European 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 in European airspace. The analysis was performed from an airline perspective, and focused on the value to the airlines of transitioning from two separate baselines to VDL Mode 2 for AOC and ATC communications: from airplanes currently using Airline Communication, Addressing and Reporting System (ACARS) for AOC operations to VDL Mode 2, and from airplanes not currently using data link for AOC to VDL Mode 2. 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 that serves both the Airline Operational Control (AOC) function and the Air Traffic Services (ATS) function.** The initial investment, while significant, provides a positive return on investment and lays the foundation for future potential benefit. En route delay savings and the value of maintaining AOC data link capability are the primary benefit drivers, and provide a convincing case for both retrofit and forward fit equipage of airplanes. 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 and reducing surface delay. 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 delay is a significant factor in the investment analysis. The European Commission has noted that one-third of the flights in Europe today are delayed. This situation angers passengers and is very costly to the airlines. Industry consensus is that the situation will worsen over the next five years, even with implementation of currently planned airspace improvements.

The cost of AOC non-availability is another 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 demand exceeds its bandwidth capacity. Many areas of Europe and 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.

VDL Mode 2 has been proposed as a means of mitigating both the AOC frequency congestion and as an enabler for Air Traffic Services Data Link to reduce 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 both Eurocontrol and the FAA have taken initiatives to implement Air Traffic Services Data Link -based on a subset of Aeronautical Telecommunications Network (ATN) messages over VDL Mode 2. Eurocontrol has specified ATS D/L functionality in its LINK2000+ initiative, while the FAA has funding commitments for Controller Pilot Data Link Communication (CPDLC) Builds 1 and 1A.

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1. Introduction

The CNS/ATM Focused Team (C/AFT) has agreed that future gate-to-gate capacity is the number one driver for global airspace system changes. C/AFT is proposing to achieve airspace capacity gains through incremental operational enhancements that can be enabled by Communication Navigation Surveillance (CNS) technologies.

In its *Communication to the Council and the European Parliament - The Creation of the Single European Sky*, the European Commission noted that "In Europe today one flight in three is not on time. The average delay is 20 minutes and this can stretch up to several hours at peak periods. This situation angers passengers, it frustrates airlines and some do not shrink from talking about chaos. It also creates costs to the economy, over and above lost business and ruined holidays damage to the environment. It also raises concerns about the impact of air traffic on the environment. Even specialists, working on the basis of realistic forecasts and assuming that the plans for improvement now in the offing go ahead as planned, are of the opinion that the situation will worsen still further over the next five years. Responsibility for these delays is, of course, shared, and although operators and airports both account for a quarter of delays half of them are due to the saturation of airspace." [1]

The EUROCONTROL ATM Strategy for 2000+ identifies data link as one of the key enablers for the coming decade. Data link will bring reductions in communication workload for controllers and pilots, increase communication reliability, and allow airborne-and ground-based systems to exchange information. [2]

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 for Air Traffic Services Data Link (ATS D/L), including those needed to support future radar-controlled 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 AOC and ATS (ATN VDL Mode 2). C/AFT published the results of a VDL Mode 2 analysis for US airspace in April 1999. [14] The purpose of this paper is to document the results of the economic analysis for European airspace.

VDL Mode 2 was chosen for this analysis because it has been selected by the LINK 2000+ Drafting Group. [3] The analysis has been performed from an airline industry point of view. This document presents the results of C/AFT’s study of the costs and benefits of equipping with data link in Europe.

2. Scope of Analysis

This analysis evaluates the value to the airlines of digital data link-based AOC operations as well as ATC benefits derived from a defined set of airport and en route data link services in core Europe. The model includes airlines that do not have data link AOC functionality as well as airlines that currently use ACARS. 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 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 ATC 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.

In order to focus on the delay-reduction benefits, the C/AFT has decided not to consider some quantifiable ATC benefits such as the cost avoidance of sub-optimal accommodation of the demand or the cost avoidance of the non-accommodated demand due to flight cancellation because of delay level. Other benefits not captured in this model include loss of revenue due to alternative forms of transportation, and exponential capacity savings due to the non-linear nature of delay.

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

ACARS use has grown tremendously over the past ten years. The AOC data traffic congestion situation is quite serious in Europe, even though only approximately half of the European airlines are currently using ACARS. At this point there are no more frequencies available for growth in ACARS traffic in spite of the fact that the ICAO European Air Navigation Planning Frequency Management Group is exerting pressure for better utilization of frequencies. There is little hope for improvement since ATC will be using up channels freed by 8.33 kHz voice communications, and two frequencies that were designated for ACARS will have to go to VDL Mode 2 in the 2003-2005 timeframe.

To make matters worse, the number of airplanes equipping with ACARS is increasing, and AOC applications are growing, leading to increased AOC traffic per airplane. There is potential for very high growth in AOC traffic as more airlines equip, and airlines are relying more on data link AOC than ever before to increase the efficiency and effectiveness of their operations. In a presentation prepared for C/AFT, SITA states that "SITA is convinced VDL is required to avert ACARS service breakdown in 2003/2004 timeframe. VDL will provide a better service to customers and increase VHF medium efficiency". [4]

