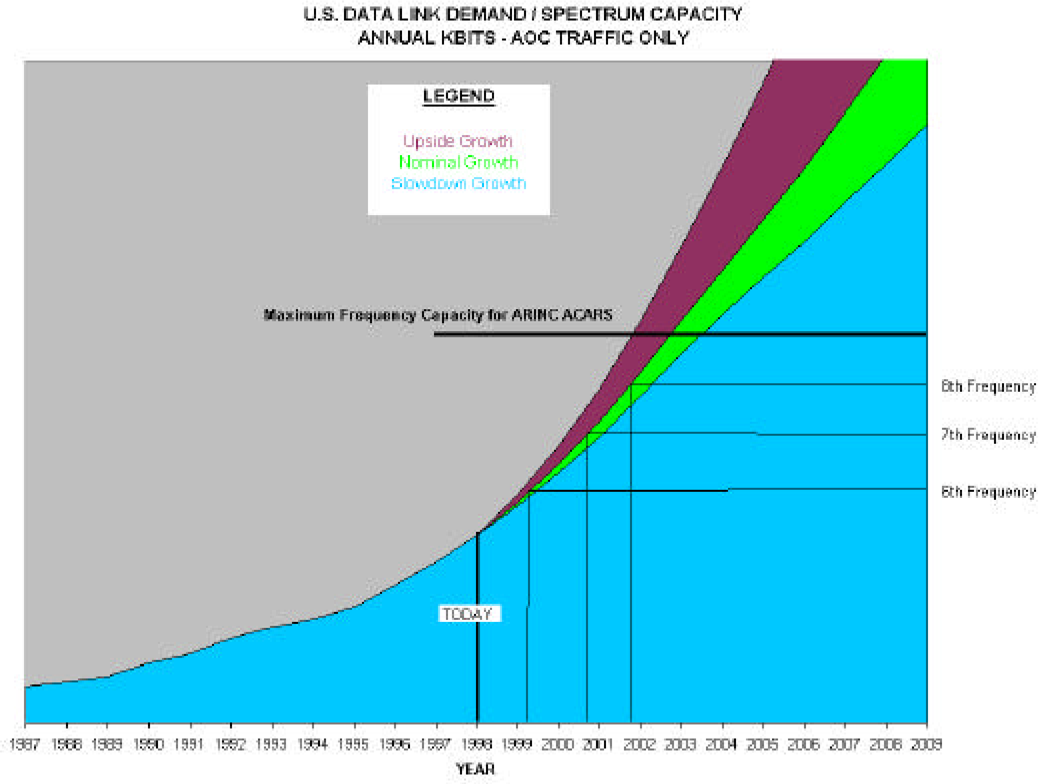


Figure 3.0-1. US Data Link Demand / Spectrum Capacity

ARINC estimates that there are approximately 7100 ACARS users today (5600 US and 1500 non-US), and predicts that there will be up to 1200 more airline users over the next three to five years (these numbers include international airplanes that fly into and use the ARINC system). In addition there is a potential for increased demand from new ACARS users (regional and cargo airlines, business airplanes, and the military), with a total estimate of more than 4500 additional aircraft. The primary reason for increasing ACARS demand, however, is the appearance of new data link applications, such as aircraft performance monitoring and crew management.

As a result of the clear trend of increasing frequency congestion and spectrum depletion, ARINC has published plans to provide incentives for transition to VDL Mode 2. Once the infrastructure is available (currently estimated to be 2001 for the US) ARINC will provide favorable prices for services using VDL Mode 2. In addition, any new POA airplanes will be assessed a significant monthly surcharge (see Appendix H). The strategy is that as more airplanes equip, prices for VDL Mode 2 communication will decrease and prices for POA will increase.

4. ATC Communication Issues

Captain Russell Chew's paper "Free Flight, Preserving Airline Opportunity" studied the impact of delay on airline schedule. American Airlines and AMR SABRE Group simulated traffic growth in the US NAS and its effects on delay. The study analyzed effects of traffic growth under two scenarios: 1) with today's separations, and 2) with some 'Future NAS' where technological and procedural enablers have allowed reduced separations. The study did not propose specific solutions to achieve the reduced separations, but rather its goal was to determine the effect on airlines of doing nothing. Their simulation suggests that airline operations will be critically constrained by the year 2005: "From this study, AA concluded that the Current NAS problems are real, and that with conservative traffic growth projections, traffic delays from congestion of U.S. domestic airspace will increase at an accelerating rate. We expect that the range of delay will increase at an even faster rate, and that airspace delays will begin to economically constrain airline operations and scheduling opportunities in the next decade."

The other side of this coin is that by reducing separations, airline schedules can be maintained: "We also generally concluded that a Future NAS solution is possible, and that Free Flight (i.e. global CNS/ATM) can significantly extend NAS capacity, even without new arrival runways in the near term."

Recent industry activities suggest that digital data link is a key enabler to reduce delay. The FAA published the results of a data link benefits study in February 1995 entitled "User Benefits of Two-way Data Link ATC Communications: Aircraft Delay and Flight Efficiency in Congested En Route Airspace" (aka "The Atlanta Study") in which ATC productivity was increased (and airline delay decreased) by using data link to reduce voice frequency congestion. (It should be noted that the FAA's "Congested En Route Airspace" corresponds to the C/AFT definition of Cruise/Terminal Transition Area airspace.)

PETAL-II (Preliminary Eurocontrol Test of Air/Ground Data Link) trials are underway in Europe to evaluate data link operational implementation issues. PETAL-II is the second in a series of operationally-oriented air/ground data link trials conducted by Eurocontrol. The aim of PETAL-II (and its predecessor PETAL-I) is to allow currently active aircrew and controllers to examine and modify the international operational procedures and use of air/ground data link in CNS/ATM.

The FAA has recently received funding approval for Builds 1 and 1A CPDLC (based on ATN) over VDL Mode 2. Builds 1 and 1A message sets are a subset of the PETAL-II set. CPDLC Build 2 will include initial oceanic message support, will have international scope, and will define the beginning of the transition from FANS-1 to ATN.

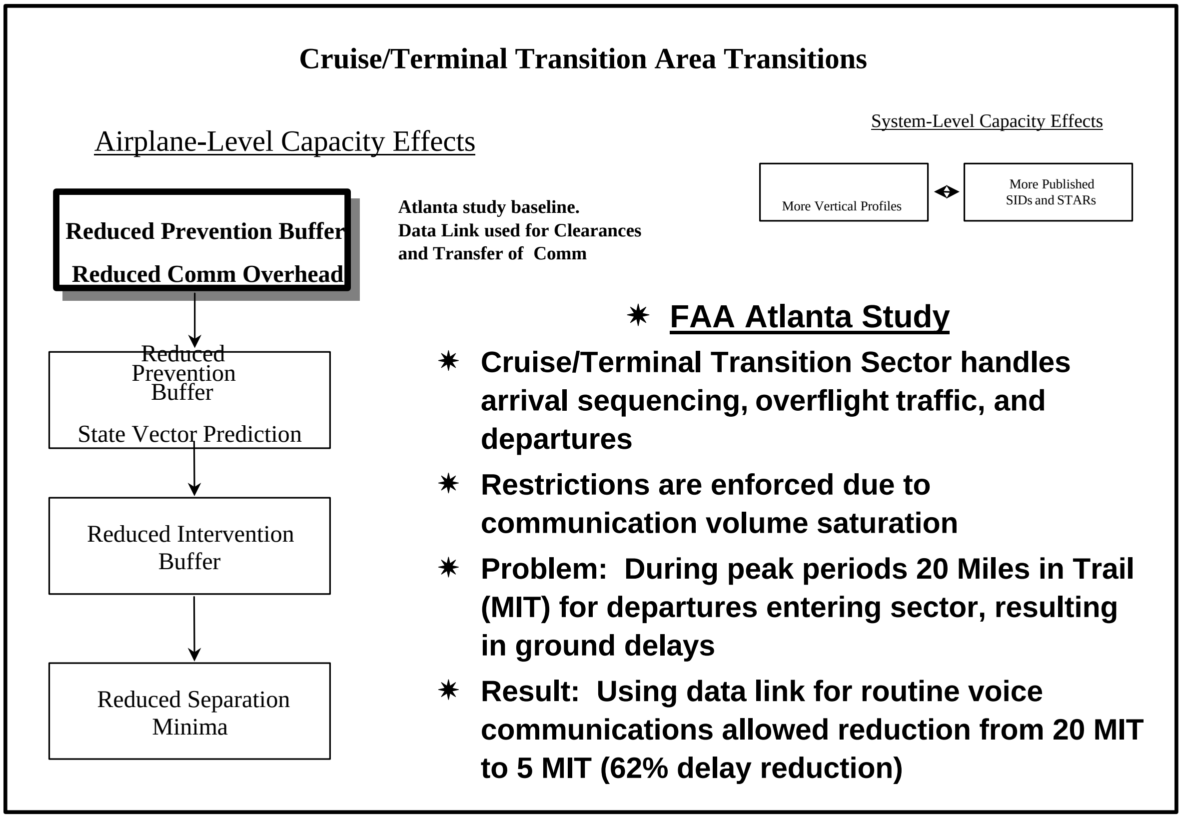
Eurocontrol and various European States are requesting a joint FAA/European collaboration to define a follow-on data link implementation project. This activity is expected to be a key element in setting the international standard for ATC data link in congested, highly developed airspace. C/AFT believes that a joint US and European solution is needed, and will continue to work to facilitate the convergence.

5. Data Link Model Structure

C/AFT transition logic diagrams were used to frame the data link investment analysis. This analysis dealt only with the near-term delay reduction benefits and associated costs achievable in the first operational enhancement step, Reduced Prevention Buffer, through reduction in controller workload by using CPDLC for routine clearances and transfer of communication. Figure 5.0-1 summarizes the capacity impacts of the FAA Atlanta Study and places them in the context of C/AFT transition logic diagrams. The results of the

Atlanta study form the basis for delay-reduction benefit estimates. AOC-related investments were also fundamental to the near-term analysis, but did not have a capacity impact.

There is potential for data link-enabled benefits in the subsequent operational enhancement steps of Figure 5.0-1, as well as in other phases of flight. Appendix A shows the capacity-related operational enhancement steps that could be enabled by data link for all phases of operation. The operational enhancements in which data link has been identified as a potential enabler have been highlighted and the specific data link functions identified. These transitions help to define the mid- and long-term benefits derived by equipping for data link in the near-term.



Cruise/Terminal Transition Area Transitions

Airplane-Level Capacity Effects

System-Level Capacity Effects

Atlanta study baseline.
Data Link used for Clearances and Transfer of Comm

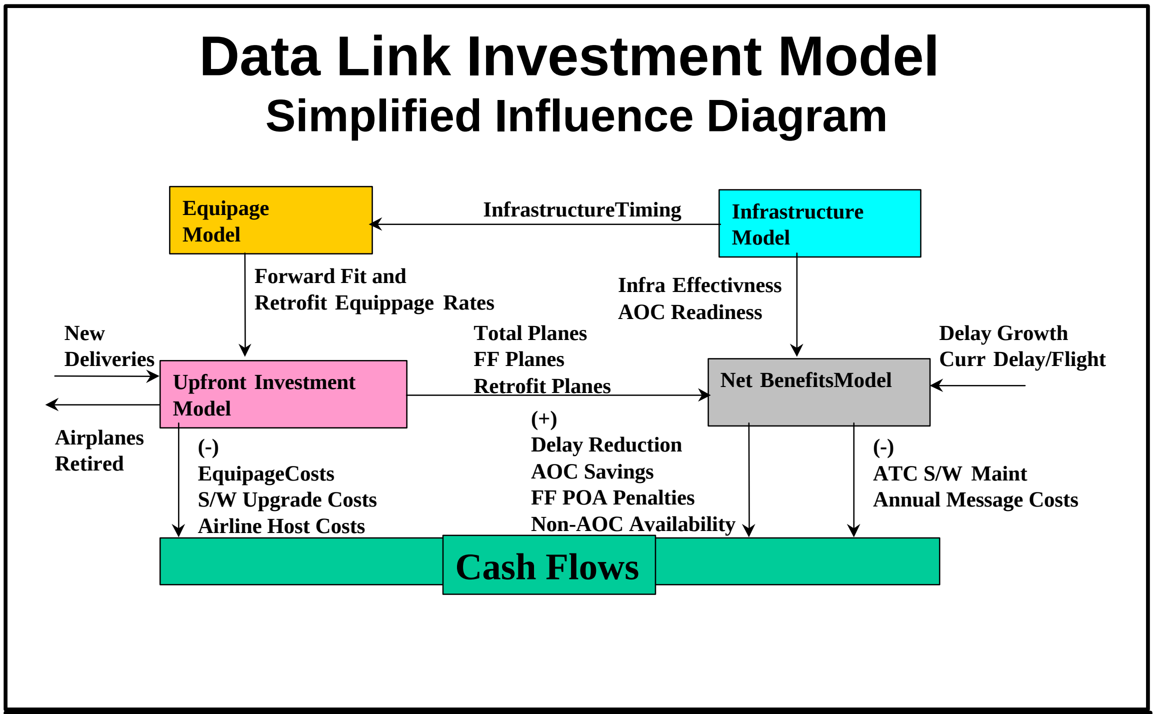
FAA Atlanta Study

- **Cruise/Terminal Transition Sector handles arrival sequencing, overflight traffic, and departures**
- **Restrictions are enforced due to communication volume saturation**
- **Problem: During peak periods 20 Miles in Trail (MIT) for departures entering sector, resulting in ground delays**
- **Result: Using data link for routine voice communications allowed reduction from 20 MIT to 5 MIT (62% delay reduction)**

Figure 5.0-1: Atlanta Study and C/AFT Transitions

5.1 Influence Diagram

Figure 5.1-1 represents a simplified influence diagram for the economic model (the complete influence diagram is shown in Appendix B). The influence diagram is a graphical representation of the variables that affect net present value for data link. The Equipage sub-model keeps track of forward fit and retrofit equipage rates, which are tied to the infrastructure timing from the Infrastructure sub-model. The Upfront Investment equipage costs are applied to the New Deliveries and Retrofits. The new deliveries in combination with the number of airplanes retired are used to keep track of the total number of airplanes in the model each year. The Benefits Model incorporates ATC delay reduction based on projected delay growth, as well as AOC viability benefits. All of this is used to develop the cash flows. All of the model inputs shown on this diagram are explained in detail in Section 5.2.



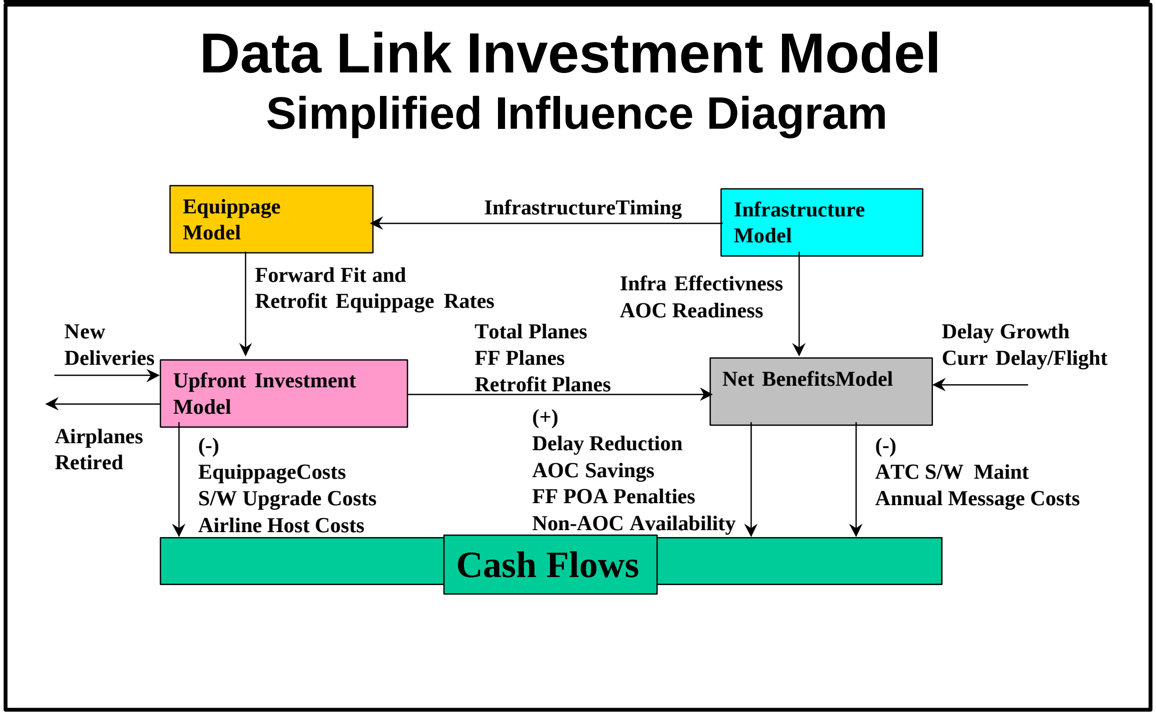


Figure 5.1-1: Data Link Investment Model

5.2 Model Inputs

The data link decision analysis model calculates the net present value (NPV) of cash flows from the years 2000 to 2020 for the proposed data link investment, and allows for probabilistic analysis. (Details of the model outputs are discussed in Section 5.3). The model has six major components that are explained below. The names and structure are consistent with the influence diagram and the underlying decision model.

All of the model inputs, except constants, are given as a range of values. The ranges represent a number so low that there is only a 10% chance the actual outcome will be below that value (10th percentile event), a number so high there is only a 10% chance the actual outcome will be above that value (90th percentile event), and a number such that the actual outcome is equally likely to be above or below (50th percentile event).

5.2.1 Constants

The economic model includes constants as variables that do not have an associated uncertainty, shown in Appendix C. The final year for benefits is five years later than final year for equipage so that benefits that accrue due to late equipage (near 2015) are fully modeled. The value for Direct Operating Cost (DOC) was considered low by some, but the C/AFT airlines agreed that it would be best to use the industry standard of $25/minute, in light of the industry-wide scope of this analysis. Consensus was that the cost of fuel will increase at a higher rate than inflation, thus the DOC includes a fuel component (30% of DOC) with a 5% increase per year.

5.2.2 Traffic Growth

The model bases traffic growth on the baseline of 5194 Total Number of Airplanes from the 1998 Air Transport Association (ATA) annual report. Each year the 'Cumulative Equipped Planes' is calculated by adding new deliveries equipped with VDL Mode 2 and by retiring a certain number of airplanes. The team did not have reliable data for the percentage of airplanes retired each year, so a variable was created, as shown in Appendix D.

5.2.3 Infrastructure

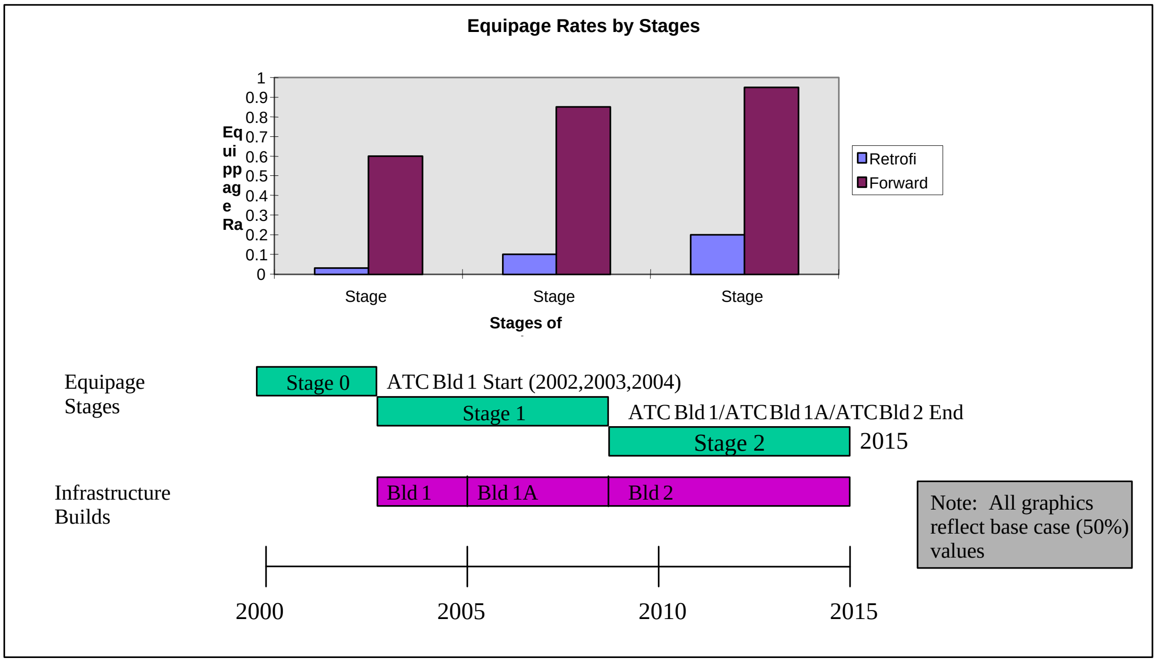
Two kinds of ground infrastructure are required before benefits can be achieved: the ARINC VDL Mode 2 network infrastructure, and the FAA CPDLC Builds 1-2 infrastructure. Confusion often reigns around the issue of equipage versus infrastructure readiness – which comes first? – similar to the old chicken or the egg question. This analysis assumes that airlines will not equip with VDL Mode 2 for delay reduction benefits until the ATC infrastructure is ready.