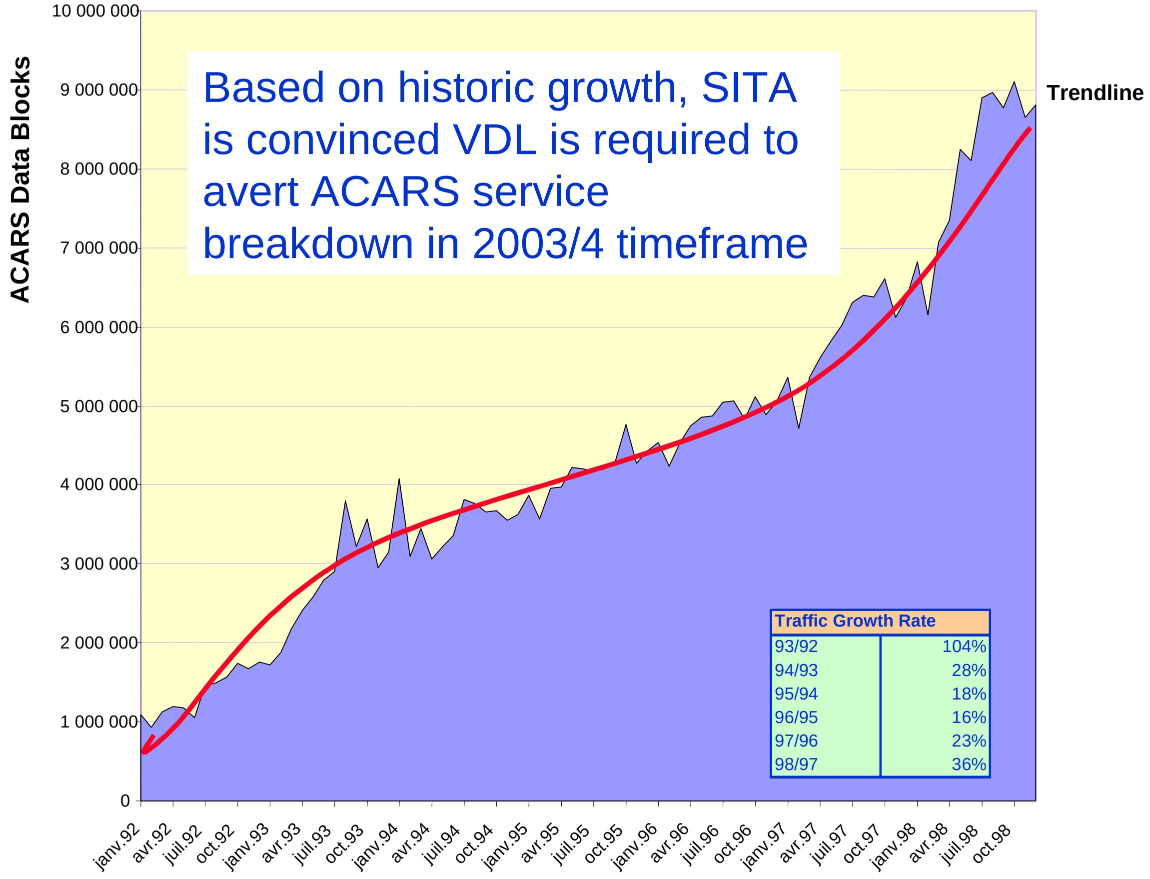

Figure 3.0-1. SITA VHF AIRCOM Traffic Growth

4. ATC Communication Issues

The ATC delay situation in Europe is very serious. According to a EUROCONTROL study published in October 1999 [6] (*Medium-term Capacity Shortfalls 2003-2005*) the average en route delay per flight by the year 2005 is estimated between 17.1-36.8 minutes, according to the assumptions retained, if there is nothing more undertaken than national and supra-national Capacity Enhancement Plans known at that date. Airlines require that the amount of existing delay be reduced so that acceptable levels of delay can be maintained in the future.

ATC delay affects airline operation seriously. The published average number of departure delays is an indication of the overall performance, but the actual ATC delay on a per flight basis (25% of flights delayed by 20 minutes) forms a serious day-to-day problem. The Association of European Airlines (AEA) and the International Air Transport Association (IATA) keep track of the development of the delay and have just started a campaign to get political attention for the problem (IATA 5 Point Action Plan). The Performance Review Commission just published its third report on Air Traffic Management (ATM) performance, showing the contribution of ATM delay to the total performance and the additional 'reactionary' delay in airline operation, representing together 50% of all delay in Europe. [7]

Recent industry activities suggest that digital data link is a key enabler to reduce delay. In 1995 the FAA published the results of a data link benefits study entitled *User Benefits of Two-way Data Link ATC Communications: Aircraft Delay and Flight Efficiency in Congested En Route Airspace* [13] in which ATC productivity was increased, thereby decreasing airline delay, by using data link to reduce voice frequency congestion. These results were used as inputs to the C/AFT U.S. data link business case. [14]

EUROCONTROL performed a simulation called LINK 2000+ Business Case Development Simulation (L2KBC) in support of this analysis which is described in detail in Section 4.1. It was conducted as a comparative study of a baseline system and an advanced system employing data link communication. Simulation results, published in February 2000 [5] show that significant delay savings result from data link equipage. These results were used for ATC delay reduction benefit estimates in this economic model.

PETAL-IIe (Preliminary EUROCONTROL Test of Air/Ground Data Link, extension) trials are underway in Europe to evaluate data link operational implementation issues. PETAL-IIe is the third in a series of operationally-oriented air/ground data link trials conducted by EUROCONTROL. The aim of PETAL-IIe (and its predecessor PETAL-I,-II) 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 is implementing data link in the US National Airspace System (NAS). CPDLC Build I represents the first implementation of an ATN-based air ground data link in support of en route ATC in the US domestic airspace. It will provide four initial services for aircraft transiting the Miami Air Route Traffic Control Center (ARTCC) airspace, with initial operational capability slated for June 2002. CPDLC Build IA will expand upon the CPDLC Build I services to a total of nine ATC services including transmittal of clearances. The CPDLC Build IA program is fully funded and its key site initial operational capability is scheduled for 2003 with national deployment planned for all ARTCCs from 2003-2006. ADLS Build II will be the next major expansion of data link capability across the NAS. To date five spirals have been identified that provide integration with fielded decision support tools as well as expand and extend data link services to other flight domains. The implementation of these spirals may or may not be sequential and will be dependent on industry needs. The first spiral implementation of ADLS Build II at a key site is planned for 2006. National implementation would follow.

The LINK 2000+ Drafting Group has issued a position statement on ATN and VDL Mode 2 stating that: "A communications infrastructure based on the Aeronautical Telecommunications Network (ATN) and the VHF Digital Link Mode-2 Subnetwork, has been selected to support the identified LINK 2000+ services, in the target timescales." [3]

EuroCAE and RTCA have formed a joint committee SC-189/WG 53 to define a follow-on data link implementation project called Baseline 2. Baseline 2 seeks to define data link capabilities to be used in all phases of flight operations and includes services to be used in US and European airspace.

4.1 LINK 2000+ Business Case Simulation

To determine the impact of the introduction of data link communications on the delays experienced by air traffic in Europe, the following steps were taken:

1. a real time simulation conducted to measure the radio/telephony () workload reduction;
2. a calculation of the overall workload reduction;
3. a calculation of the sector capacity increase based on the workload reduction;
4. a fast time simulation (COSAAC) to determine the delay reduction resulting from the capacity increase; and
5. a fast time simulation (CAPAN) to confirm the calculation in step 3.

4.2 Real Time Simulation – Bretigny

To determine the benefits of data link implementation, the first step was the Real Time Simulation conducted at the EUROCONTROL Experimental Center (EEC) in Bretigny, France in September 1999. The simulation lasted two weeks and involved seven controllers. It was organized in four sectors in the core area of Europe:

- YR- Reims, upper airspace, as the measured sector, manned by two controllers from Reims, familiar with this airspace.
- Paris, Maastricht and Reims sectors, ground-to-upper airspace, as feed sectors, manned by Romanian controllers.

Three different traffic volumes were used: baseline (7 August '98), 150% and 200%, with four equipage rates for each traffic volume: 0%, 50%, 75% and 100%. Simulated data link services were:

- DLIC – Data Link Initiation Capability
- ACL – ATC Clearances
- ACM – ATC Communications Management
- CAP – Controller Access Parameters

There were two sets of results:

- Objective results consisting of the number and the duration of the voice communications, aircraft profiles and interaction of controllers with the Human Machine Interface (HMI); and
- Subjective feedback e.g. Instantaneous Self Assessment (ISA, a tool that allows controllers to record their perceived workload), questionnaires, comments, observation during exercises.

As input for the next steps only objective data were used, namely the reduction of R/T communications.

4.3 Calculation of the Overall Workload Reduction

Studies by National Air Traffic Services (NATS), UK, and the Centre d'Etudes de la Navigation Aérienne (CENA), France [16], have shown that R/T workload is generally 35% - 50% of the total workload. We have chosen the conservative value of 35% (assuming that R/T occupancy is equal to R/T workload). Applying this value, the overall workload reduction with data link was obtained.

Example: For 100% data link equipage, high traffic (double than the baseline) there were 0.65 communications per aircraft. For the same traffic sample with 0% data link equipage there were 3.79 communications per aircraft. So, the R/T workload using 100% data link represents only 17% of the R/T workload without data link. We considered that R/T workload is 35% of the total workload. Using data link, the new workload is 65% (non-R/T workload) plus 17% of 35% (R/T workload using data link) equal with 71%. The workload reduction is thus 29%.

4.4 Calculation of the Sector Capacity Increase Based on the Workload Reduction

The CAPAN simulation experience shows that it is reasonable to consider that the capacity increase is half the saved workload (see Section 4.6 for a description of CAPAN). This general rule was applied to the real-time simulation findings. The results are shown in Table 4.4-1.

Rate of equipage	Workload reduction (considering 35% R/T)	**Capacity gain**
0% data link	0%	**0%**
50% data link	16%	**8%**
75% data link	22%	**11%**
100% data link	29%	**14%**

Table 4.4-1. Capacity Gain vs. Rate of Equipage

4.5 COSAAC (Common Simulator to Assess ATFM Concepts)

In order to obtain the delay reduction from the capacity increase the COSAAC tool was used. COSAAC is an analytical simulator developed at the EEC – Bretigny. This tool was developed to investigate the impact of traffic and capacity variations on Air Traffic Flow Management (ATFM) delays. For this purpose the tool is using a slot allocation module very similar to the module that is used in real time by the Central Flow

Management Unit.

For this simulation we used *a traffic sample from 16 April 1999* (approximately equal to the 100% traffic volume of the real time simulation). The results are in the Table 4.5-1, below.

Rate of equipage	Capacity increase	**ATFM Delay reduction**
25%	3.4%*	**10%**
50%	8%	**31%**
75%	11%	**44%**
100%	14%	**53%**

* This value is from the CAPAN simulation, see Section 4.6.

Table 4.5-1. ATFM Delay Reduction vs. Rate of Equipage

The same traffic sample (16 April 1999) was increased with 50% and 100%, using a 'clone' method. The results that were obtained running the simulator with those traffic samples are shown in Tables 4.5-2 and 4.5-3.

traffic sample from 16 April 1999 **+ 50%** and **baseline capacity**		
Rate of equipage	Capacity increase	ATFM Delay reduction
25%	3.4%*	4%
50%	8%	11%
75%	11%	16%
100%	14%	22%

Table 4.5-2. ATFM Delay Reduction vs. Rate of Equipage at +50%

traffic sample from 16 April 1999 **+ 100%** and **baseline capacity**		
Rate of equipage	Capacity increase	ATFM Delay reduction
25%	3.4%*	3%
50%	8%	8%
75%	11%	11%
100%	14%	14%

Table 4.5-3. ATFM Delay Reduction vs. Rate of Equipage at +100%

The baseline capacity used to obtain these last two sets of results was the same as for the baseline traffic sample. However, it is very unlikely that the baseline capacity will stay the same when the traffic has increased by 50% and by 100%. That is why only the results with the base line traffic sample and with the baseline capacity have been taken into account as an input for the business case. It can be assumed that, for the same rate between traffic demand and sector capacity, the implementation of data link offers equal benefits.

4.6 CAPAN Simulation – ATC Capacity Analyser

CAPAN is a fast-time simulator using a task-based model. The purpose of the simulation was to assess the impact of the use of data link, in terms of capacity increase, independently from the real-time simulation

The communication task execution times were determined through expert judgment. [8] The inputs were verified against the real-time simulation measurements, but no major inconsistencies were detected and no adjustments were made. The CAPAN simulation environment consisted of the Karlsruhe UAC (one of the most heavily loaded airspaces in Europe), with a traffic sample of 9 July 99 (peak day of the summer of '99) increased by 35% in order to obtain the 2005 traffic.

The output of the simulation was the sector capacity increase achieved by using data link. The CAPAN simulation confirmed what experience had shown before, as shown in Table 4.6-1, that the capacity increase is roughly half the workload reduction.