CPDLC Builds have an associated 'Delay Reduction Effectiveness' which represents the percentage of data link-related delay that is affected with each build. These delay reduction effectiveness numbers were estimate by FAA Air Traffic Services based on frequency of use of each message as demonstrated in the PETAL-II trials in 1998. Build 1 delay reduction effectiveness is now at 0%, since the FAA made the decision to limit its deployment to Miami. Builds 1A and 2 have a range of delay reduction effectiveness values, based on the delay reduction achievable with each build’s message set and controller tools. Infrastructure assumptions are summarized in Appendix E.

5.2.4 Equipage

The model assumes three stages of equipage, each of which has a different driver (in the form of benefits received), thus different equipage levels. Stage 0 is tied to AOC infrastructure readiness, Stage 1 to ATC infrastructure readiness, and Stage 2 to a more ‘mature’ ATC infrastructure (e.g., Build 1A or 2 readiness).

In Stage 0 there will be no ATC delay reduction benefits and there will be cost penalties for POA-equipped forward fit airplanes (shown in the benefits section as a cost avoidance). These penalties will drive a relatively high forward fit rate in Stage 0. In Stage 1 ATC infrastructure readiness will drive equipage, thus it begins when Build 1 is ready. It is assumed that equipage will happen slowly until a point when the ATC infrastructure is mature and proven, and airlines actually realize delay reduction benefits. Stage 1 ends, and Stage 2 begins, when airlines begin the more aggressive retrofit due to realized benefits. It is not clear at what point more aggressive equipage rates will begin, so the Stage 1 End Year is an uncertainty tied to different ATC infrastructure readiness dates. AOC penalty avoidance benefits for forward fit airplanes are also included in both stages. Appendix F summarizes the equipage rate assumptions, and Figure 5.2.4-1 depicts the relationship among equipage rates, the three equipage stages, and ATC infrastructure builds.



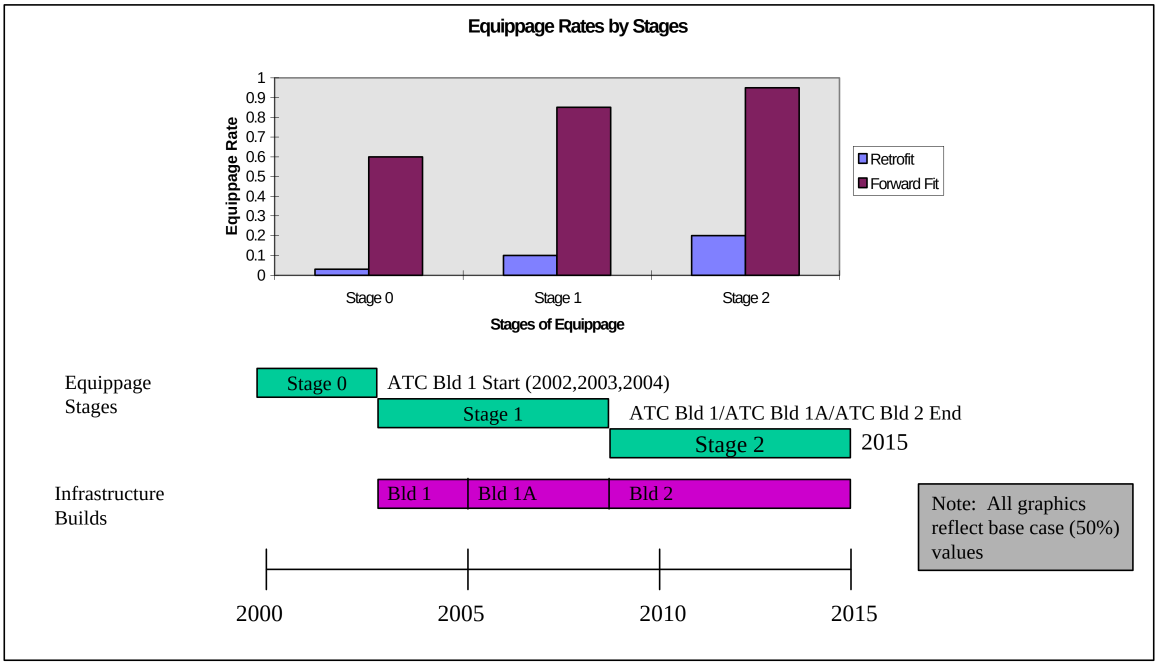


Figure 5.2.4-1: Equipage Rates by Equipage Stages

5.2.5 Costs

Two kinds of costs are modeled: 1) airline equipment costs for AOC and ATC, and 2) ATC message costs, both of which are summarized in Appendix G. The C/AFT airlines considered training costs to be negligible for the purposes of this analysis. ATM costs are not modeled either because they are not a direct cost to the airlines in the US. ATM costs would need to be included in a similar analysis for European airspace, as ATM costs are directly charged to the airlines in Europe.

Airline Equipment Costs

Airline airborne equipment costs assume minimal avionics and flight deck impact, and would involve only the Communication Management Unit (CMU - ARINC 758), VHF Digital Radio (ARINC 750), and airplane wiring. It is assumed that the VDL Mode 2 ACARS over Avionics VHF Link Control implementation will meet requirements for AOC datalink, but will require a software upgrade for ATC applications. The ATC messaging function would be hosted in the CMU, and not in the Flight Management System (FMS). The airborne equipage would occur in two stages: a hardware update for AOC applications, followed by an ATC software upgrade. (ATC software upgrades are assumed to be implemented at the end of Build 1.) Equipage cost estimates in the model are average costs assumed across all airplane models, and are not model-specific. The wide range in equipage cost variables is due to the risks inherent in airborne avionics modifications.

In addition to the airborne equipment, airlines will have to upgrade their AOC host or AOC router, and will have to pay maintenance costs on the airborne equipment.

Airline ATC Message Costs

It is uncertain at this time whether the FAA or airlines will be responsible for paying the ATC message costs. There has even been some discussion that the FAA would pay for uplinks and airlines pay for downlinks. The model takes this uncertainty into account by calculating the annual ATC message costs, then applying a multiplying factor, where 0 assumes that the FAA pays all costs, 0.5 that airlines and FAA split costs, and 1 that airlines pay all message costs. The annual message costs are calculated using the following formula:

**(ATC msgs per equipped flight) * (kbits per msg) * (Cost per ATC kbit) *
(Cumulative Equipped Planes) * (Total Flights per year)**

5.2.6 Benefits

The model quantifies benefits related to AOC operations and to ATC delay reduction, summarized in Appendix H.

AOC Operations

There are four AOC benefit mechanisms modeled in this analysis. Two of them are associated with the ARINC plans to provide incentives for VDL Mode 2 equipage as discussed in Section 3, one is related to efficiencies inherent in VDL Mode 2 operations, and the last has to do with the value of AOC operations to the airlines. Current AOC message costs per flight are used as a baseline. The range used in this variable reflects the difference in AOC costs among airline operators.

There are plans in place to penalize POA operations in the US NAS once the VDL Mode 2 infrastructure is ready. Rather than include the penalties as a cost, the model assigns a benefit to the cost avoidance since we are looking at the value of equipping with VDL Mode 2. There will be a significant monthly surcharge applied to all forward fit airplanes not equipped with VDL Mode 2, as well as a yearly increase in the rates charged for POA communication costs.

VDL Mode 2 is a binary-oriented system, as opposed to character-oriented for POA, thus the number of bits required to transmit messages is reduced. The model assigns a cost savings benefit due to this message length reduction of VDL Mode 2 AOC messages. The low-end estimate of this assumes at least a 2:1 improvement due to the bit-oriented format, while a maximum of 6:1 improvement was estimated at the high end because large amounts of data are transferred by ACARS subsystems (e.g. Flight Management Computer, Central Maintenance Computer) whose applications will not be modified to the bit-oriented format.

AOC operations are extremely valuable to the airlines and the non-availability of AOC data is a high cost item. Again, this is modeled as a cost avoidance benefit of VDL Mode 2. Each airline has unique AOC operations, thus a fairly large range was assigned to this variable. ARINC has estimated that if nothing is done to alleviate the spectrum congestion, saturation will start as early as 2002. A range from 2002 – 2010 was assigned to the start year of AOC unavailability to take into account the fact that some regions (such as the US Northeast Corridor) will reach frequency saturation before others. This assumes that the baseline case is to do nothing, thus frequency saturation is inevitable.

ATC Delay Reduction

ATC delay reduction benefits are based on results from the FAA's Atlanta Study (discussed in Section 4) where ATC productivity was increased (and airline delay decreased) by using data link to reduce voice frequency congestion. There is some uncertainty about the method used to extrapolate the Atlanta sector savings to a nationwide basis, so the model assigns what is called an 'Atlanta discount factor'. This variable discounts the nationwide benefits by 30 – 80%. The range is large because a thorough analysis was not performed to determine errors in the extrapolation.

The relationship between equipage levels and delay reduction per equipped flight, shown in Figure 5.2.6-1, is critical to this analysis, and is one that is very uncertain at this time. A large variation was thus assigned in the curves showing this relationship. The figure shows the three functions that were used. The 10% case is the top-most curve and the most optimistic, followed by the 50% case which shows a linear relationship between equipage and delay reduction per equipped flight, then the 90% case on the bottom, which is the least optimistic relationship between equipage and delay reduction per equipped flight. There is assumed to be a minimum equipage rate, before which time benefits will not be achieved. Risks associated with minimum equipage rate and delay vs. equipage curves are many, and deal with issues such as pilot/controller acceptance and application of procedural changes.

There is also a delay savings multiplier which is based on the delay that would increase each year if nothing were done. The delay growth factor was estimated from "Free Flight, Preserving Airline Opportunity", by Captain Russell Chew. The delay growth curve in Figure 6.2.6-1 of Captain Chew's paper was extrapolated to 2015, and a scaling factor determined. The scaling factor (2.65) was converted to an annual percent delay growth over 15 years (7%). The range of this variable is large because: 1) Capt. Chew's study was using a conservative estimate for good weather days, 2) this represents delay over optimum (not schedule), and 3) this takes into account unmet traffic growth due to capacity constraints.

ATC delay savings are calculated using the following formulas:

Percent Equipped Planes = Cumulative Equipped Planes / Total Planes

Atlanta Delay Savings per Flight = Atlanta study national delay minutes saved / number of departures

Delay Savings per Flight = Atlanta Delay Svngs per Flt * Atlanta discnt factor * (1+Delay Growth per Yr)^Yr

Value of Delay = Delay Savings per Flight * DOC per minute * Total Planes * Flights per Year

The final Delay Savings was found by applying the Percent Equipped Planes and the Value of Delay to the delay vs. equipage curve. The Percent Equipped Planes is used against the Y-axis of Figure 5.2.6-1 (once the Minimum Equipage Required is met) to find the corresponding Percent of Full-Up Delay Reduction Achieved per Equipped Flight. This Percent is then multiplied to the Value of Delay to give the Delay Savings.

In this analysis it is assumed that all airplanes received delay reduction benefits because the mechanism for benefit in the Atlanta study (reduction in voice congestion) affects all airplanes, not just those equipped. The FAA has not published any plans to provide preferential treatment to equipped aircraft, so this was thought to be the most conservative assumption to make. This introduces the risk that only a portion of airlines will equip, thus paying for benefits for their competitors. See Appendix I for a discussion of this issue.

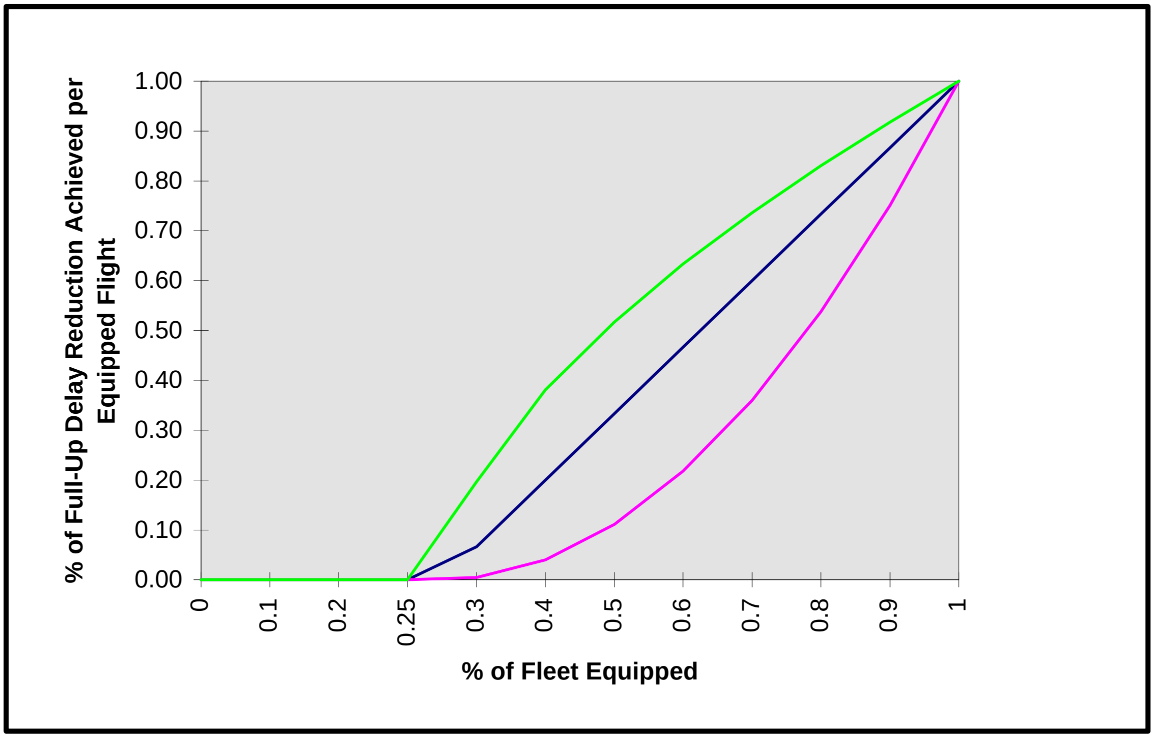


Figure 5.2.6-1: Delay vs. Equipage Curve

5.3 Model Results

Because this is a complex model it is worthwhile to break it into ‘digestible’ pieces in order to fully understand all of its implications. Section 5.3.1 discusses the value of investing for the AOC benefits only. Section 5.3.2 includes the full model results, with both AOC and ATC benefits. Section 5.3.3 shows the benefits for ATC only, where the AOC benefits are kept at zero.

5.3.1 AOC Only

The AOC-only scenario uses the Stage 0 Equipage levels of Appendix F. Figures 5.3.1-1 and 5.3.1-2 show a breakdown of the net present value (NPV) of costs and benefits by category. Retrofit equipage is the dominant cost factor, while AOC non-availability avoidance is the largest benefit factor.

In the deterministic modeling phase we do a deterministic sensitivity analysis to build a diagram that shows the impact each uncertainty has, **in isolation**, on NPV. The purpose of this diagram is to identify critical uncertainties (those which have the greatest impact on net present value) and help focus information gathering on those uncertainties. The base case value is the value of the project with each uncertainty set at the base case.

Figure 5.3.1-3 shows the deterministic sensitivity of the variables included in the AOC only analysis.

- The first column lists the variable names.
- The second column shows the base case value for each variable.
- The third column lists each variable’s contribution to NPV variance (we want to focus information gathering on those top variables which contribute between 80-95% of the project variance).

- The bars in the fourth column show each variable's impact on NPV. The bars are created by varying each variable from its low value to its high value (while keeping all other variables at the base case) and calculating the NPV for that scenario. The numbers on each end of the bar represent the value of the variable for that particular scenario. The number at the bottom of the chart that creates the center spine for the chart is the project's base case value—the value when all the variables are set at the base case.

In this AOC-only case, the base case NPV (all variables at their 50% value) is $1029.73 million. The most sensitive variable is the cost of AOC non-availability which contributes 44.0% to the variance. The other significant variable is the equipage scenario, which contributes 34.8% to the variance.

In the probabilistic modeling phase, we evaluate each alternative on the entire range of possible outcomes. We develop probability distributions for the critical uncertainties (in this case we approximated the probability distribution by assuming a 25% chance of the low end event, 25% chance of the high end event and 50% chance of the base case event) and then compute the cumulative probability distribution and expected value for the project over the range of possible outcomes for the project. (Example: If there are four uncertainties, with three possible outcomes for each uncertainty, we compute the expected value and probability for every possible combination of outcomes—in this case 3**4 = 81 possible outcomes. The cumulative probability distribution is a compact way of displaying this information and showing the project's overall risk and return.) We usually vary only the top 5-6 uncertainties (as identified in the deterministic sensitivity diagram) and set the rest at the base case for computation reasons and because it turns out to be a pretty good approximation of the risk/return for the project.

The cumulative probability distribution shown in Figure 5.3.1-4 illustrates the overall risk and return for the AOC-only case. The expected value is $1019.38M, and there is a 10% chance the project outcome will be below $511.82M, a 50% chance it will be below $1005.41M, and a 90% chance it will be below $1675.86M.

Figure 5.3.1-5 shows the cash flows for the AOC-only case with Stage 0 equipage rates for both forward fit and retrofit. Figure 5.3.1-6 shows the cash flow for retrofit only, and Figure 5.3.1-7 for forward fit only. Looking at these charts it can be seen that the payback period is up to nine years for the retrofit only case (cash flow does not cross zero until 2009), but that the negative upfront cash flow is negligible for the forward fit case. The negative cash flow is almost entirely due to retrofit. In addition, the long-term benefit potential is quite high.