Rate of equipage	**Capacity increase CAPAN**	Capacity increase resulting from the Real Time Simulation
25%	**3.4%**	-
50%	**7.8%**	8%
75%	**11.2%**	11%
100%	**15.9%**	14%

Table 4.6-1. Comparison of CAPAN and L2KBC+ Results

4.7 Summary of L2000+ Simulations

It is important to note that the delay reductions are referring only to ATFM delays[1]. In 1999 ATFM delays only generate 25% of all delays [9]. For example with 50% data link equipage, the overall delay will decrease with 31% of 25%, i.e.8%.

Figure 4.7-1. Summary of L2000+ Simulations Results

Rate of Equipage	**ATFM Delay reduced by**	**Overall reduced by**
25%	**10%**	**2.5%**
50%	**31%**	**8%**
75%	**44%**	**11%**
100%	**53%**	**13%**

Equipage Rate	**Capacity Increase %**	**ATFM Delay Reduction**
25%	**3.4**	**10%**
50%	**8**	**31%**
75%	**11**	**44%**
100%	**14**	**53%**

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[1] An ATFM Delay is given by the duration between the last take off time requested by the aircraft operator and the take off slot received from CFMU.

4.8 C/AFT Assessment of L2KBC

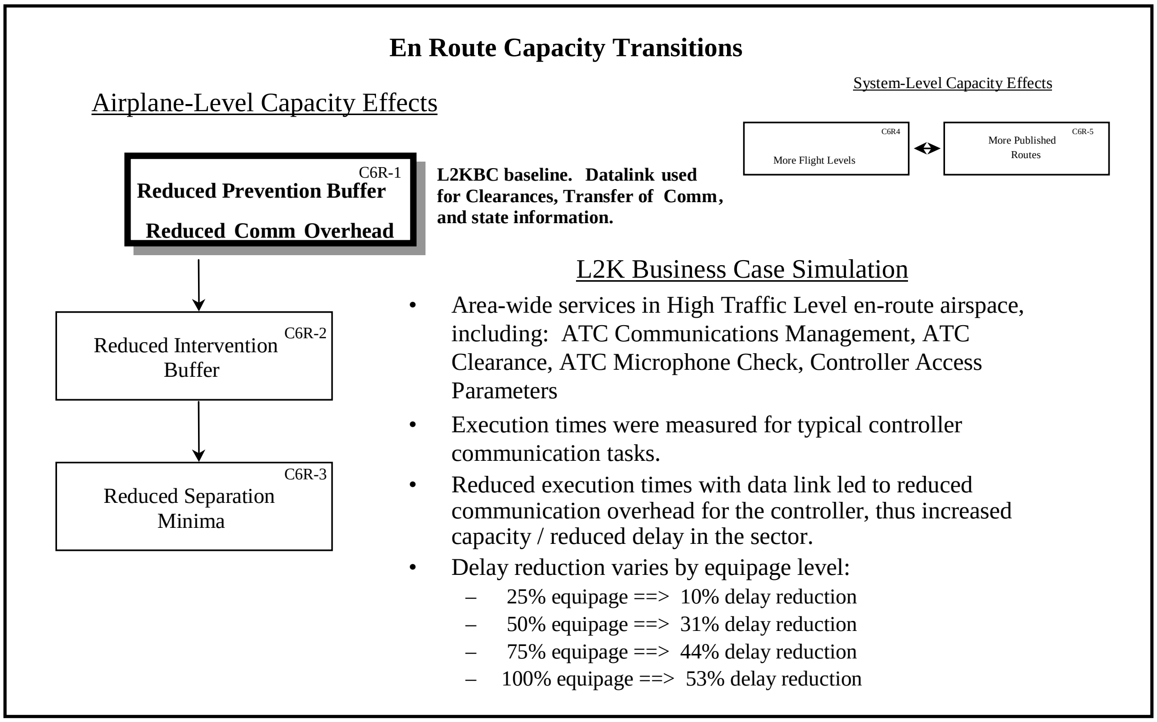
C/AFT analysis suggests that the L2KBC simulation results may actually be conservative for the following reasons:

- L2KBC uses the conservative assumption that R/T workload is 35% of total workload (it is generally accepted that R/T workload is between 35 - 50% of total workload)
- L2KBC assumes that capacity gain equals one-half of workload reduction. Capacity gain is actually dependent on the level of delay in the sector. Benefits could be much higher due to the exponential nature of this relationship.
- In L2KBC there was no delegation of workload from executive controller to planner controller. Other studies indicate that increased productivity can result by reallocation/sharing of duties between the two controllers. [12] [13]
- There may be additional benefit because data link greatly reduces problems due to language barriers.
- L2KBC simulation modeled only four of the nine services included in the LINK 2000+ master plan
- The L2KBC-modeled day had twice the average delay for the year.

5. Data Link Model Structure

C/AFT transition logic diagrams [10] were used to frame the data link investment analysis (Figure 5.0-1). This analysis dealt with delay reduction benefits using data link services in surface operations (reduced schedule uncertainty) and in the en route phase of flight. Figure 5.0-1 summarizes the en route delay reduction impacts demonstrated in the LINK 2000+ Business Case Simulation (L2KBC) and places them in the context of C/AFT transition logic diagrams. Figure 5.0-2 shows the airport delay reduction benefits in the form of reduced turn-around time.

There is potential for data link enabled benefits in subsequent operational enhancement steps of these figures, as well as in other phases of operation. Data link is essential for future CNS/ATM applications. Unfortunately it is not possible to model the value of data link in future applications in this probabilistic model, thus the option value of being positioned to take advantage of savings from incremental future operational enhancements is not quantified. Other benefits not captured in this model include loss of revenue due to alternative forms of transportation, and exponential capacity savings due to the non-linear nature of delay.



En Route Capacity Transitions

L2KBC baseline. Datalink used for Clearances, Transfer of Comm, and state information.