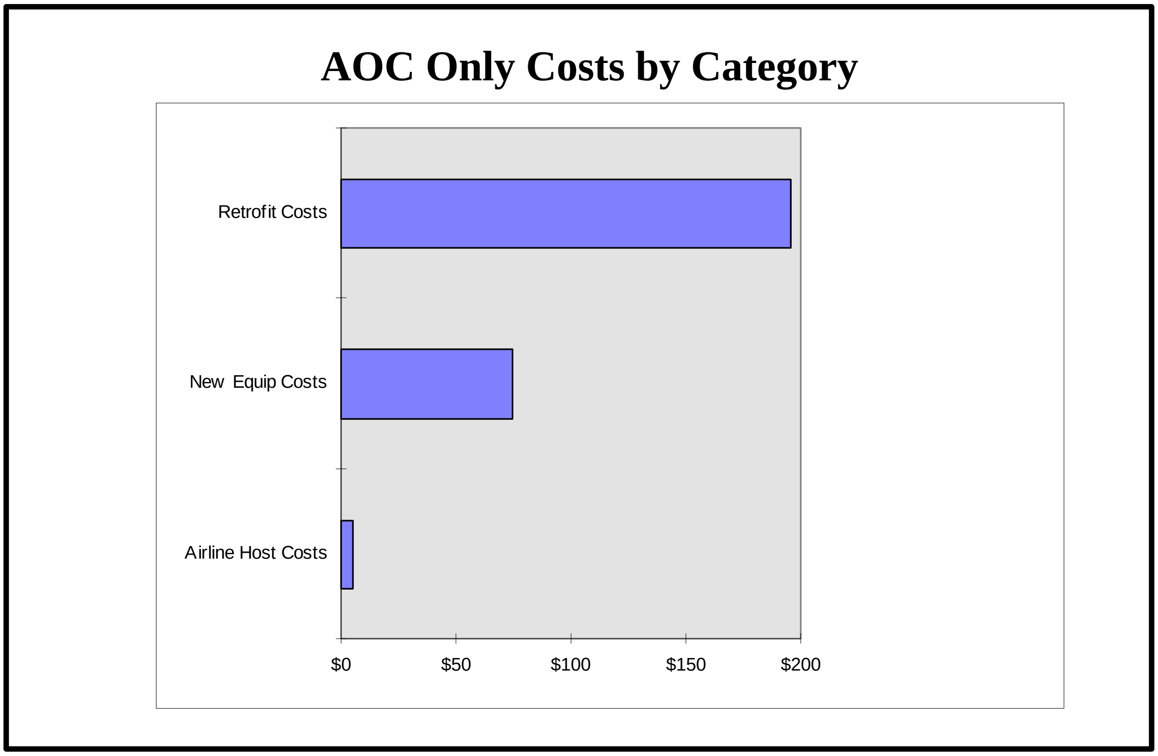


Figure 5.3.1-1. AOC Only Costs by Category

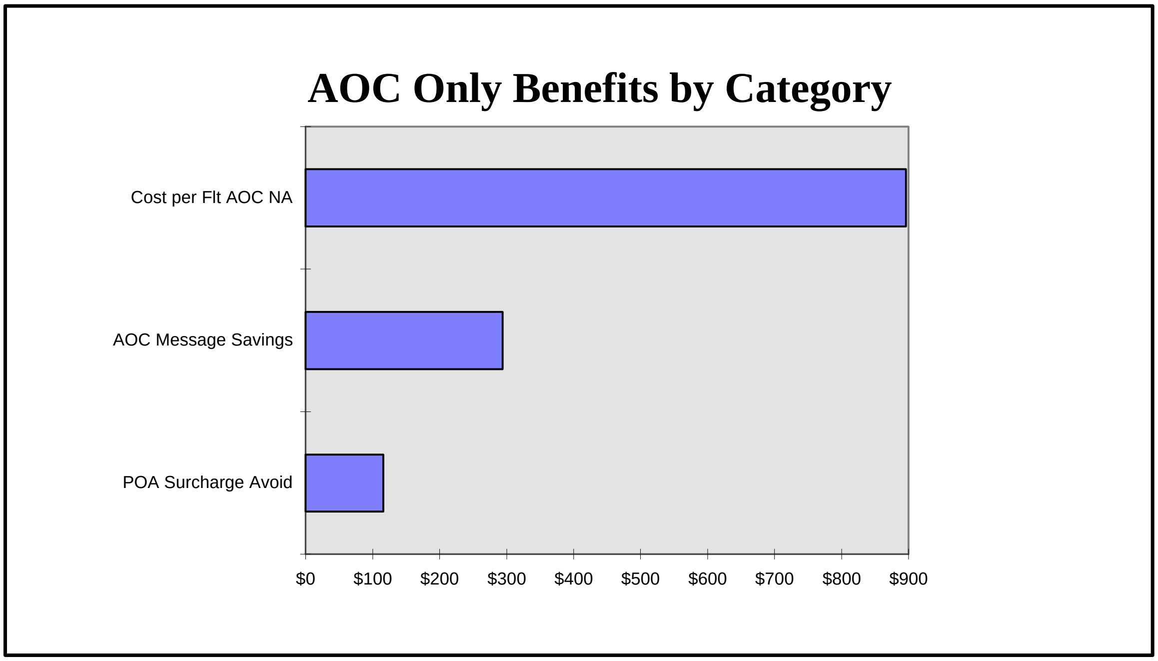
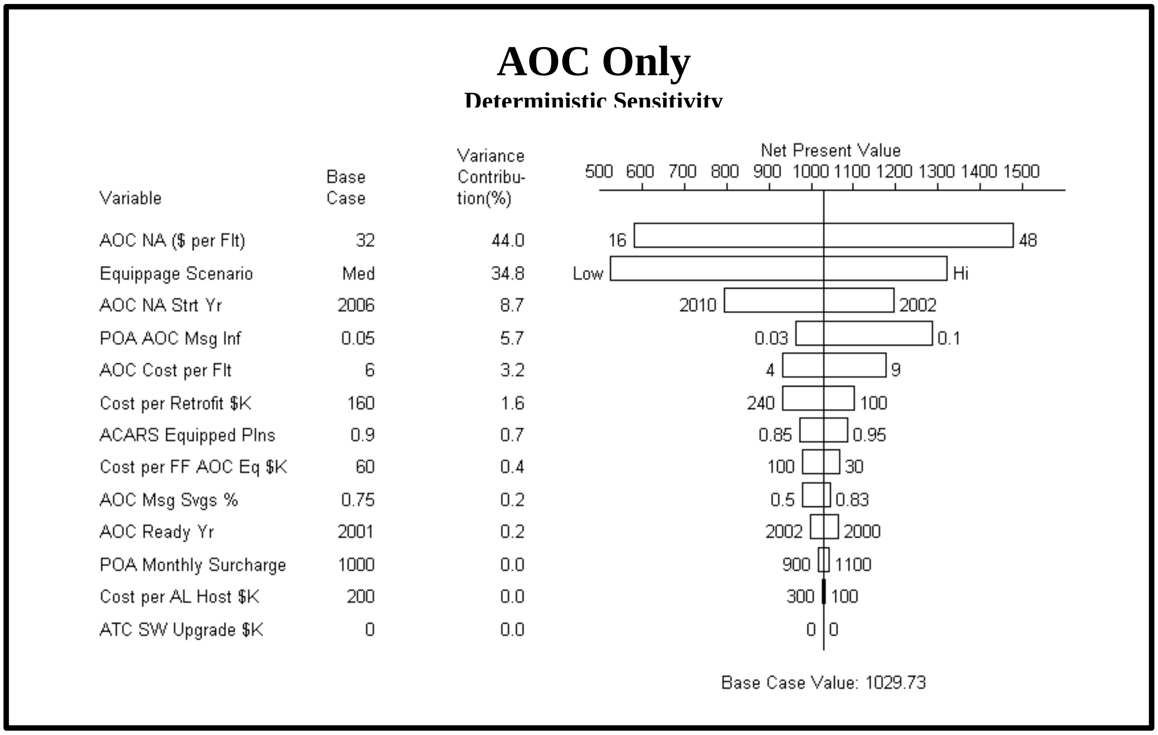


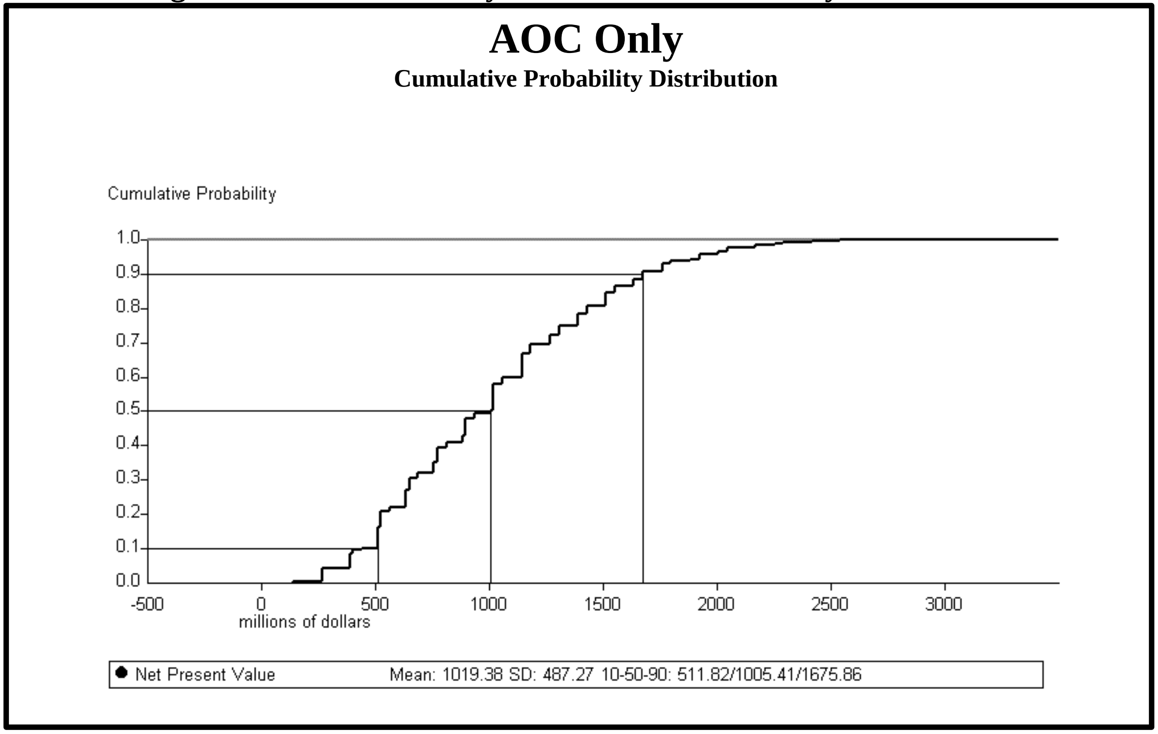
Figure 5.3.1-2. AOC Only Benefits by Category



Variable	Base Case	Variance Contribution(%)
AOC NA ($ per Flt)	32	44.0
Equippage Scenario	Med	34.8
AOC NA Strt Yr	2006	8.7
POA AOC Msg Inf	0.05	5.7
AOC Cost per Flt	6	3.2
Cost per Retrofit $K	160	1.6
ACARS Equipped Plns	0.9	0.7
Cost per FF AOC Eq $K	60	0.4
AOC Msg Svgs %	0.75	0.2
AOC Ready Yr	2001	0.2
POA Monthly Surcharge	1000	0.0
Cost per AL Host $K	200	0.0
ATC SW Upgrade $K	0	0.0

Figure 5.3.1-3. AOC Only Deterministic Sensitivity

Figure 5.3.1-4. AOC Only Cumulative Probablility Distribution



AOC Only--Cash Flow Summary

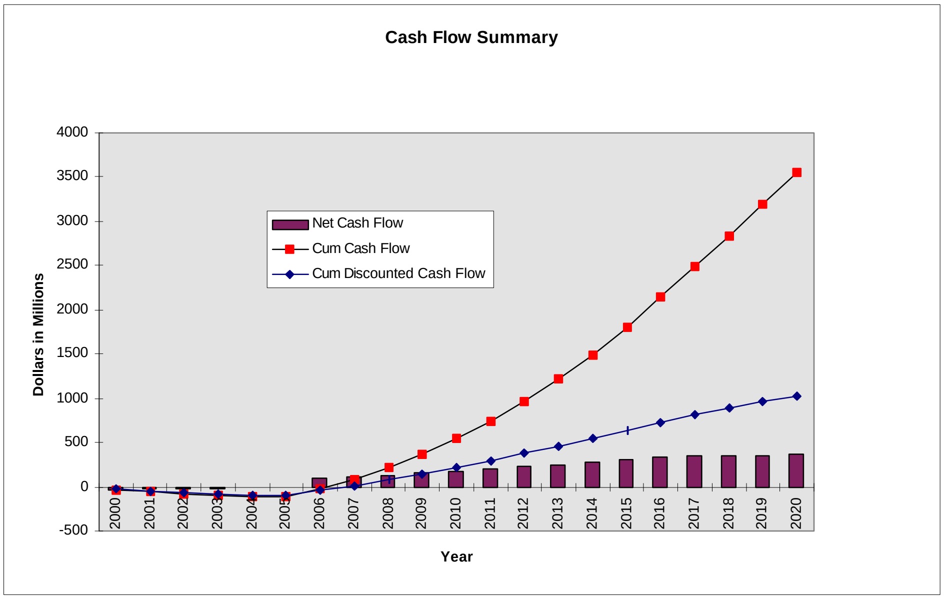


Figure 5.3.1-5. AOC Only Cash Flow Summary

AOC Only Retrofit--Cash Flow Summary

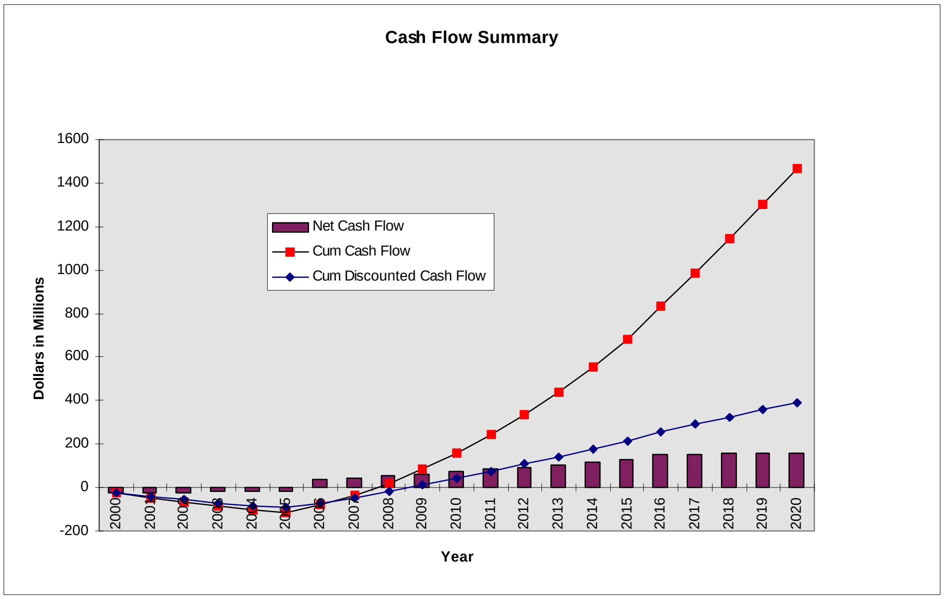


Figure 5.3.1-6. AOC Only Retrofit Cash Flow Summary

AOC Only FF--Cash Flow Summary

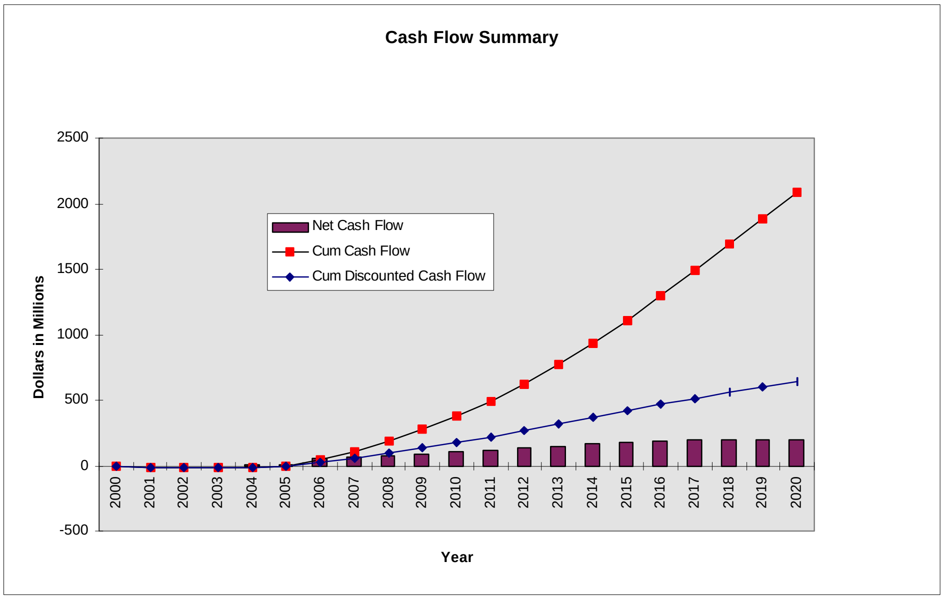


Figure 5.3.1-7. AOC Only Forward Fit Cash Flow Summary

5.3.2 Full Data Link

The Full Data Link case includes AOC and ATC benefits and uses the full equipage levels of Appendix F. Figures 5.3.2-1 and 5.3.2-2 show a breakdown of the NPV of costs and benefits by category. Retrofit equipage is still the dominant cost factor, and ATC Delay Savings is the largest benefit factor. AOC non-availability avoidance is still a significant benefit factor in this case.

Figure 5.3.2-3 shows the deterministic sensitivity of the variables included in the Full Data Link analysis. In this case, the base case NPV (all variables at their 50% value) is $3037.35 million. The four most sensitive variables are: Delay Increase Percent per Year (24.3% variance), the equipage scenario (24%), the Atlanta Study Discount Factor (18.5%), and the cost of AOC non-availability (16%).

The cumulative probability distribution shown in Figure 5.3.2-4 shows that the expected value is $2932.51M, there is a 10% chance the project outcome will be below $1480.34M, a 50% chance it will be below $2750.62M and a 90% chance it will be below $4573.88M. There is no chance for a negative NPV.

Figure 5.3.2-5 shows the cash flows for the Full Data Link case. Figure 5.3.2-6 shows the cash flow for retrofit only, and Figure 5.3.2-7 for forward fit only. The payback period is nine years for the retrofit case (cash flow does not cross zero until 2009), but the negative cash flow is negligible for the forward fit case. The negative cash flow is due almost entirely to retrofit. In addition, the long-term benefit potential is quite high.

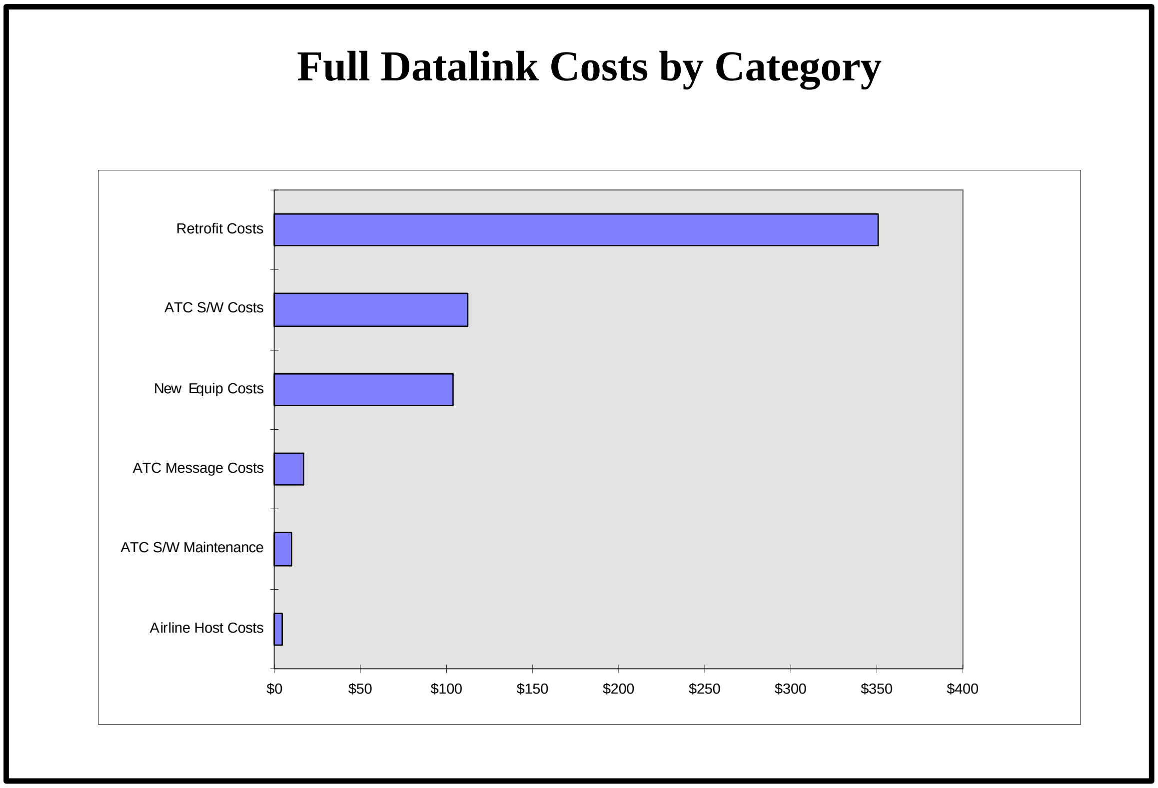


Figure 5.3.2-1. Full Data Link Costs by Category

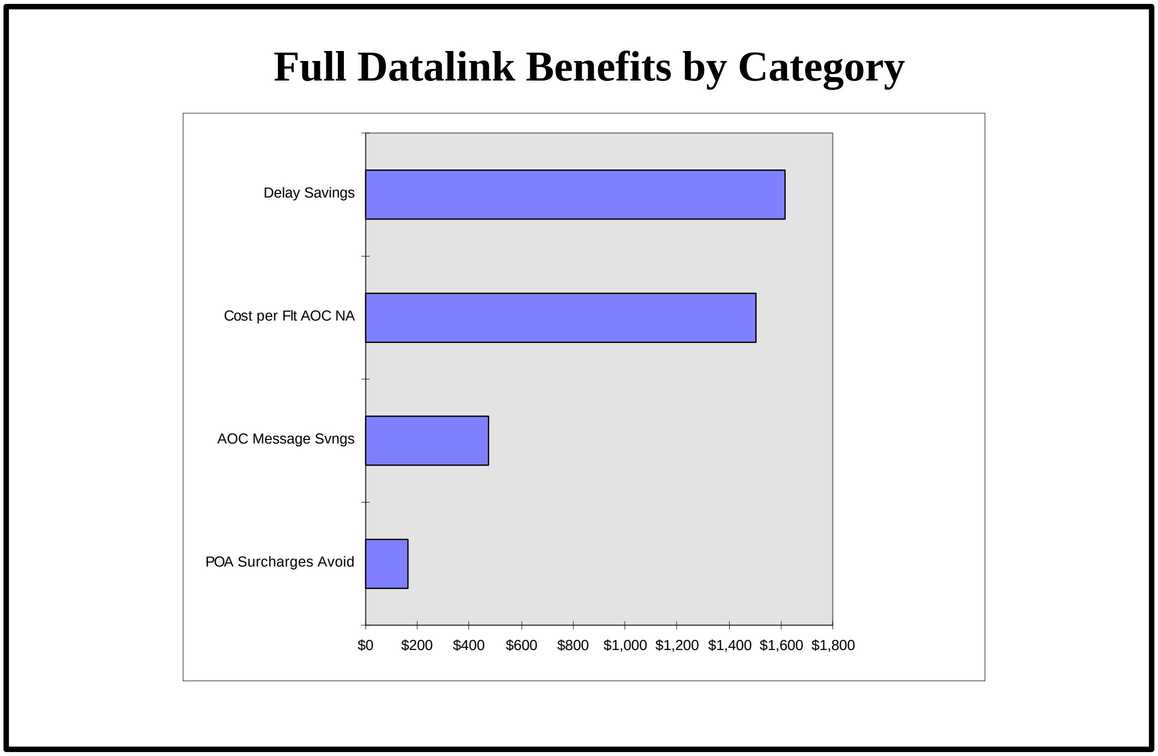


Figure 5.3.2-2. Full Data Link Benefits by Category

Full Datalink

Deterministic Sensitivity

Variable	Base Case	Variance Contribu-tion(%)
Delay Incr % per Yr	0.07	24.3
Equippage Scenario	Med	24.0
Atlanta Discount Factor	0.5	18.5
AOC NA ($ per Flt)	32	16.0
Delay vs Equip Curve	1	4.0
AOC NA Strt Yr	2006	3.4
POA AOC Msg Inf	0.05	1.8
ACARS Equipped Plns	0.9	1.2
AOC Cost per Flt	6	1.1
ATC Build 2 Eff %	0.9	1.0
ATC SW Upgrade $K	30	0.9
ATC Build 1 Start Yr	2003	0.6
Cost per Retrofit $K	160	0.6
Message Cost Resp	0.5	0.5
ATC Build 1 Duration	2	0.2
Equip Rampup Yr	Bld 1A E-Yr	0.2
Minimum Equip Reqd	0.25	0.1
ATC Build 1A Duration	3	0.1
Cost per FF AOC Eq $K	60	0.1
ATC Build 1A Eff %	0.7	0.0
AOC Msg Svgs %	0.75	0.0
Retired Planes % of New	0.22	0.0
AOC Ready Yr	2001	0.0
Avg bytes per message	56	0.0
ATC Build 2 Duration	4	0.0
ATC Mssges per E-Flt	229	0.0
POA Monthly Surcharge	1000	0.0
Cost per AL Host $K	200	0.0
ATC Build 1 Eff	0	0.0

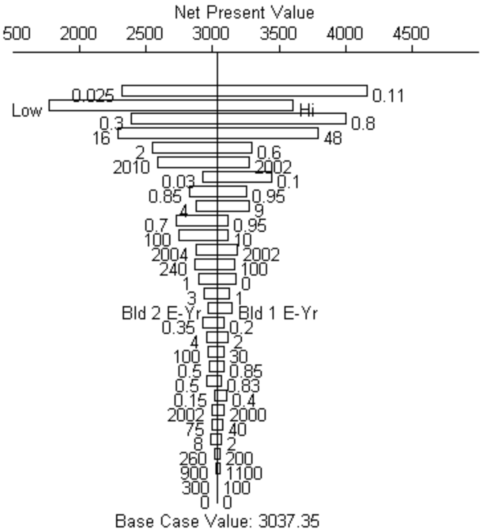


Figure 5.3.2-3. Full Data Link Deterministic Sensitivity

Full Datalink

Cumulative Probability Distribution

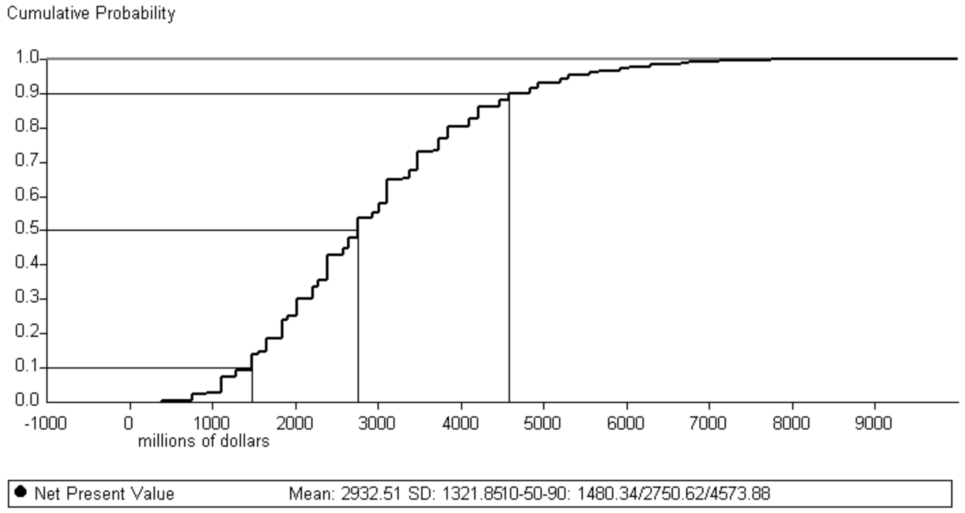
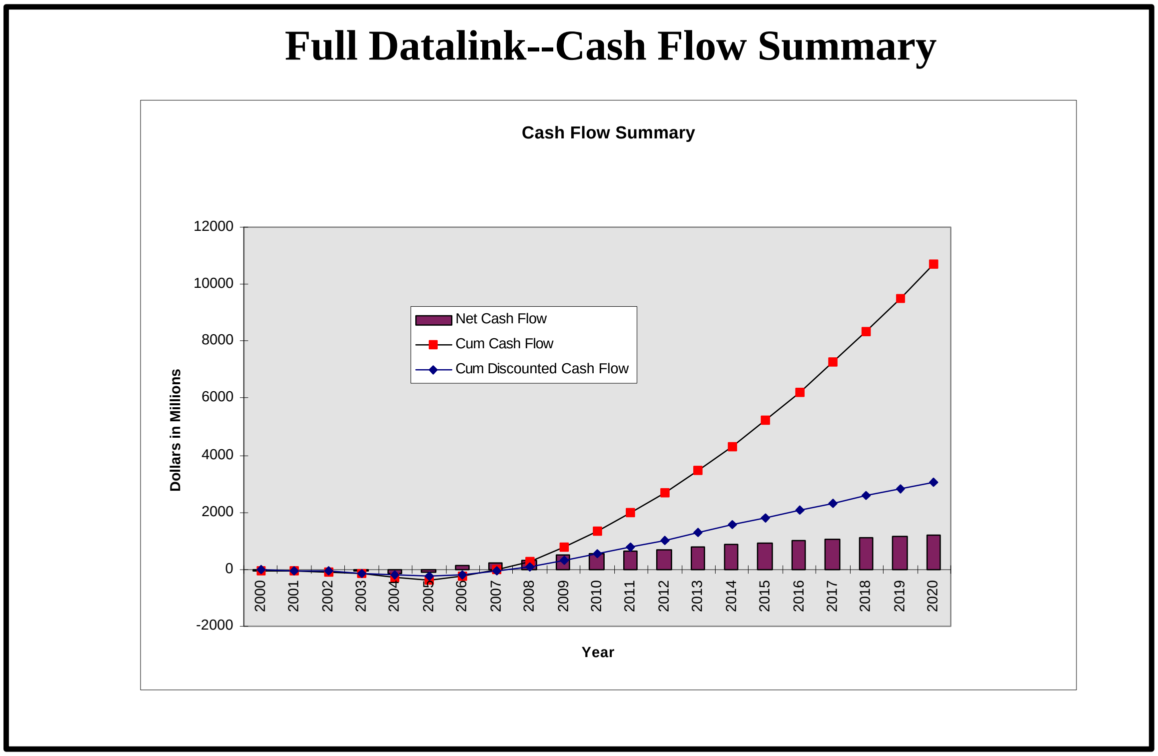


Figure 5.3.2-4. Full Data Link Cumulative Probability Distribution



Full Datalink--Cash Flow Summary

Figure 5.3.2-5. Full Data Link Cash Flow Summary

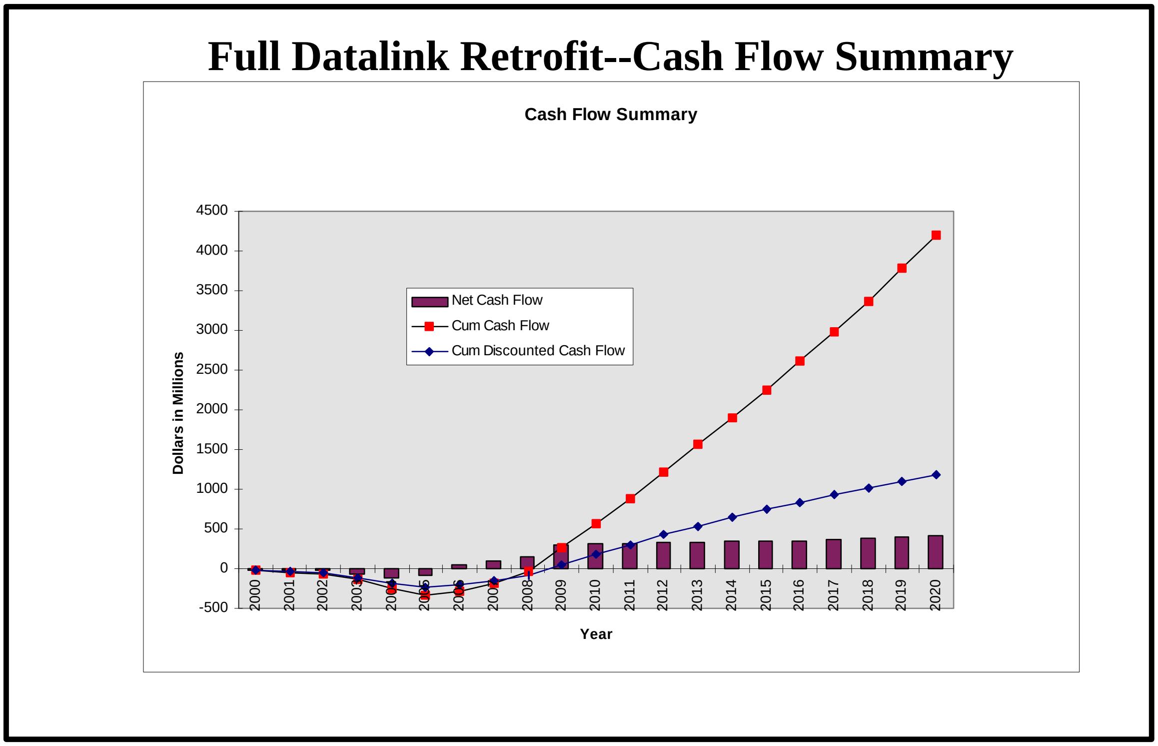


Figure 5.3.2-6. Full Data Link Retrofit Cash Flow Summary

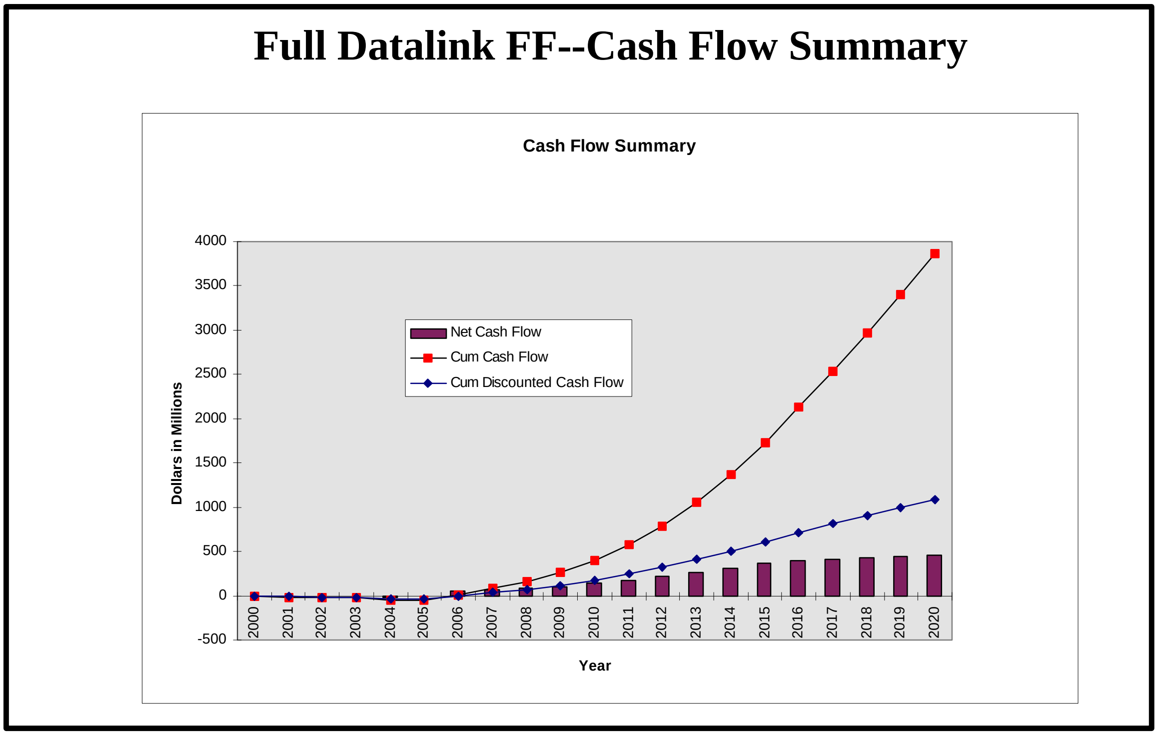


Figure 5.3.2-7. Full Data Link Forward Fit Cash Flow Summary

5.3.3 ATC Only

The ATC-Only Data Link case includes ATC benefits only and uses the full equipage levels of Appendix F. Figures 5.3.3-1 and 5.3.3-2 show a breakdown of the NPV of costs and benefits by category. Retrofit equipage is still the dominant cost factor, and ATC Delay Savings is the only benefit factor in this case.

Figure 5.3.3-3 shows the deterministic sensitivity of the variables included in the ATC-only analysis. In this case, the base case NPV (all variables at their 50% value) is $897.68 million. The most sensitive variable is the Delay Increase Percent per Year, which contributes 43.6% to the variance. The other significant variable is the Atlanta Discount Factor, which contributes 33.2% to the variance.

The cumulative probability distribution shown in Figure 5.3.3-4 shows that the expected value is $824.27M, there is a 10% chance the project outcome will be below $(171.09)M, a 50% chance it will be below $637.18M and a 90% chance it will be below $2232.39M.

Figure 5.3.3-5 shows the cash flows for the Full Data Link case. Figure 5.3.3-6 shows the cash flow for retrofit only, and Figure 5.3.3-7 for forward fit only. Looking at these charts it can be seen that there is negative cash flow until 2013, at the earliest, and the long-term benefit potential is much lower than in the Full Data Link case.

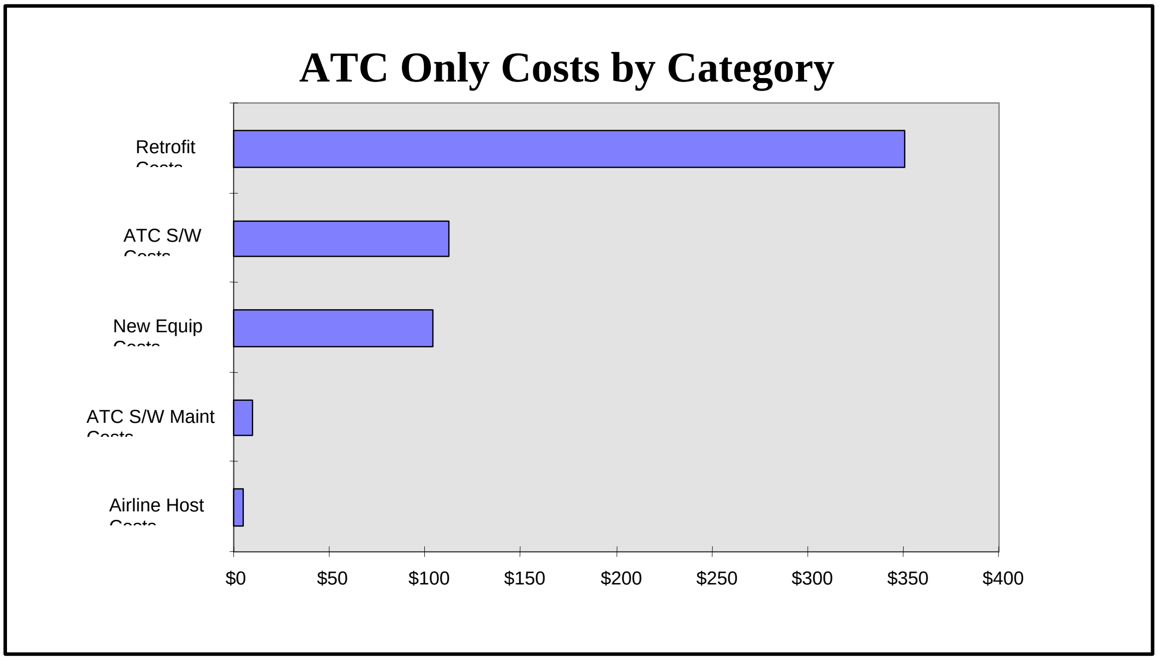


Figure 5.3.3-1. ATC Only Costs by Category

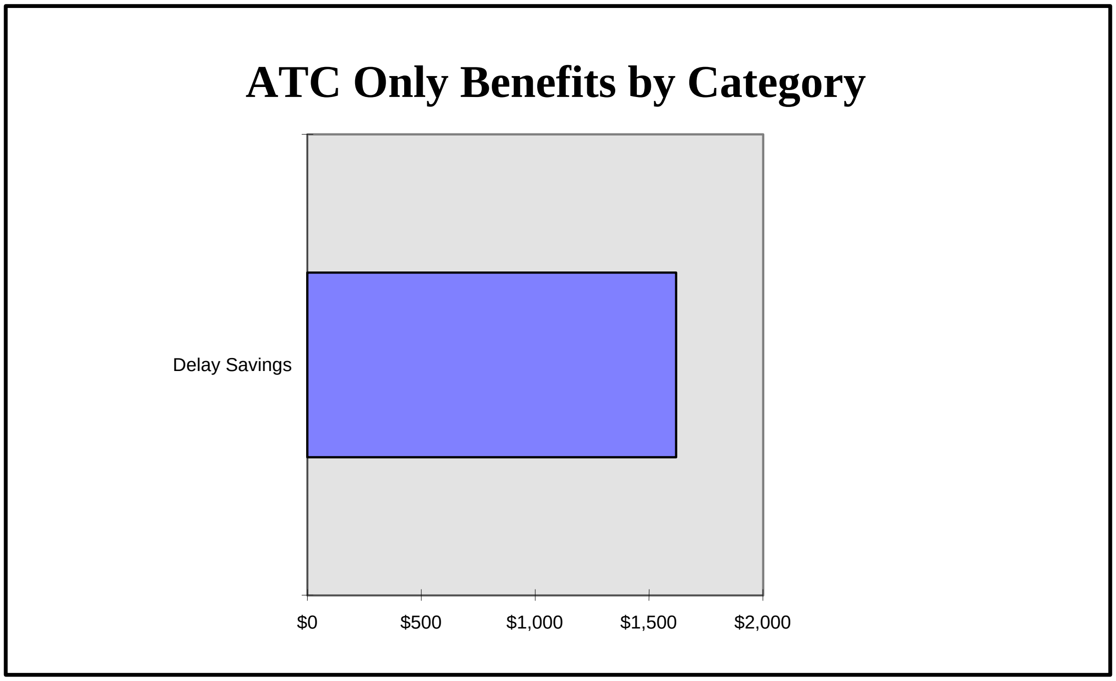
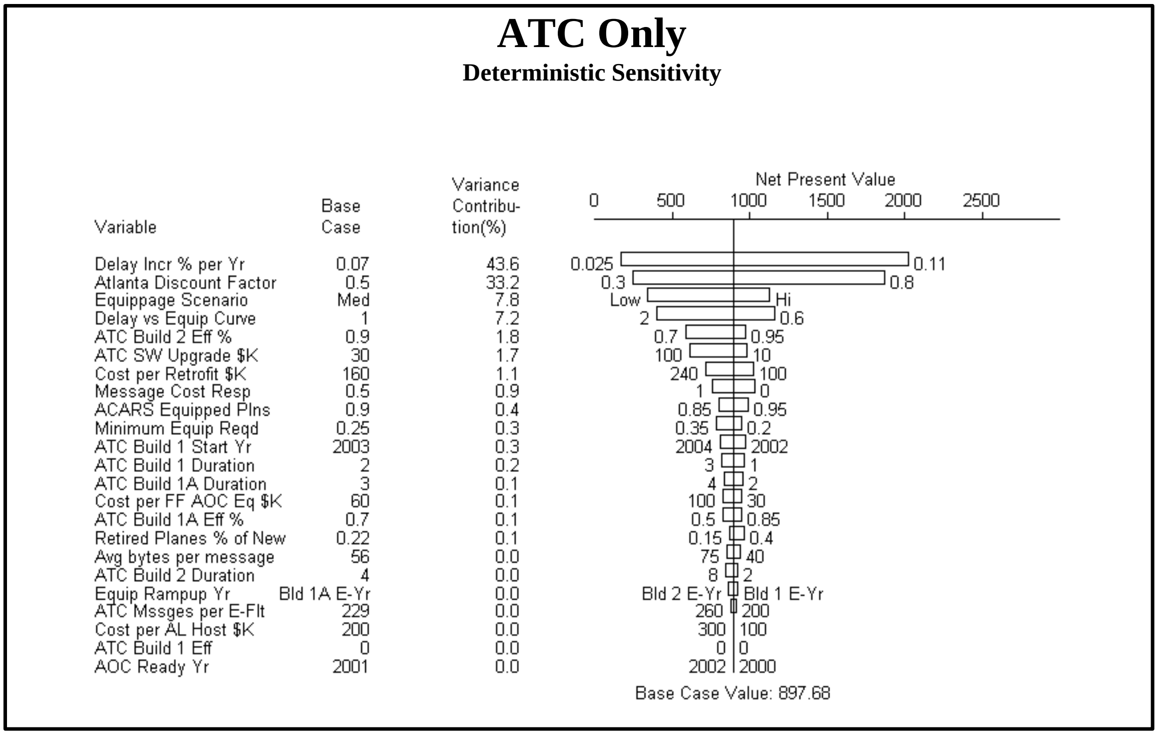