L2K Business Case Simulation

- Area-wide services in High Traffic Level en-route airspace, including: ATC Communications Management, ATC Clearance, ATC Microphone Check, Controller Access Parameters
- Execution times were measured for typical controller communication tasks.
- Reduced execution times with data link led to reduced communication overhead for the controller, thus increased capacity / reduced delay in the sector.
- Delay reduction varies by equipage level:
  - 25% equipage ==> 10% delay reduction
  - 50% equipage ==> 31% delay reduction
  - 75% equipage ==> 44% delay reduction
  - 100% equipage ==> 53% delay reduction

Figure 5.0-1. L2KBC and C/AFT Transitions

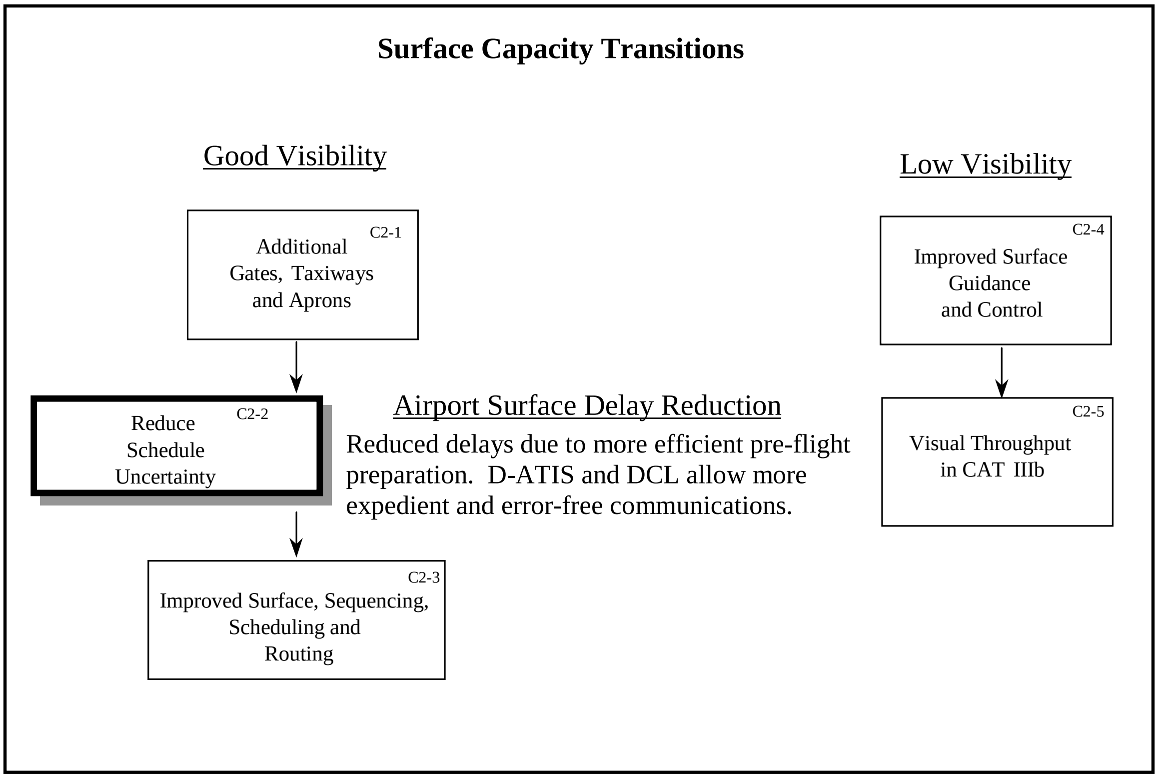


Figure 5.0-1. Airport Delay Reduction and C/AFT Transitions

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 A). 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.

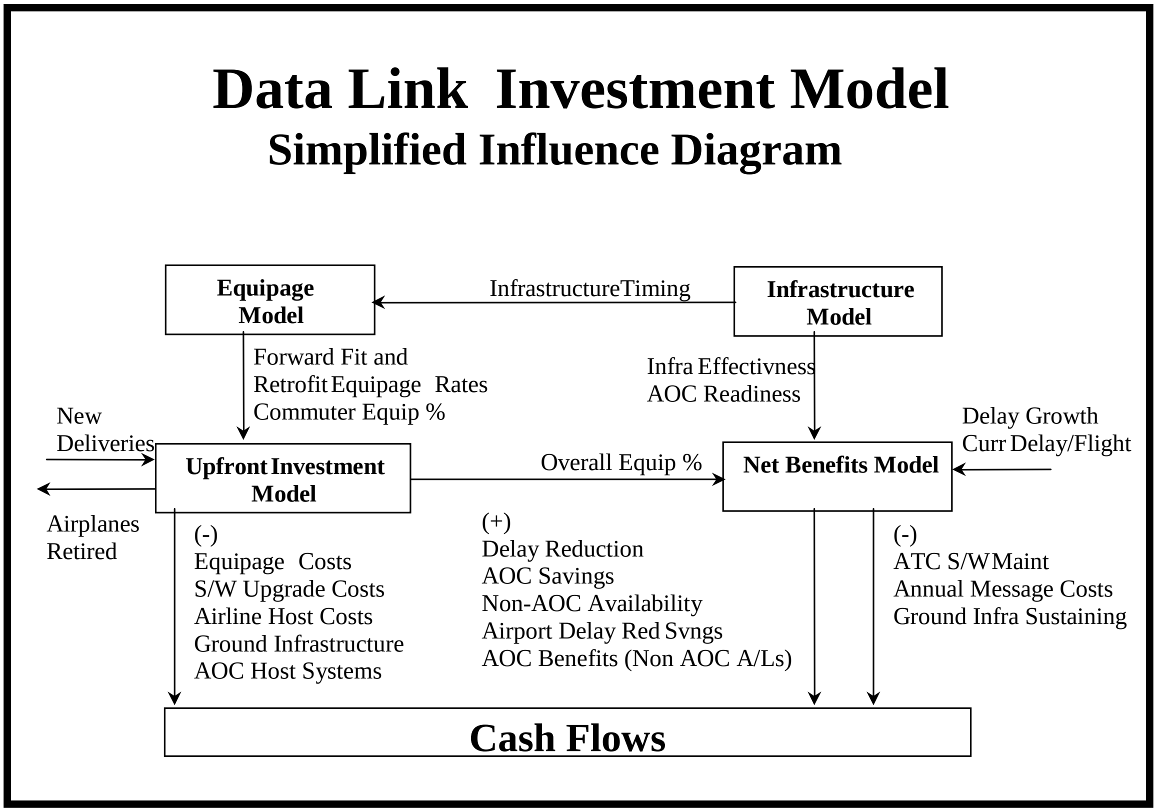


Figure 5.1-1. Data Link Investment Model

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, some of which are shown in Appendix B. Other constants are listed in the sections where they apply. The model starts in 2000, and 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 discount rate is 12%, and the inflation rate 2%. Consensus was that the cost of fuel will increase at a higher rate than inflation, thus the DOC includes a fuel component (15% of DOC) with a 5% increase per year.

5.2.2 Traffic and Delay Growth

Traffic and delay growth input data are shown in Appendix C.

BACKGROUND:
Costs and benefits were calculated for scheduled airlines flying 70+ seat airplanes in Europe. Aircraft types falling into this category include: Avro RJ and BAe 146 series, BAC 1-11, Fokker jet series, Airbus A319, 320, 321, Boeing 727, 737, 757, MD80, Airbus A300, 310, 330, 340, Boeing 747, 767, 777, DC10, MD11, Lockheed L-1011 Tristar. The number of these airplanes in the model is an extrapolation for the year 1999 of a figure cross-checked with several sources (EUROCONTROL and European Union, including the 8.33 kHz Program, EGNOS Project, RVSM Program, Emerald Project, CRCO Statistical Data Base).

Commuter airplanes are also included in the model for the purposes of determining total data link equipage levels, but costs and benefits are not calculated for these planes.

The model bases traffic growth on the baseline of 4443 Total Number of 70+ seat Airplanes. Traffic growth assumptions retained in this report are based on the baseline scenarios from reference [11]. Each year the cumulative planes are calculated by adding new deliveries and by retiring a certain number of airplanes. For simplicity the number of commuter airplanes equipped with VDL Mode 2 is expressed as a percentage of the 70+ seat airplanes equipped.

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

Low Estimate (10% case):	5721
Medium Estimate (50% case):	6104
High Estimate (90% case):	6253

Delay was assumed to grow at different rates at different times in the model, as shown in Table C-3. The model assumes a very high delay growth per year, based on EUROCONTROL's ATFM delay variation for 1997/1998 and *Medium-term Capacity Shortfalls* study [6], and that from 2005 -2010 delay growth slows down due to planned operational improvements planned in the EUROCONTROL ATM 2000+ strategy [15]. After 2010 both delay and traffic growth are capped in the model. The rationale for this is as follows:

> ATS/ATN Data Link (as LINK2000+) is a limited (first step) implementation of Air Traffic Services Data Link functionality. The investment and functionality will only have a limited lifetime. The gate-to-gate capacity improvement and related efficiency and punctuality enabled by ATS D/L will not be sufficient to provide the capacity needed to match the demand. Other CNS/ATM functionality is in development stages, both as additional subsets of ATS/ATN D/L or as other functionalities like Airborne Separation Assurance System (ASAS) (such as ADS-B, etc.).
>
> The capacity improvement as enabled by LINK2000+ functionality, although expressed as percentage, is related to the present capacity. There is no modeling or real time simulation that indicates that this percentage can be used for 2005/2010/2020 traffic levels.
>
> We do know/have:
> - The present (European) ATC delay levels (delay in percentage of flights and delay per delayed flight)
> - Air traffic growth prediction numbers
> - Indication that delay will grow exponentially in relation to traffic growth.
> - Indication from the L2KBC simulation that based on a 1999 traffic density scenario, a reduction of controller workload can be attributable to the implementation of a data link, and that workload reduction can be translated into an increase capacity of the airspace and a concomitant reduction of air traffic delay.
> - Indication that other CNS/ATM technologies will contribute their share in

the future.

We do not know/have:

- A well-founded rationale that reduction of delay with LINK 2000+ functionality is proportionally related to traffic increase (on the contrary, LINK 2000+ real time simulations show an increase in controller workload in a 200% traffic density scenario)
- While it is true that for the 200 % workload the simulations showed an increase in controller workload, we also don't know where the break point is – i.e. the point where the workload begins to increase.

With a predicted air traffic growth of 100% related to 1997 traffic levels and the predicted delay increase in a do-nothing scenario, we do have a margin of improvement in which we can reap the benefits of LINK2000+. It is reasonable to assume though, that by 2010 other capacity-enabling functionality will have to be introduced to provide the extra capacity in excess of what LINK2000+ is providing (this could even be an extension of LINK 2000+ functionality: Baseline 2).

Therefore, we assumed that the benefit attributable to LINK2000+ would not increase after 2010, simply because LINK2000+ is not the only capacity provider and that other infrastructural/avionics investments will have to be made to provide the capacity needed. Only the cost of implementing LINK2000+ is estimated, we have to model the benefit related to the presently defined LINK2000+ functionality.

5.2.3 Infrastructure

Three kinds of ground infrastructure are required before benefits can be achieved: the ATN VDL Mode 2 network infrastructure, local services at Air Traffic Control Centers, airports, and area-wide services in en route. The airport infrastructures are assumed to be ready at the start of the model, and the ATN VDL Mode 2 infrastructure is assumed to be ready in 2001. This analysis assumes that airlines will not equip with ATN VDL Mode 2 for en route delay reduction benefits until the ATC infrastructure is ready.

Infrastructure stages are shown in Appendix D. Stage 1 includes benefits from AOC applications and airport ATC services. Stage 2 includes area-wide en route services in high-level traffic areas (HLTA) of Europe, in addition to the AOC and ATC benefits from Stage 1. Stage 3 expands the benefits of Stages 1 & 2 to additional HLTAs (the number of HLTAs will grow over time, as traffic is increased). The stages do not overlap.

The effectiveness of the infrastructure for each stage is quantified by determining the number of airplanes that are equipped with ATN VDL Mode 2, and the number of flights through airspace with the appropriate services available (expressed as a percent of flights 'covered'). The infrastructure effectiveness numbers are met at the end of the stage with a linear ramp-up during the stage duration.

5.2.4 Equipage

The model assumes three different types of jet airplanes in the total population, as shown in Appendix E, and each will equip at different rates. The three types are: 70+ seat airplanes that are ACARS AOC-equipped; 70+ seat airplanes that are not data link-equipped; and commuter airplanes.

There is a significant portion of European airlines that do not currently use data link for AOC. The model assumes that some of these will transition to VDL Mode 2 either for more efficient AOC operations or to receive the ATC delay reduction benefits. The number of non-ACARS-equipped planes and their retrofit rates are expressed as a percentage of ACARS-equipped plane rates.