Figure 5.3.3-2. ATC Only Benefits by Category

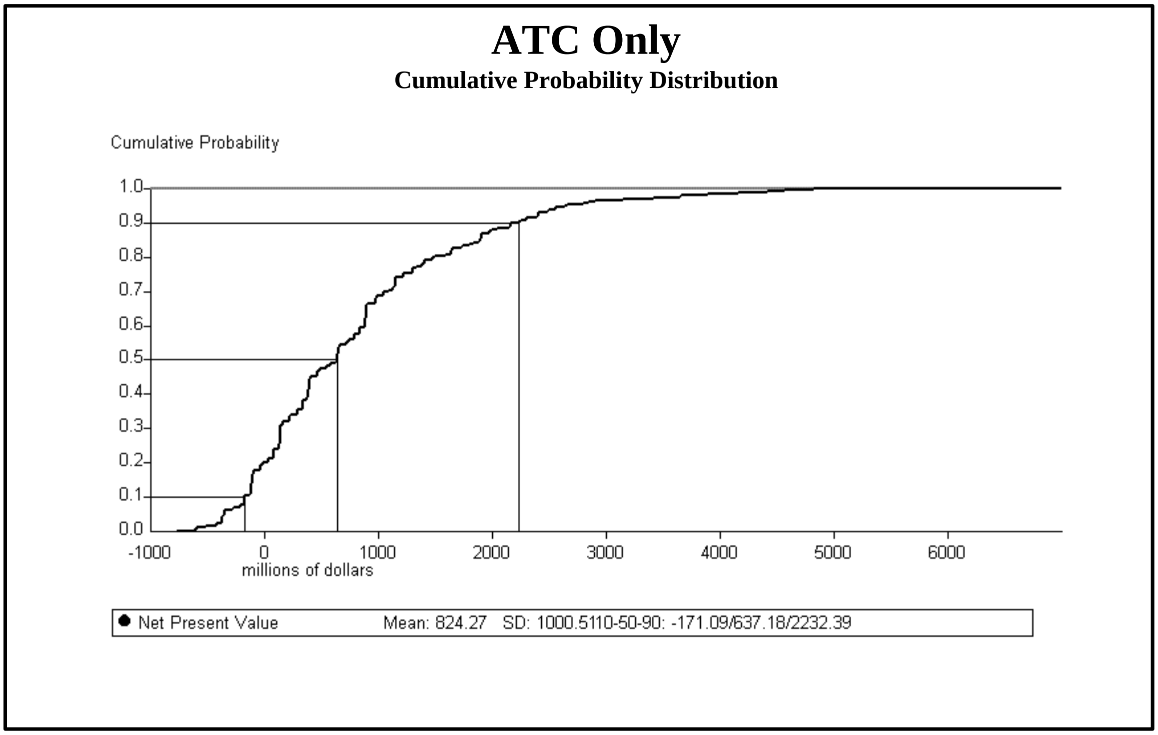


ATC Only

Deterministic Sensitivity

Variable	Base Case	Variance Contribu-tion(%)		
Delay Incr % per Yr	0.07	43.6	0.025	0.11
Atlanta Discount Factor	0.5	33.2	0.3	0.8
Equippage Scenario	Med	7.8	Low	Hi
Delay vs Equip Curve	1	7.2	2	0.6
ATC Build 2 Eff %	0.9	1.8	0.7	0.95
ATC SW Upgrade $K	30	1.7	100	10
Cost per Retrofit $K	160	1.1	240	100
Message Cost Resp	0.5	0.9	1	0
ACARS Equipped Plns	0.9	0.4	0.85	0.95
Minimum Equip Reqd	0.25	0.3	0.35	0.2
ATC Build 1 Start Yr	2003	0.3	2004	2002
ATC Build 1 Duration	2	0.2	3	1
ATC Build 1A Duration	3	0.1	4	2
Cost per FF AOC Eq $K	60	0.1	100	30
ATC Build 1A Eff %	0.7	0.1	0.5	0.85
Retired Planes % of New	0.22	0.1	0.15	0.4
Avg bytes per message	56	0.0	75	40
ATC Build 2 Duration	4	0.0	8	2
Equip Rampup Yr	Bld 1A E-Yr	0.0	Bld 2 E-Yr	Bld 1 E-Yr
ATC Mssges per E-Flt	229	0.0	260	200
Cost per AL Host $K	200	0.0	300	100
ATC Build 1 Eff	0	0.0	0	0
AOC Ready Yr	2001	0.0	2002	2000

Figure 5.3.3-3. ATC Only Deterministic Sensitivity



ATC Only

Cumulative Probability Distribution

Figure 5.3.3-4. ATC Only Cumulative Probability Distribution

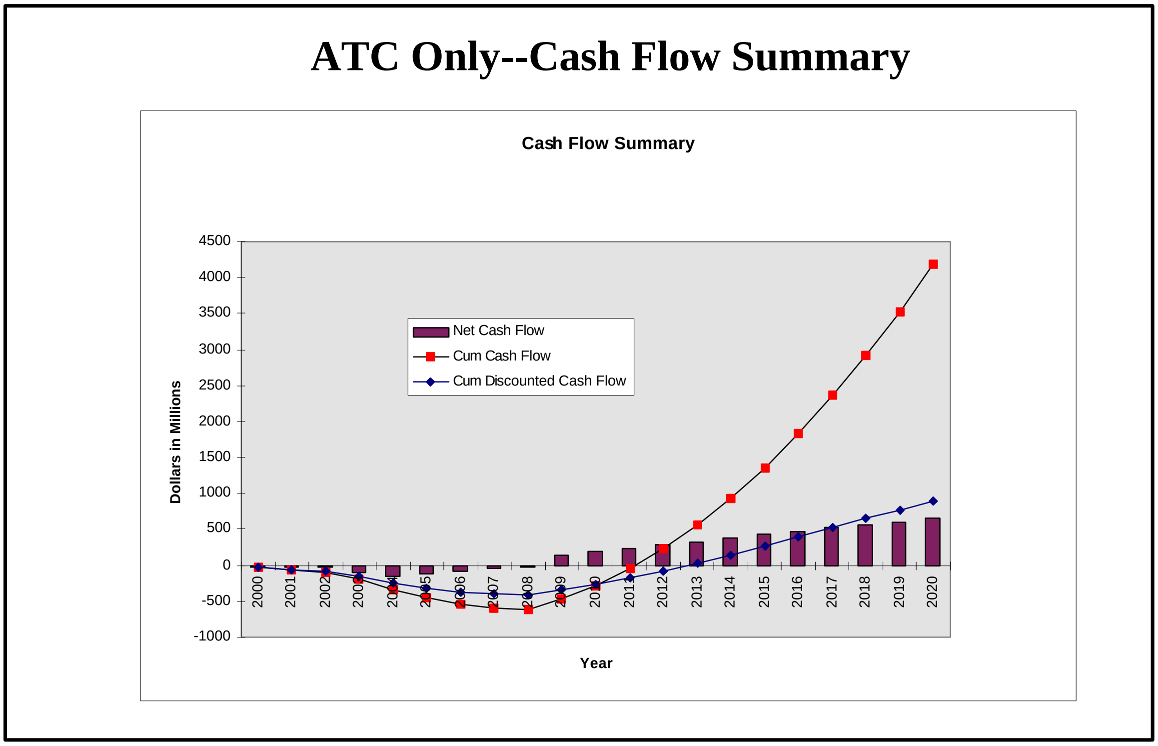


Figure 5.3.3-5. ATC Only Cash Flow Summary

ATC Only Retrofit--Cash Flow Summary

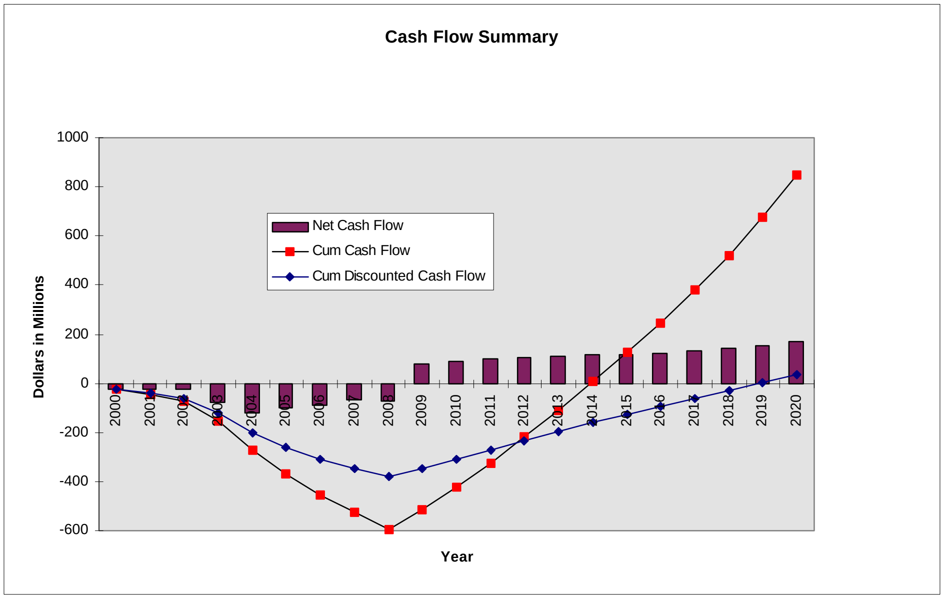


Figure 5.3.3-6. ATC Only Retrofit Cash Flow Summary

ATC Only Forward Fit--Cash Flow Summary

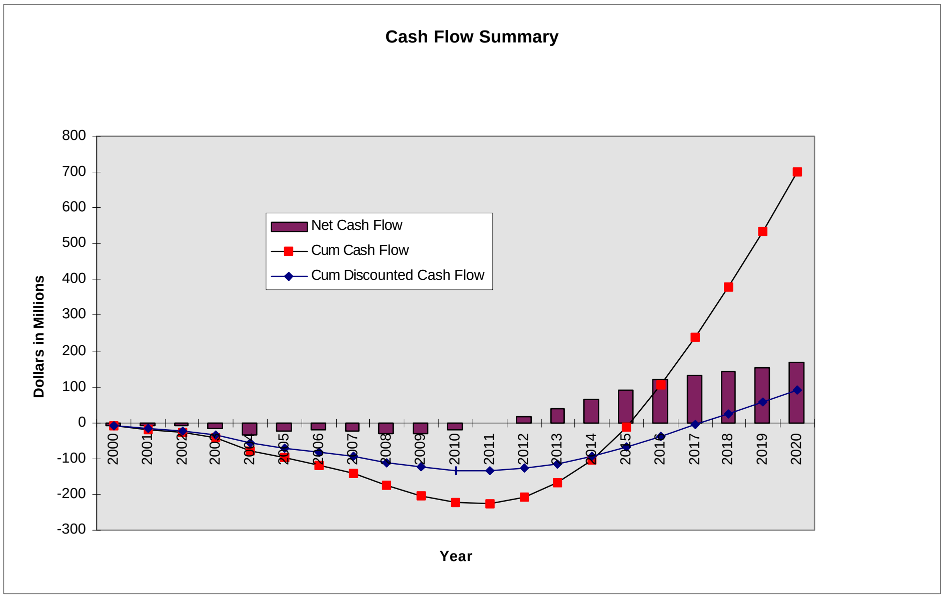
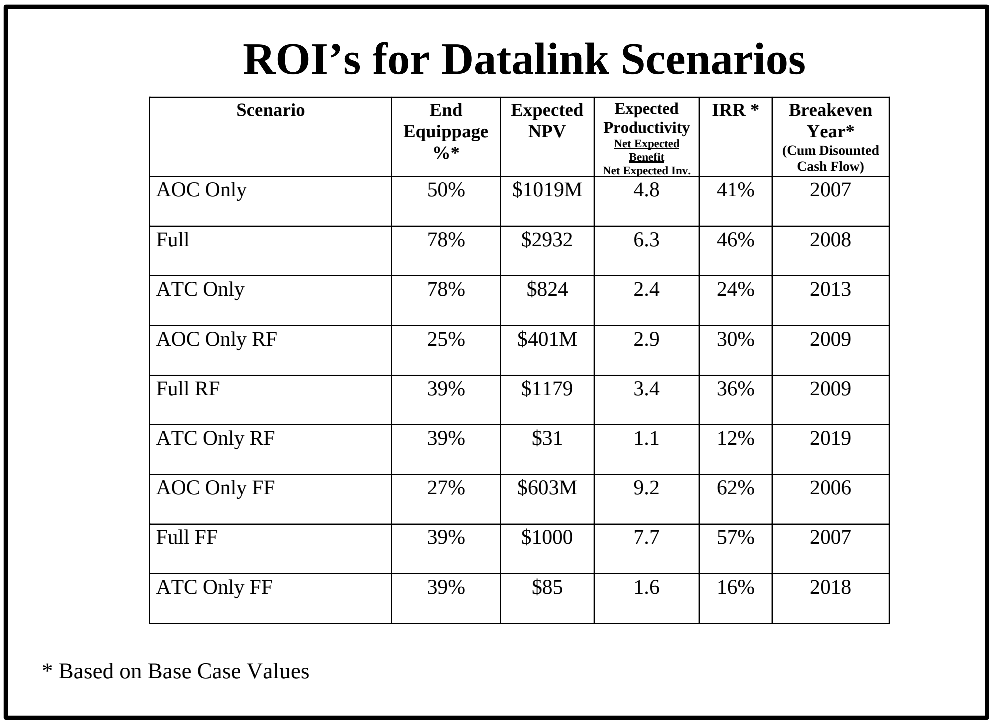


Figure 5.3.3-7. ATC Only Forward Fit Cash Flow Summary

6. Conclusions

Table 6.0-1 summarizes the results for the three data link scenarios (AOC-Only, Full Data Link, ATC-only), and further breaks down the results by forward fit and retrofit cases. The table shows the base case and equipage rate for each scenario, the expected NPV (from the cumulative probability distributions), the expected productivity (which is simply the net expected benefit divided by the net expected investment), the Internal Rate of Return, and the breakeven year.



ROI's for Datalink Scenarios

Scenario	End Equippage %*	Expected NPV	Expected Productivity $\frac{\text{Net Expected Benefit}}{\text{Net Expected Inv.}}$	IRR *	Breakeven Year* (Cum Disounted Cash Flow)
AOC Only	50%	$1019M	4.8	41%	2007
Full	78%	$2932	6.3	46%	2008
ATC Only	78%	$824	2.4	24%	2013
AOC Only RF	25%	$401M	2.9	30%	2009
Full RF	39%	$1179	3.4	36%	2009
ATC Only RF	39%	$31	1.1	12%	2019
AOC Only FF	27%	$603M	9.2	62%	2006
Full FF	39%	$1000	7.7	57%	2007
ATC Only FF	39%	$85	1.6	16%	2018

* Based on Base Case Values

Table 6.0-1: Data Link Scenario Summary

In the first three lines of Table 6.0-1 it can be seen that the AOC-only and Full Data Link scenarios have similar expected productivities, IRR's and breakeven years. The primary difference in the two is the End Equipage Percent (because the AOC-only scenario is assuming Stage 0 equipage rates), and the Expected NPV. The Expected NPV for the Full Data Link is 2.9 times higher than for AOC-only, but the actual return on investment is approximately the same. For the airlines, the risk of going to Full Data Link from AOC-only is negligible because the airlines can delay their incremental investment, ATC Software Upgrade, until the infrastructure and minimum levels of equipage required for benefit are achieved. The ATC-only case has a relatively low return on investment over a very long time frame.

The next three lines of Table 6.0-1 show ROIs for retrofit-only in the three scenarios. Here we see a similar pattern, where retrofit for the AOC-only and Full Data Link have similar ROIs and breakeven years, while ATC-only has a very low ROI and a very late breakeven year. At the bottom of the table we can compare the ROIs for forward fit only, where we see that there is a much stronger case for forward fit than retrofit. For example, the AOC-only forward fit case shows a 62% IRR, while retrofit is only 30%. Similarly, in the Full Data Link case, forward fit shows a 57% IRR and retrofit 36%. Again, the ATC-only case has low IRRs and very long time frame for ROI.

From this data the following conclusions can be drawn:

- Forward fit equipage of VDL Mode 2 for AOC applications has a good return on investment:
  - Risk is very low.
  - The AOC benefits enable airline equipage.
  - The value of maintaining AOC data link capability is one of the primary cost-avoidance drivers.
  - Forward fit equipage should start as soon as possible to avoid the high retrofit costs.
- Forward fit equipage of VDL Mode 2 for Full Data Link has a reasonable return on investment:
  - Risk is higher than AOC-only scenario.
  - Risks to the airlines associated with investing in ATC data link are mitigated by the need to preserve AOC and the ability to delay additional investment required for ATC benefits until infrastructure and minimum equipage levels are reached.
  - ATC benefits are highly sensitive to uncertainties that cannot be managed: Delay Increase per Year and the Atlanta Discount Factor.
- Retrofit equipage will be driven by ATC applications:
  - ATC delay reduction benefits are highly dependent on equipage levels, thus providing an incentive for airlines to retrofit.
  - AOC frequency congestion constraints may be sufficiently alleviated by forward fit equipage, thus providing little incentive to retrofit for AOC benefits.
- Data link equipage for ATC-only does not provide a reasonable return on investment:
  - Return on investment is low.
  - Time frame is too long.
- **VDL Mode 2 data link is a strategic, long-term investment.**

C/AFT Data Link Investment Analysis

Scenario	End Equipage %*	Expected NPV	Expected Productivity Net Expected Benefit / Net Expected Inv.	IRR *	Breakeven Year* (Cum Disounted Cash Flow)
Full Data Link	75%	$1950M	4.8	43%	2008
AOC Only	50%	$853M	4.9	42%	2009
Data Link Only—No AOC	75%	$235M	1.4	14%	2016
Full Data Link for FF	38%	$742M	6.1	53%	2006
Full Data Link for RF	37%	$756M	3.2	34%	2009
AOC Only for FF	26%	$507M	9.0	63%	2006
AOC Only for RF	24%	$316M	2.8	31%	2009
ATC Only for FF	38%	$110M	0.7	11%	After 2020
ATC Only for RF	37%	$228M	0.6	7%	After 2020

Scenario	End Equipage %*	Expected NPV	Expected Productivity Net Expected Benefit / Net Expected Inv.	IRR *	Breakeven Year* (Cum Disounted Cash Flow)
Full Datalink	75%	$1950M	4.8	43%	2008
AOC Only	50%	$853M	4.9	42%	2009
Datalink Only—No AOC	75%	$235M	1.4	14%	2016
Full Datalink for FF	38%	$742M	6.1	53%	2006
Full Datalink for RF	37%	$756M	3.2	34%	2009
AOC Only for FF	26%	$507M	9.0	63%	2006
AOC Only for RF	24%	$316M	2.8	31%	2009
ATC Only for FF	38%	$110M	0.7	11%	After 2020
ATC Only for RF	37%	$228M	0.6	7%	After 2020

7. List of Acronyms

ACARS	Airline Communication Addressing and Reporting System
AOC	Airline Operational Control
ATA	Air Transport Association
ATC	Air Traffic Control
ATN	Aeronautical Telecommunication Network
C/AFT	CNS/ATM Focused Team
CMU	Communication Management Unit
CPDLC	Controller-Pilot Data Link Communication
DOC	Direct Operating Cost
FANS	Future Air Navigation System
FMS	Flight Management System
NAS	National Airspace System
NPV	Net Present Value
PETAL	Preliminary Eurocontrol Test of Air/Ground Data Link
POA	Plain Old ACARS
SARPS	Standards and Recommended Practices
SID	Standard Instrument Departure
STAR	Standard Terminal Arrival Route
VDL	Very High Frequency Data Link

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3. Data Link Benefits Study Team, *Benefits of Controller-Pilot Data Link ATC Communications in Terminal Airspace*, US Federal Aviation Administration, Report DOT/FAA/CT-96/3, September 1996. Available on the World Wide Web at **Error! Bookmark not defined.**.
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6. Luehrman, Timothy A., "Investment Opportunities as Real Options: Getting Started on the Numbers", *Harvard Business Review*, July-August 1998, pp. 51-67.
7. Kern, John, *Data Link Issues Team Recommendations to the NAS Modernization Task Force*, presentation to the Task Force, July 21, 1998.