Commuter airplanes are included in the model for the purposes of determining total data link equipage levels, but costs and benefits are not calculated for these planes. The number of commuter airplanes equipped and retrofit rates are also expressed as a percentage of ACARS-equipped plane rates.

It was assumed that AOC frequency congestion would drive forward fit and retrofit rates early in the model, and that ATC delay reduction benefits will drive equipage at the later stages. The model assumes that all new airplanes added (as traffic growth per Section 5.2.2) will be forward fit-equipped.

5.2.5 Non-Recurring Costs

Three kinds of costs are modeled: 1) airline equipment costs for AOC and ATC, 2) AOC host costs, and 3) airline training costs, all of which are summarized in Appendix F.

Airline Equipment Costs

Airline airborne equipment costs assume avionics and flight deck impact, and would involve the Communication Management Unit (CMU - ARINC 758), VHF Digital Radio (ARINC 750), a dedicated display, and airplane wiring. The Flight Data Recorder would also be affected because of the ICAO Annex 6 requirement to record all digital communications. In addition upgrades will be required to support CAP functionality.

It is assumed that the VDL Mode 2 ACARS over Avionics VHF Link Control implementation will meet requirements for AOC data link, 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).

Equipage cost estimates in the model are average costs assumed across all airplane models, and are not model-specific, but have different values depending on whether or not the airplane was originally ACARS-equipped. The range in equipage cost variables is due to the risks inherent in airborne avionics and aircraft modifications, and is wide enough to include all associated costs such as upgrade of data recorder or other airplane systems. In reality, airplanes equipped with 8.33 kHz radios will have different equipage costs, but that too is represented in the range of the cost variables.

AOC Host Costs

In addition to the airborne equipment, airlines currently using ACARS AOC will have to upgrade their AOC host or AOC router. Those not currently using ACARS AOC will have to pay for the total cost of a new AOC host.

Training

Training costs represent the cost of simulator upgrades, but do not include changes in crew training time.

5.2.6 Benefits and Recurring Costs

The model quantifies benefits related to AOC operations and to ATC delay reduction, and subtracts recurring costs from the benefit total, as summarized in Appendix G.

Figure 5.2.6-1 summarizes the European benefits in the model and how they are applied. The purpose of this matrix is to map the benefits to the population of airplanes that receive them. This analysis is complicated by the fact that we have included airlines that do not currently use ACARS AOC as well as those that do. The "AOC Message Savings" and "AOC benefits for non-ACARS airlines" benefits are dependent on the baseline, either ACARS or non-ACARS. All other benefits can be applied based on VDL

Mode 2 equipage because they are obtained independently of the ACARS baseline. The specific benefit mechanisms are discussed below.

	VDL-2 Equipage Baseline		ACARS or non-ACARS Baseline			
Benefits	**VDL-2 Equipped**	**Non VDL-2 Equipped**	**ACARS Baseline Equipped**	**ACARS Baseline Non-Equipped**	**Non-ACARS Baseline Equipped**	**Non-ACARS Baseline Non-Equipped**
ATC Delay Reduction						
Airport Delay Reduction	X	X	X	X	X	X
En-Route Delay Reduction	X	X	X	X	X	X
Recurring Costs (negative benefit)						
ATC Message Costs	X		X		X	
ATC SW Maint Costs	X		X		X	
Infrastructure Costs	X	X	X	X	X	X
AOC Benefits						
AOC N/A Avoidance	X		X		X	
AOC Msg Savings			X			
for non-ACARS baseline airlines that equip					X	

Figure 5.2.6-1. Benefits Matrix

AOC Benefits

There are three AOC benefit mechanisms modeled in this analysis. One is related to efficiencies inherent in VDL Mode 2 operations, one with the value of AOC operations to the airlines, and the last has to do with the value of data linked AOC to airlines that are not currently ACARS-equipped. 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.

VDL Mode 2 is a binary-oriented system, as opposed to character-oriented for ACARS, 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. This was not higher 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.

As stated in Section 3.0, SITA has stated that without VDL Mode 2, ACARS AOC service will break down in the 2003/2004 timeframe. AOC operations are extremely valuable to the airlines and the non-availability of AOC data is a high cost item. Use of VDL Mode 2 allows the airline to avoid paying the cost of AOC non-availability. The model assumes an AOC N/A cost-avoidance benefit with a large range in value due to the uniqueness of each airline's AOC operations.

For airlines that are not currently using ACARS it is assumed that there would be a benefit to transitioning to VDL Mode 2 data link for AOC operations. This is a difficult value to estimate, so was assumed to be equal to the current average AOC cost per flight segment for the ACARS -equipped airlines.

ATC Delay Reduction

ATC-related benefits are taken as delay minutes reduced and quantified using Direct Operating Costs (DOC) per minute saved. In order to keep the model at an airline-industry level, and therefore very high-level, we were not able to model more complex delay reduction benefit mechanisms, such as increased revenue, increased number of available slots, reduced number of missed connections, or customer perception of air travel.

ATC delay reduction benefits occur in three stages. Stage 1 consists of local services at airports: Departure

Clearance and Digital-ATIS. Stage 1 airport delay reduction benefits are based on a per-flight surface delay savings and were based on airline estimates of actual savings. These benefits are applied to equipped airplanes only.

Stages 2 & 3 are area-wide services in en route: ATC Communications Management, ATC Clearance, ATC Microphone Check, and Controller Access Parameters. Stages 2 & 3 differ only in the number of airplanes receiving benefits. Stages 2 & 3 en route ATC delay reduction benefits are based on results from EUROCONTROL's L2KBC simulation (discussed in Section 4) where ATC productivity was increased, and airline delay decreased, by using data link to reduce voice frequency congestion. These benefits are applied to all 70+ seat airplanes in the model.

There is some uncertainty inherent in any simulation, thus the model applies what is called the "European discount factor" (alternatively called the “European Scaling Factor”). This variable discounts the L2KBC delay reduction estimates at 100% equipage (53% delay savings per flight) by 30 – 80%. This range is large because we don't have calculated results for increased traffic densities over today's levels.