Appendix A – Operational Enhancements enabled by Data Link

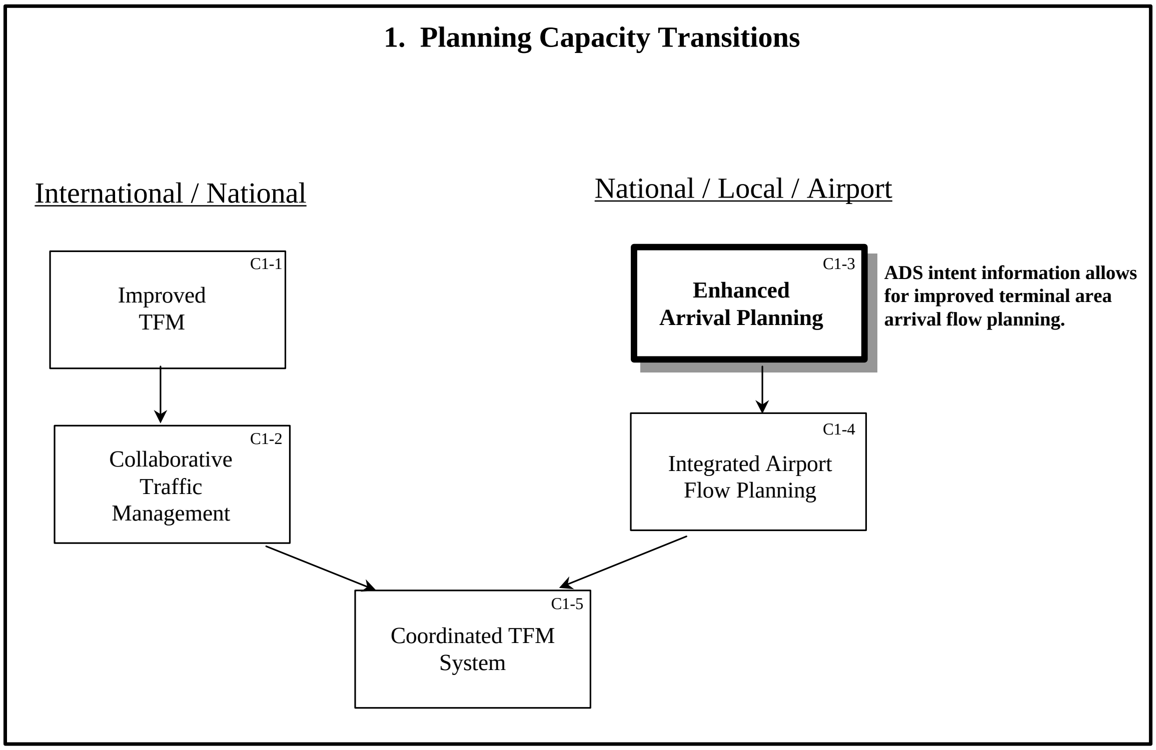
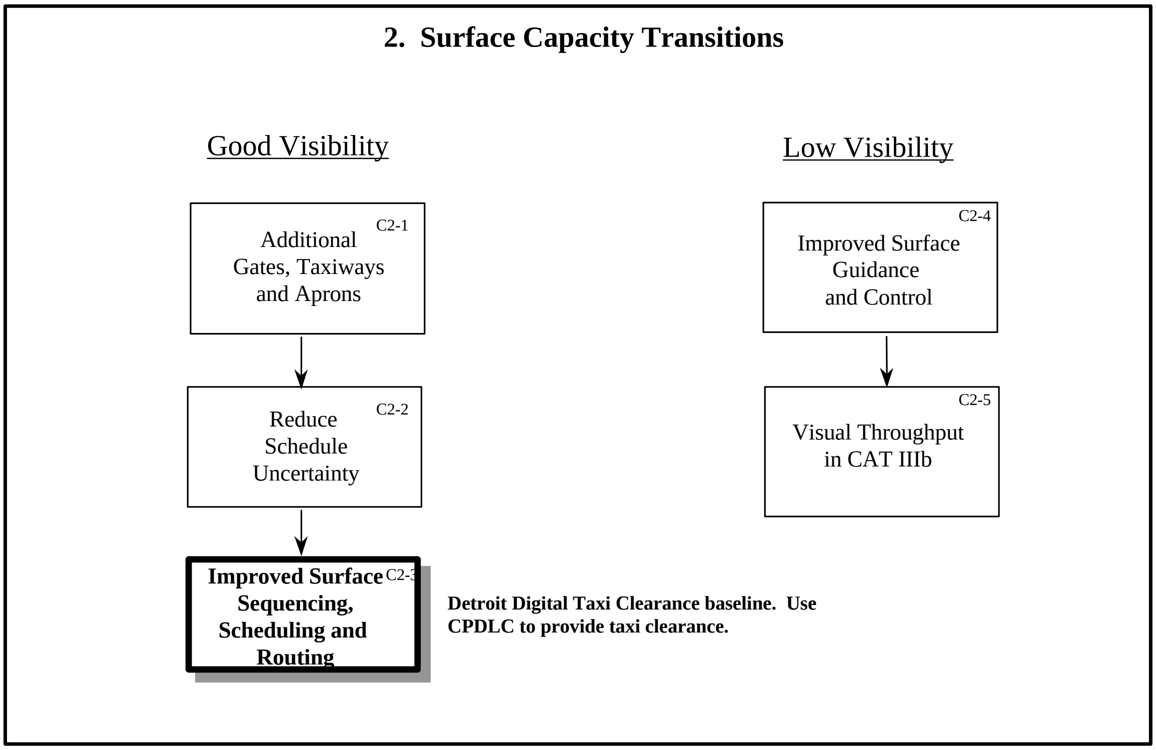


Figure A-1. Datalink-Enabled Operational Enhancements in Planning Phase

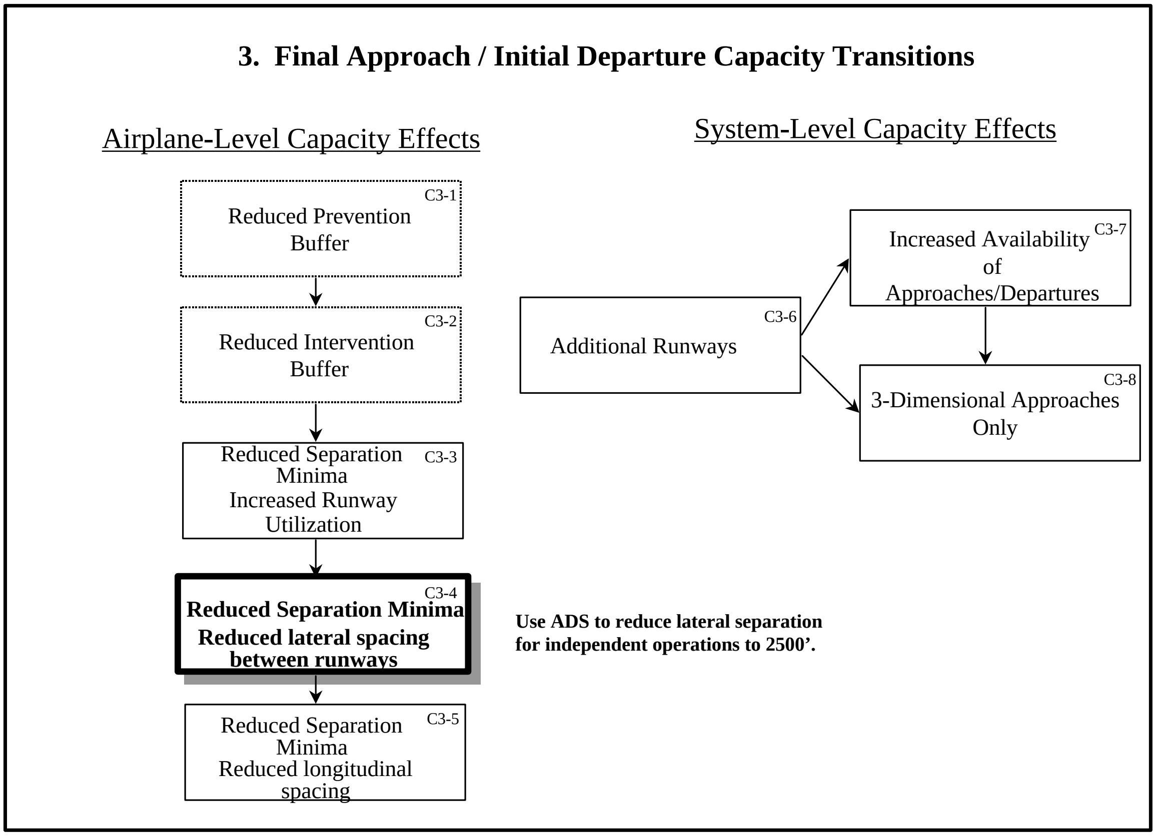


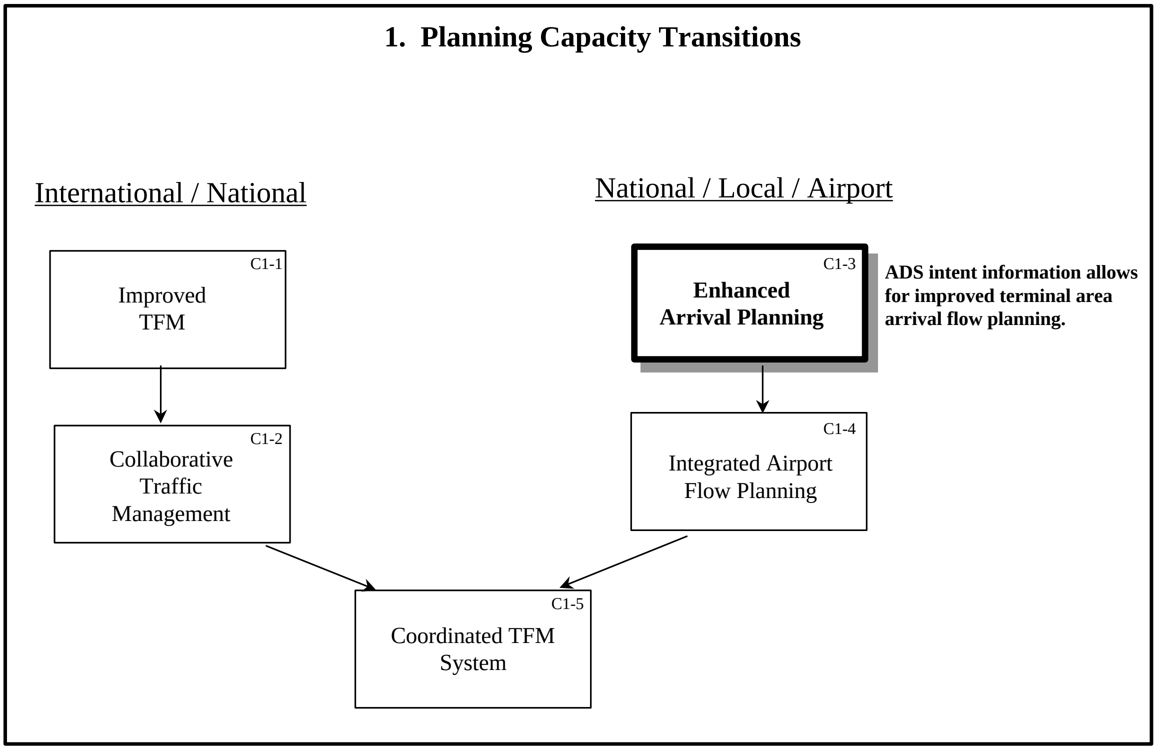
2. Surface Capacity Transitions

Detroit Digital Taxi Clearance baseline. Use CPDLC to provide taxi clearance.

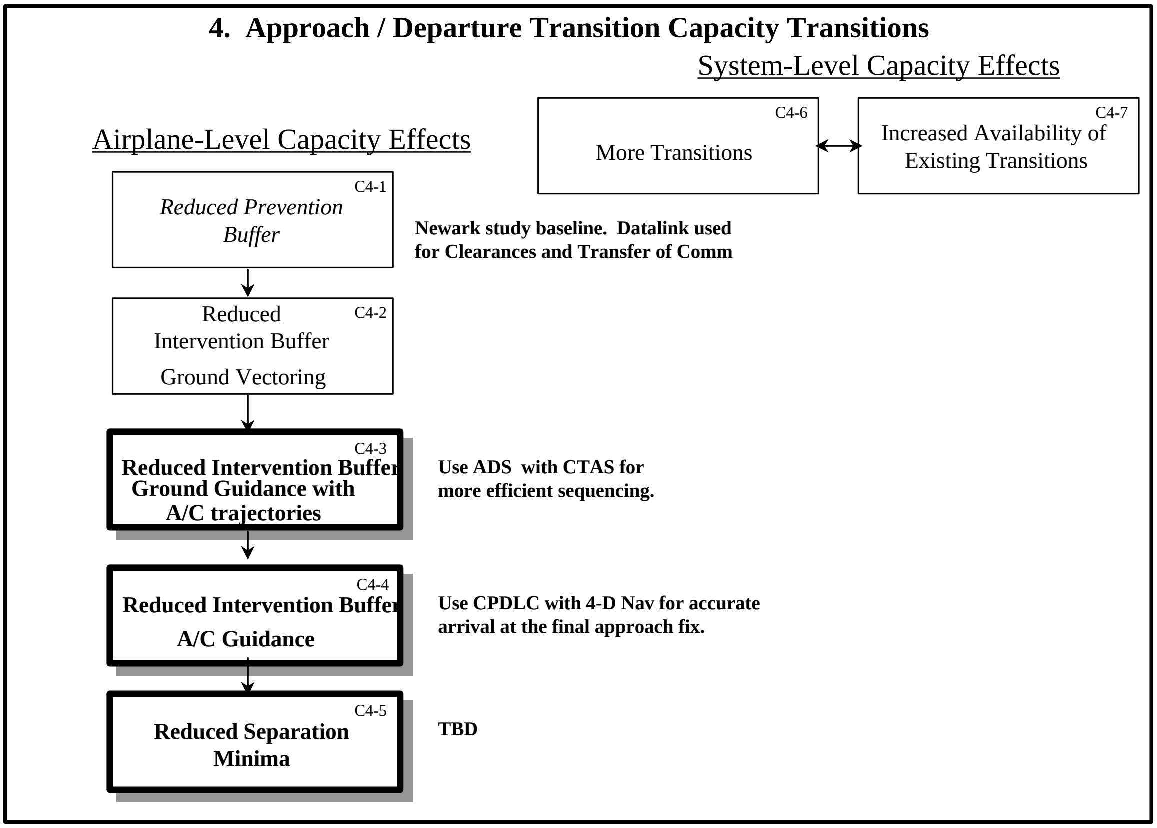
Figure A-2. Datalink-Enabled Operational Enhancements in Surface Phase

Figure A-3. Datalink-Enabled Operational Enhancements in Final Approach / Initial Departure Phase





ADS intent information allows for improved terminal area arrival flow planning.



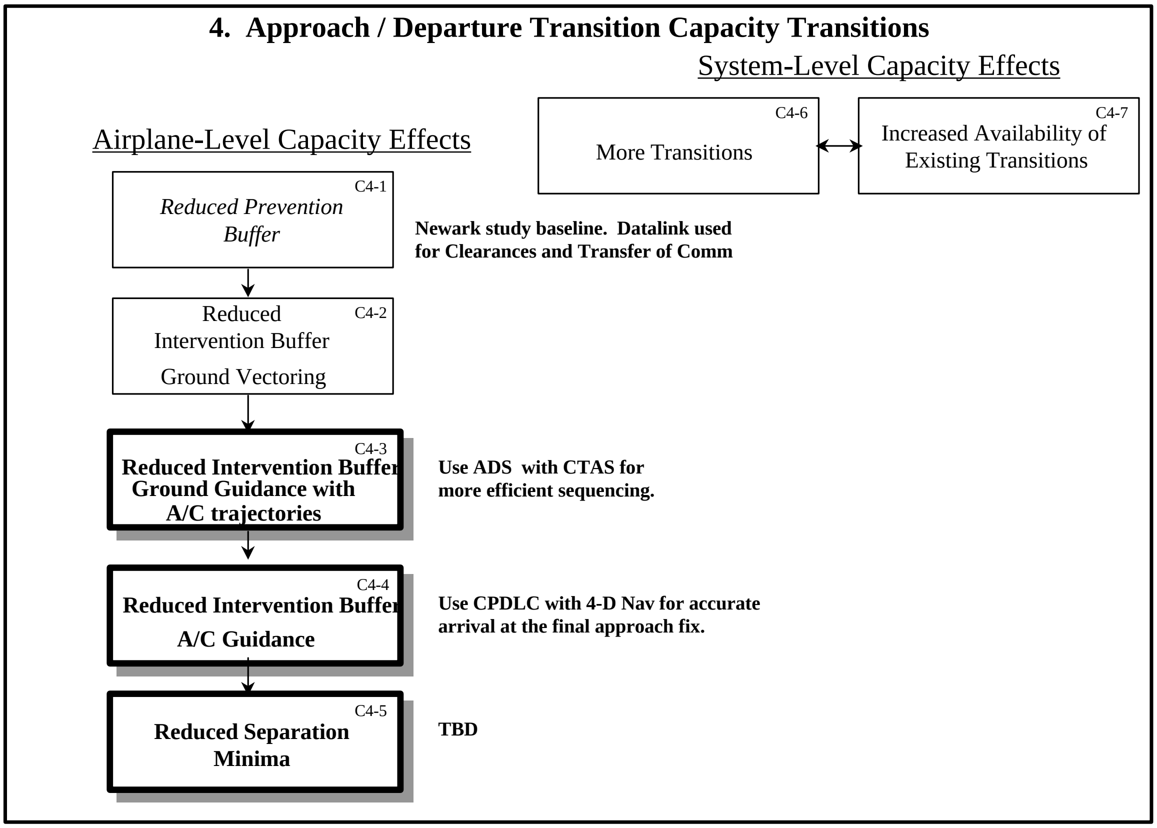
Newark study baseline. Datalink used for Clearances and Transfer of Comm

Use ADS with CTAS for more efficient sequencing.

Use CPDLC with 4-D Nav for accurate arrival at the final approach fix.

TBD

Figure A-4. Datalink-Enabled Operational Enhancements in Approach / Departure Transition Phase



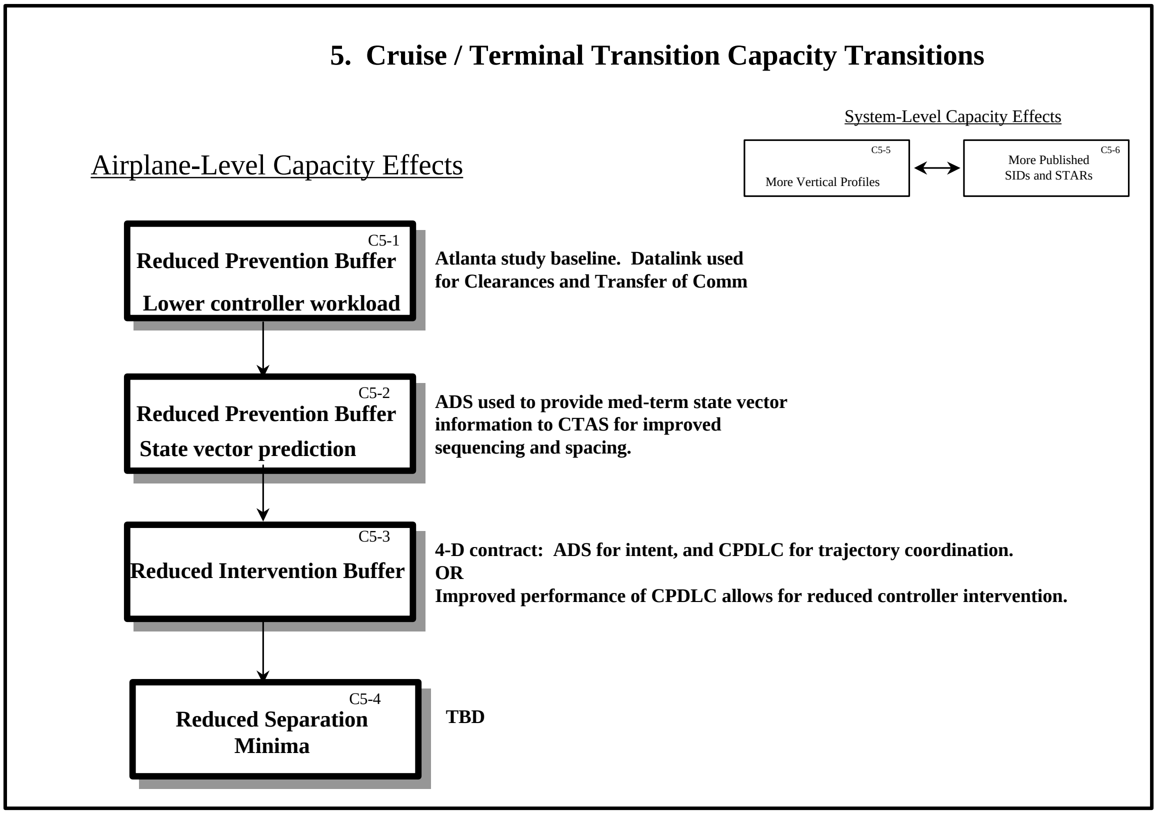
4. Approach / Departure Transition Capacity Transitions

Newark study baseline. Datalink used for Clearances and Transfer of Comm

Use ADS with CTAS for more efficient sequencing.

Use CPDLC with 4-D Nav for accurate arrival at the final approach fix.

TBD



Atlanta study baseline. Datalink used for Clearances and Transfer of Comm

ADS used to provide med-term state vector information to CTAS for improved sequencing and spacing.

4-D contract: ADS for intent, and CPDLC for trajectory coordination.
OR
Improved performance of CPDLC allows for reduced controller intervention.

Figure A-5. Datalink-Enabled Operational Enhancements in Cruise / Terminal Transition Phase

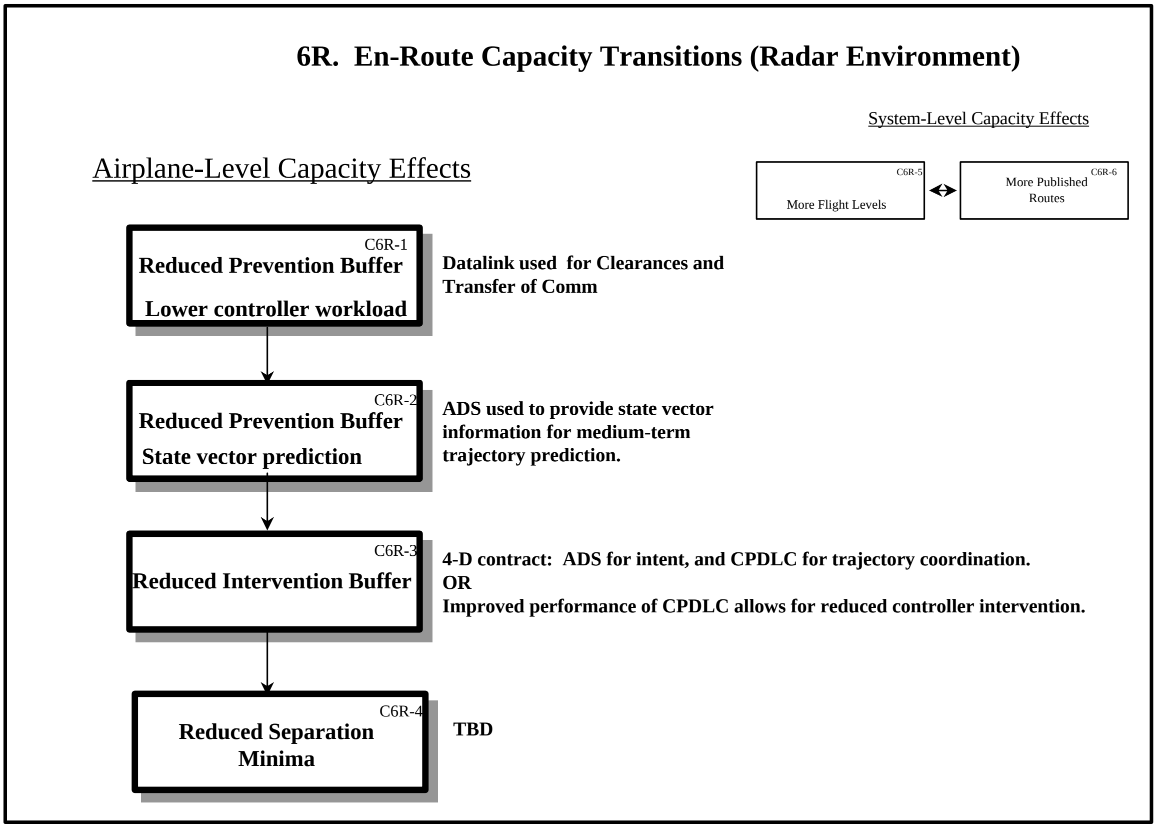
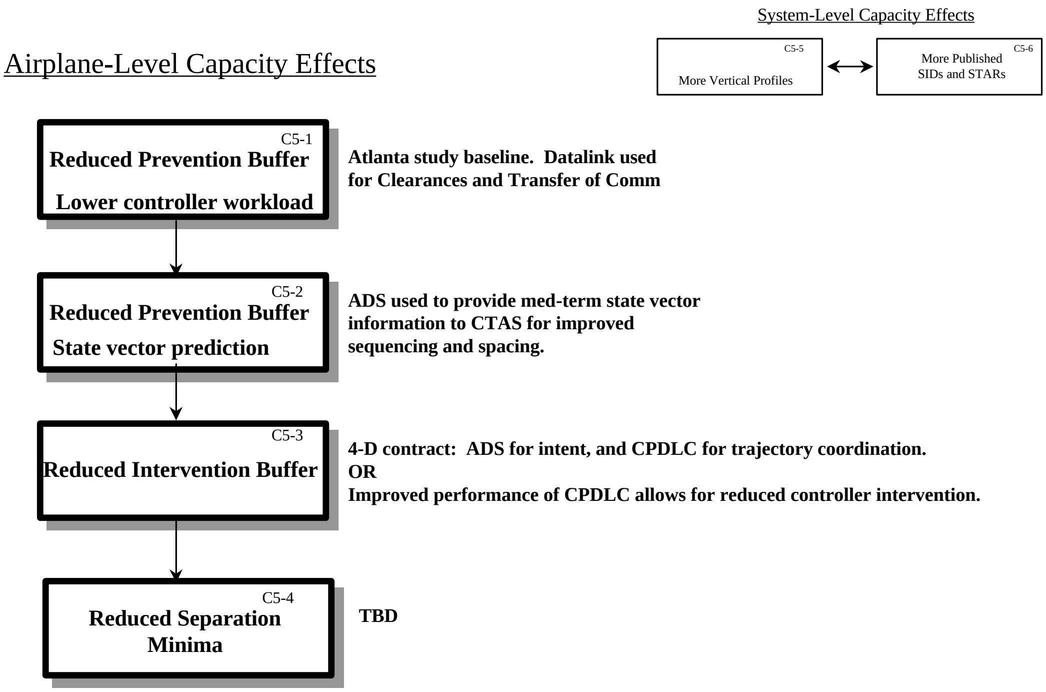


Figure A-6. Datalink-Enabled Operational Enhancements in En-Route (Radar Environment) Phase

5. Cruise / Terminal Transition Capacity Transitions



System-Level Capacity Effects

C5-5 More Vertical Profiles ↔ C5-6 More Published SIDs and STARs

Airplane-Level Capacity Effects

C5-1 Reduced Prevention Buffer — Lower controller workload

Atlanta study baseline. Datalink used for Clearances and Transfer of Comm

C5-2 Reduced Prevention Buffer — State vector prediction

ADS used to provide med-term state vector information to CTAS for improved sequencing and spacing.

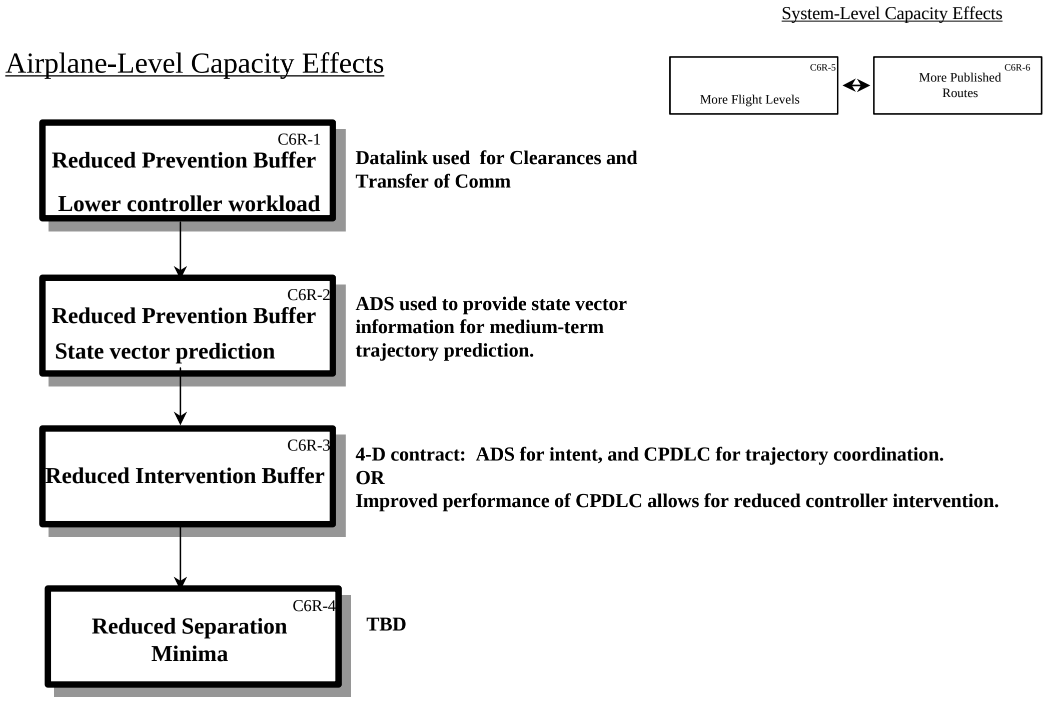
C5-3 Reduced Intervention Buffer

4-D contract: ADS for intent, and CPDLC for trajectory coordination.
OR
Improved performance of CPDLC allows for reduced controller intervention.

C5-4 Reduced Separation Minima

TBD

6R. En-Route Capacity Transitions (Radar Environment)



System-Level Capacity Effects

C6R-5 More Flight Levels ↔ C6R-6 More Published Routes

Airplane-Level Capacity Effects

C6R-1 Reduced Prevention Buffer — Lower controller workload

Datalink used for Clearances and Transfer of Comm

C6R-2 Reduced Prevention Buffer — State vector prediction

ADS used to provide state vector information for medium-term trajectory prediction.

C6R-3 Reduced Intervention Buffer

4-D contract: ADS for intent, and CPDLC for trajectory coordination.
OR
Improved performance of CPDLC allows for reduced controller intervention.

C6R-4 Reduced Separation Minima

TBD

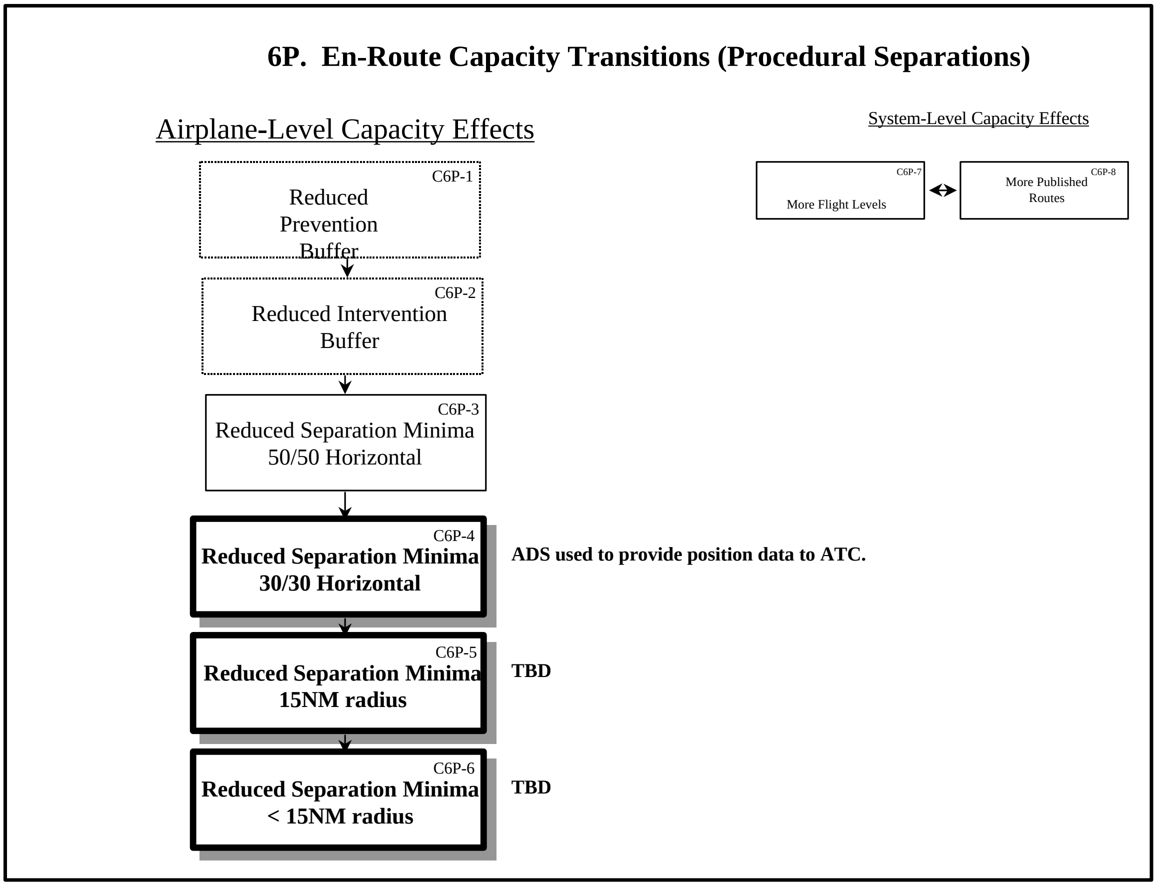
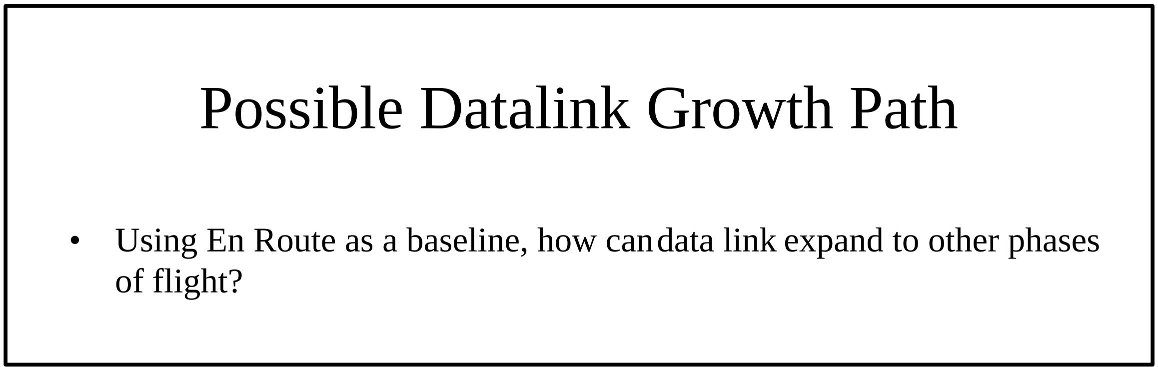
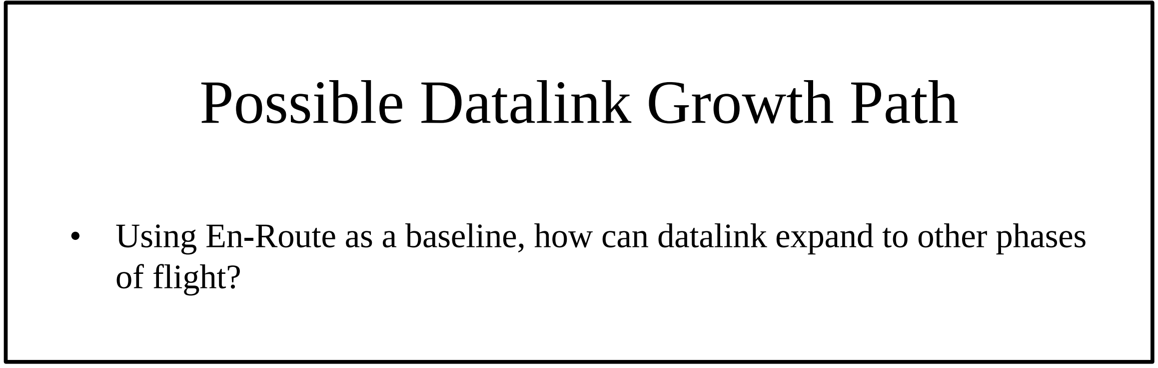


Figure A-7. Datalink-Enabled Operational Enhancements in En-Route (Procedural Environment) Phase



Possible Datalink Growth Path

- Using En Route as a baseline, how can data link expand to other phases of flight?



Possible Datalink Growth Path

- Using En-Route as a baseline, how can datalink expand to other phases of flight?

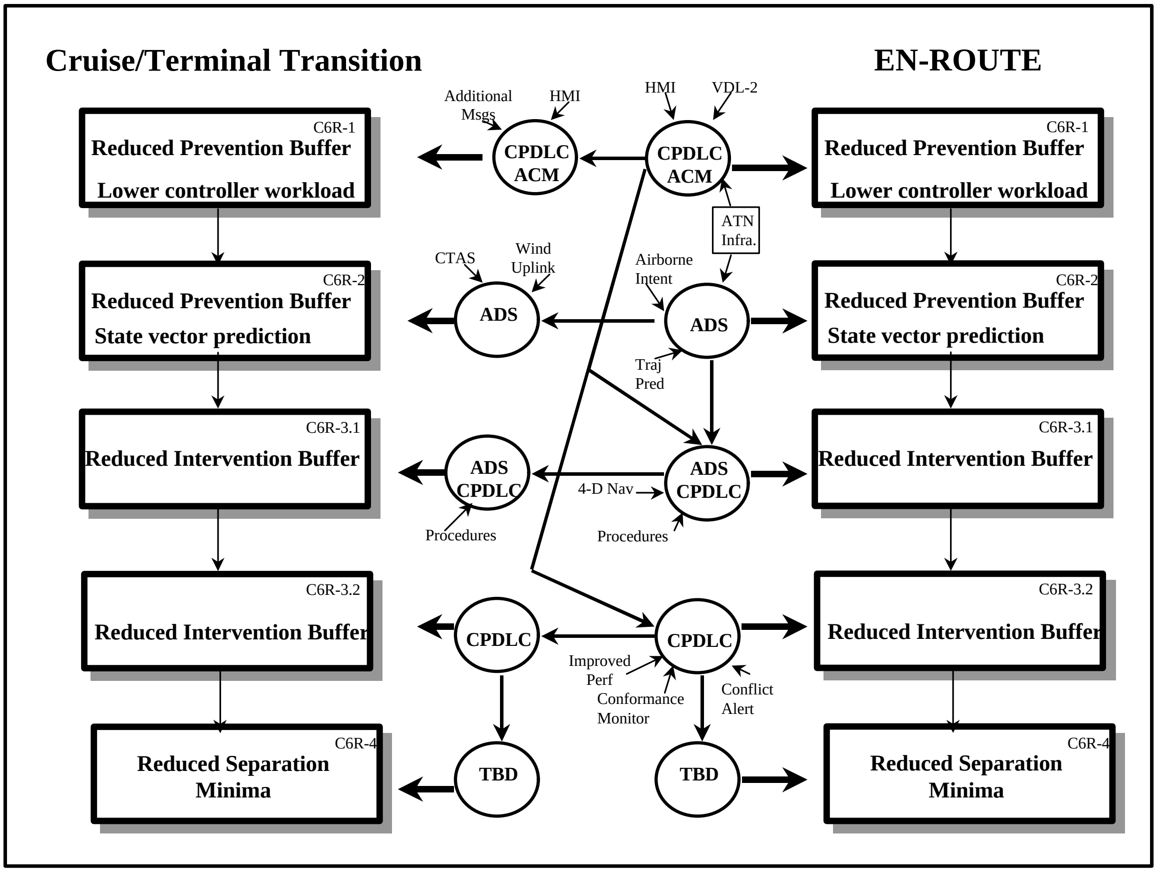


Figure A-8. Datalink-Enabler Growth Path -- Cruise / Terminal Transition

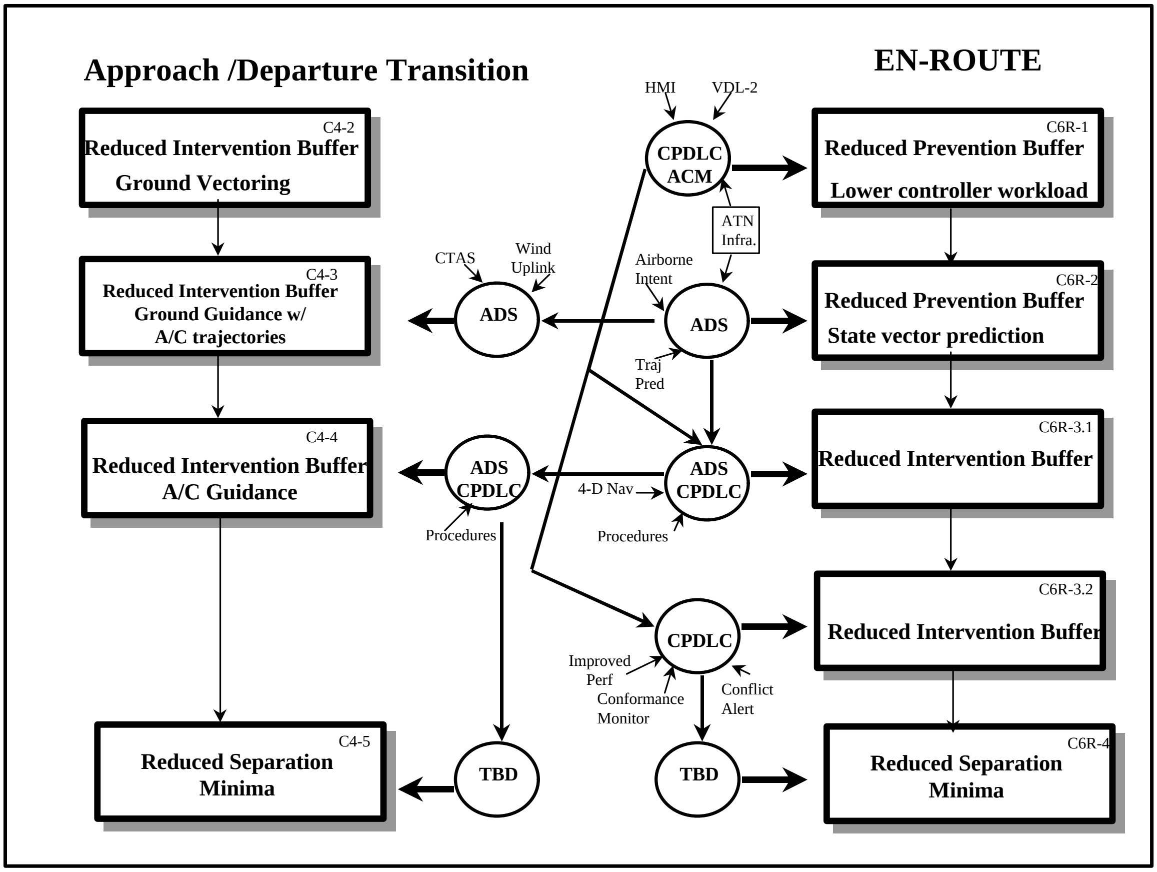


Figure A-9. Datalink-Enabler Growth Path -- Approach / Departure Transition

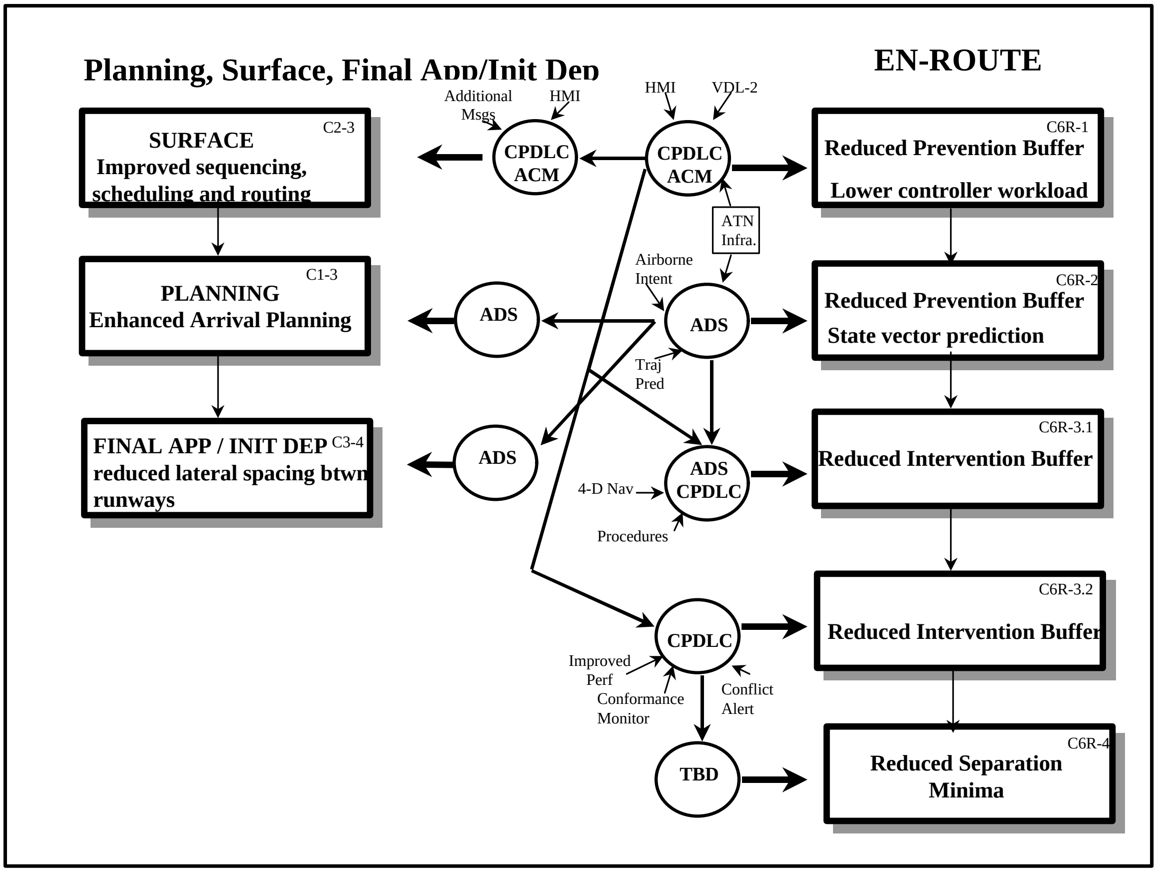
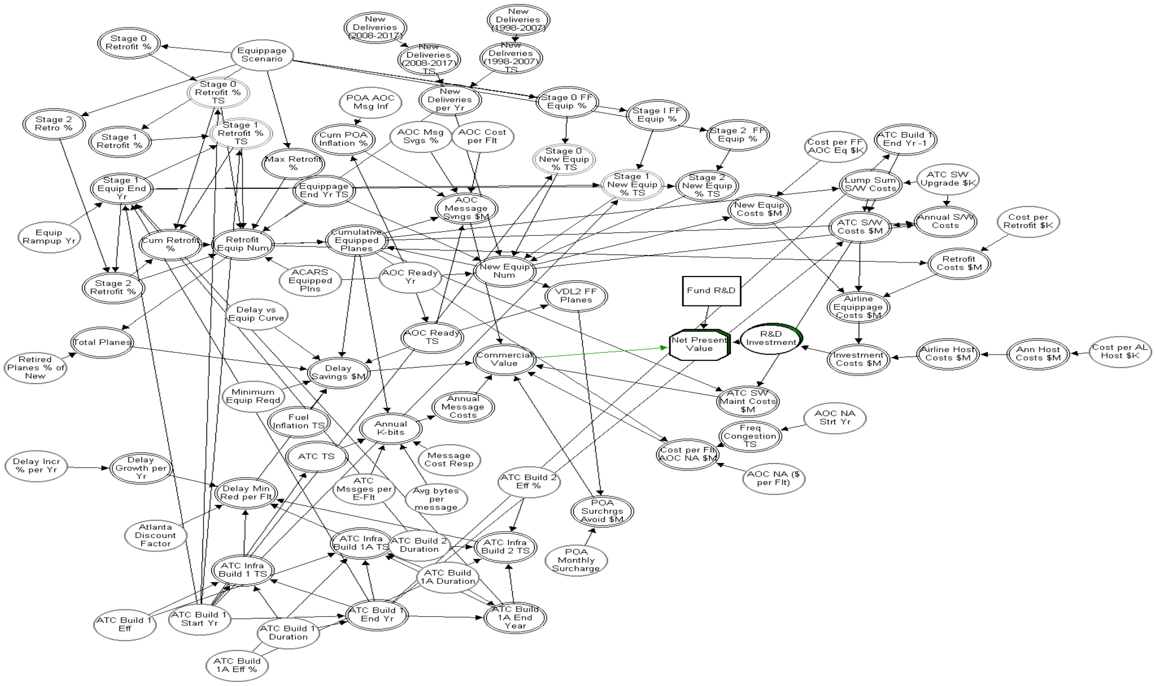


Figure A-10. Datalink-Enabler Growth Path -- Planning, Surface, Final Approach / Initial Departure

Appendix B – Full Influence Diagram

Figure B-1. Full Influence Diagram

Datalink Investment Model--Influence Diagram



Appendix C – Constants

The Total Number of Airplanes and New Deliveries are used in traffic growth calculations, as discussed in Section 5.2.2. The Total Flights per Year and Average Cost per ATC Kilobit are used in the cost calculations of Section 5.2.5.

Constants	Value	Source
Start Year of Model	2000	C/AFT consensus
Final Year for Equipage	2015	C/AFT consensus
Final Year for Benefits	2020	C/AFT consensus
Discount Rate	12%	Airline consensus
Inflation Rate	3.5%	Airline consensus
Direct Operating Cost (DOC) per minute (not including ownership costs)	$25	Airline consensus (industry standard)
Fuel percent of DOC	30%	Airline consensus
Fuel inflation rate	5%	Airline consensus
1997 Total Number of Airplanes	5194	ATA annual report 1998 (12/31//97 data)
New Deliveries (1998 to 2007)	233	Boeing Current Market Outlook
New Deliveries (2008 to 2017)	326	Boeing Current Market Outlook
Total Flights per Year	8,157,000	ATA data (1997)
Average Cost per ATC kilobit (annual)		C/AFT consensus
up to 1 Million Kbits per year	$0.18	
1 - 4 Million Kbits per year	$0.14	
4 -8 Million kbits per year	$0.10	
8 - 15 Million Kbits per year	$0.06	
Atlanta study national delay savings	11,491,387	Atlanta study
1996 Number of departures	12,783,708	1997 ACE Table A1, total # of operations divided by 2

Table C-1. Constants

Appendix D – Traffic Growth Assumptions

Using this data results in the following number of airplanes in the model in the year 2015:

Low Estimate (10% case):	8054
Medium Estimate (50% case):	8943
High Estimate (90% case):	9289

Variables	10	50	90	Source
Retired Planes as % of New per year	15%	22%	40%	Based on estimates using data from the Boeing Current Market Outlook

Table D-1. Traffic Growth

Appendix E – Infrastructure Assumptions

Variables	10	50	90	Source
ARINC VDL Mode 2 Infrastructure Readiness Year	2000	2001	2002	ARINC
ATC Infrastructure				Based on John Kern Data Link Issues Team Recommendations to the NAS Modernization Task Force, presentation dated July 21, 1998. Assume that end year of a build is equal to the start year of subsequent build.
Build 1 Start Yr	2002	2003	2004	
Duration of Build 1 (years)	1	2	3	
Duration of Build 1a (years)	2	3	4	
Duration of Build 2 (years)	2	4	8	
Build 1 Delay Reduction Effectiveness	0%	0%	0%	The percentage of data link-related en route delay that is affected with this build. This is an FAA estimate. This factor is applied to ALL flights, not just those VDL Mode 2 equipped.
Build 1A Delay Reduction Effectiveness	50%	70%	85%	
Build 2 Delay Reduction Effectiveness	70%	90%	95%	

Table E-1. Infrastructure

Appendix F – Equipage Rate Assumptions

Table F-1 summarizes the timing assumptions for the three equipage stages, while Table F-2 shows low, medium, and high equipage scenarios corresponding to the three stages. The low scenario corresponds to the 10% values for forward fit and retrofit, medium scenario to the 50% values, and high scenario to the 90% values. The maximum retrofit percentage per year (90% case) was estimated by the C/AFT airlines to be 25%, based on the assumption that retrofit would occur during major maintenance cycles that occur every 4-5 years.

The current percentage of airplanes equipped with ACARS is an important variable because only those airplanes are candidates for VDL Mode 2 equipage. There is, in addition, an assumed maximum total retrofit possible over the life of the model that is tied to the equipage scenarios.

Variables	10	50	90	Notes
Stage 0				
Stage 0 Start Yr		2000		Start date of model
Stage 0 End Yr		Build 1 Start		Stage 1 is assumed to start in Stage 0 End Yr.
Stage 1				
Stage 1 End Yr	Build 1a Start	Build 2 Start	Build 2 End	Stage 2 is assumed to start in Stage 0 End Yr.
Stage 2				
Stage 2 End Yr		2015		Final Year for Equipage

Table F-1. Equipage Stages

Variables	10	50	90
ACARS-equipped airplanes %	85%	90%	95%
<u>Equipage Scenarios</u>	**Low**	**Medium**	**High**
Max Retrofit Total (over life of model)	50%	75%	90%
Stage 0 Forward Fit % per yr	25%	60%	75%
Stage 0 Retrofit % per yr	2%	3%	4%
Stage 1 Forward Fit % per yr	50%	85%	90%
Stage 1 Retrofit % per yr	7%	10%	13%
Stage 2 Forward Fit % per yr	75%	95%	100%
Stage 2 Retrofit % per yr	15%	20%	25%

Table F-2. Equipage Scenarios

Appendix G – Aircraft Equipage Cost Assumptions

Cost Data	10	50	90	Source
Airborne Equipment Costs				
Retrofit (AOC VDL Mode 2, including Service Bulletin and Installation)	$ 100,000	$ 160,000	$ 240,000	Airline consensus
Forward Fit (AOC VDL Mode 2, including Master Change)	$ 30,000	$ 60,000	$ 100,000	Airline consensus
ATC Software Upgrade	$ 10,000	$ 30,000	$ 100,000	Airline consensus
Maintenance	10%/year of ATC Software Upgrade, starting 2nd year			Airline consensus
Average host/router upgrade, all airlines	$ 100,000	$ 200,000	$ 300,000	Airline & ARINC consensus
ATC Message Costs				
ATC Messages per equipped flight	200	229	260	FAA JRC charts
Average bytes per message	40	56	75	FAA JRC charts
Multiplying Factor on Message costs	0.0	0.5	1.0	

Table G-1. Equipage and Message Costs

Appendix H –Benefit Assumptions

AOC Benefits	10	50	90	Notes
Current average AOC cost per flight segment	$4	$6	$9	Airline consensus
Forward Fit POA Monthly Surcharge	$900	$1,000	$1,100	ARINC. Penalty assessed by ARINC on POA forward fit airplanes
POA Per Kilobit Penalty per year	3%	5%	10%	ARINC. Penalty assessed by ARINC on POA bits, applied to the average AOC cost per flight segment each year.
Penalties Start Year	ARINC I/F start	ARINC I/F start	ARINC I/F start	Same as "ARINC VDL Mode 2 Infrastructure Readiness Year" in Infrastructure, Section 5.2.3.
Lower messages costs for AOC	50%	75%	83%	Airline consensus. Percentages correspond to 2:1, 4:1, 6:1 savings due to message length reduction, and are applied to the average AOC cost per flight segment each year.
Cost per Flight of AOC Non-Availability	$16	$32	$48	Airline consensus. This variable is an industry estimate. This data is highly competition sensitive and will be unique for each airline.
Start Year of AOC Non-Availability Problems	2002	2006	2010	ARINC.

Table H-1. AOC Benefits

ATC Benefits	10	50	90
Minimum Equipage Required	20%	25%	35%
Atlanta Scaling Factor	30%	50%	80%
Delay Savings Multiplier percent per year (based on Delay Growth Per Year)	2.5%	7%	11%

Table H-2. ATC Benefits

Appendix I -- Discussion of Benefits vs. Equipage

This is a key issue related to all CNS/ATM enhancements, and needs to be addressed by the industry at large. What follows is a general discussion of the issue.

There are two fundamental problems associated with strategic investments that make them difficult to justify. The first is that there is an initial negative gap between costs and benefits that make the return on investment period longer than airlines are used to. Secondly, those that invest generally create benefits for those who do not invest, thus greatly increasing the risk associated with the investment.

There are, in principle, four options to overcome the risk:

1. There is a general aviation industry acceptance that the enabler is needed (using data link for the sake of this discussion). To avoid unequal benefits, the aviation industry agrees to implement data link by a certain date.
2. Regulators mandate data link from a certain date for selected airspace.
3. Air traffic service providers provide immediate exclusive operational benefits to equipped aircraft.
4. Costs of implementation and operation are reduced by subsidies.

Options 1 and 2 achieve the same result by different means. They both provide economy of scale, and apply costs equally across all users. Airlines can fully base the procedures on data link equipage and there is thus no need to support airplanes not equipped with data link. This avoids complex operational environments and investments. Operational benefits are achieved within a much shorter time because of the high percentage of equipped aircraft, thus reducing the length of the return on investment period. There are, however, many problems associated with a mandate approach (whether by agreement or by a true mandate), as is evidenced by the 8.33 kHz implementation in Europe.

In options 3 and 4, benefits are provided only to aircraft that are equipped. This will reduce the cost/benefit gap and will shorten the return on investment period. These options would be politically, technically, and operationally difficult to achieve.

Of course there is the fifth option, that has been followed until now, which is to do nothing and wait until something happens. This will not bring the industry forward, and will instead result in a gradual erosion of the ATC system's ability to deal with increased capacity.

A combination of these options could accelerate implementation. At a certain time, states may need to mandate data link for selected airspace. It will take many years until such a mandate will be effective because we will run into the same discussions and situations that were experienced with BRNAV, RVSM, 8.33, etc. in Europe; some aircraft operators will not accept the decision because of cost considerations, or act to delay the dates of implementation, or ask for exemptions, etc. To provide exemptions for mere economical reasons (and in many cases that's behind the arguments) questions the principle of equity of treatment.

Aircraft operators who are willing to invest early in order to support implementation of operational procedures which are beneficial for the whole community should get early operational benefits (e.g., better ATFM slots, preferred routing or similar benefits) and/or an economic incentive (e.g., reduced charges because they do not require the same level of service from ATC). Many people in the industry are questioning whether we should strictly pursue the 'first come first served' principle which in many cases hinders optimum usage of resources.