Delay savings are dependent on equipage levels, as indicated by the L2KBC simulation results. The model uses a curve of the 'achieved' delay vs. equipage level. Achieved delay reduction at varying equipage levels is normalized to L2KBC results at 100% equipage, i.e. how much of the total possible delay reduction is achieved. The achieved delay reduction at 75% equipage, for example, is .44 / .53, or 83%. Table 5.2.6-1 and Figure 5.2.6-1 show achieved delay reduction at varying equipage levels.

In addition, the model assumes that a minimum level of equipage (25%, 30%, 35%) must be reached before benefits are achieved.

En route ATC delay savings are a function of the percentage of equipped planes, delay savings per flight, actual delay minutes per flight each year, and direct operating costs. Delay savings are calculated using the following formulas:

Percent Equipped Planes = Cumulative Equipped Planes / Total Planes
Delay Savings per Flight = L2KBC Delay Svngs per Flt * European discnt factor * (1+Delay Growth per Yr)^Yr
Value of Delay = Delay Savings per Flight * DOC per minute * Total Planes * Flights per Year per Airplane

Final delay savings are 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 en route delay reduction benefits because the mechanism for benefit in the L2KBC simulation (reduction in voice congestion) affects all airplanes, not just those equipped. European authorities have 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.

% Equipage	Delay Reduction	Achieved Delay Reduction
0%	0%	0%
25%	10%	19%
50%	31%	58%
75%	44%	83%
100%	53%	100%

Table 5.2.6-1. Achieved Delay Reduction vs. Fleet Equipage

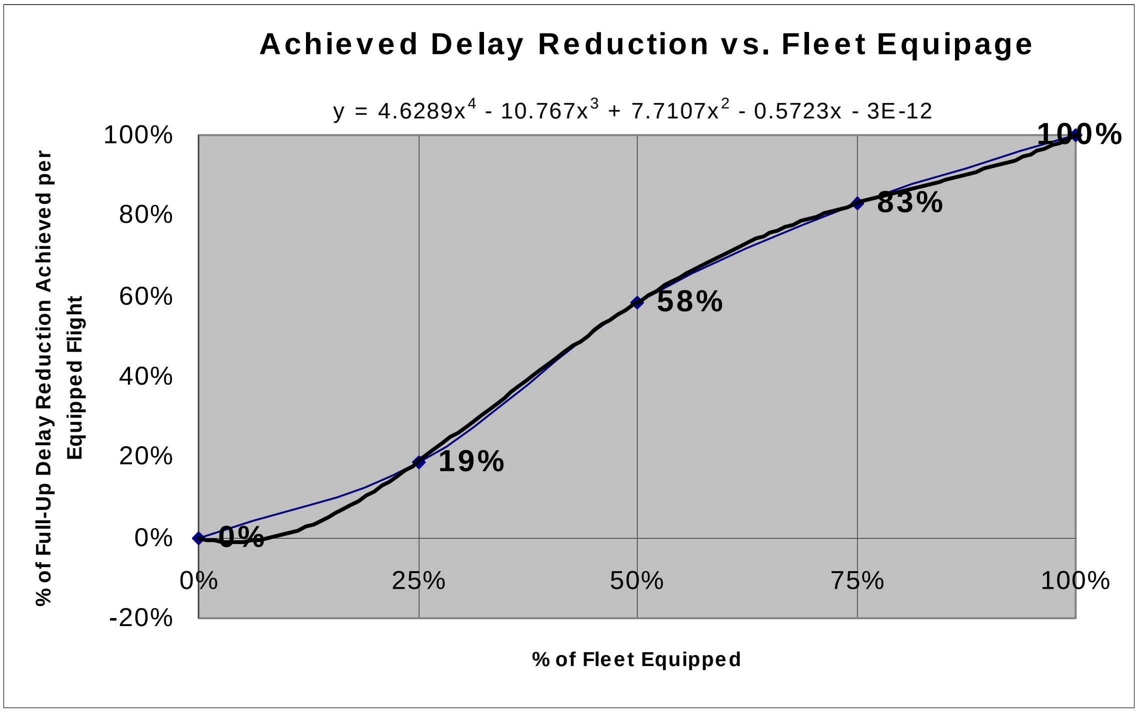


Figure 5.2.6-1. Achieved Delay Reduction vs. Fleet Equipage Curve

Recurring Costs

Recurring costs are treated as negative benefits, and are shown in Appendix G. There are three kinds of recurring costs modeled: ground infrastructure sustaining costs, ATC message costs, and ATC software maintenance.

Ground infrastructure sustaining costs are used to represent route charges to the airlines for the airport and en route data link services. Ten percent of the total implementation costs are passed on to all flights, starting at the beginning of each stage.

ATC message costs are calculated using the formula:

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

In addition to the airborne equipment airlines will have to pay maintenance costs on the ATC software.

Most maintenance costs are not modeled because they would have to be incurred even if not equipped with VDL Mode 2, thus there is no incremental cost for the new functions.

5.3 Model Results

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

5.3.1 Full Data Link

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 and ATC message costs are the dominant cost factors, while en route delay savings and AOC non-availability avoidance are the largest benefit factors.

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 Full Data Link 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.

Figure 5.3.1-3 shows that the base case NPV (all variables at their 50% value) is 3060.18 million Euro. The four most sensitive variables are: European Scaling Factor (44.9% variance), Cost per Delay Minute (15.6%), Equipage Scenario (10.7%), and Delay Increase Percent through 2005 (7.2%).

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 Full Data Link case. This figure shows that the expected value is 3540.78 million Euros, there is a 10%

chance the project outcome will be below 1617.68 million Euros, a 50% chance it will be below 3092.86 million Euros and a 90% chance it will be below 6027.98 million Euros. There is no chance for a negative NPV.

Figure 5.3.1-5 shows the cash flow for the Full Data Link case. Figure 5.3.1-6 shows the cash flow for retrofit only, and Figure 5.3.1-7 for forward fit only. The payback period for the overall case is eight years (cash flow does not cross zero until 2008), but there is negligible negative cash flow. In addition, the negative cash flow is small when compared to the long-term benefit potential. The payback period is eleven years for the retrofit only, and twelve years for the forward fit case.

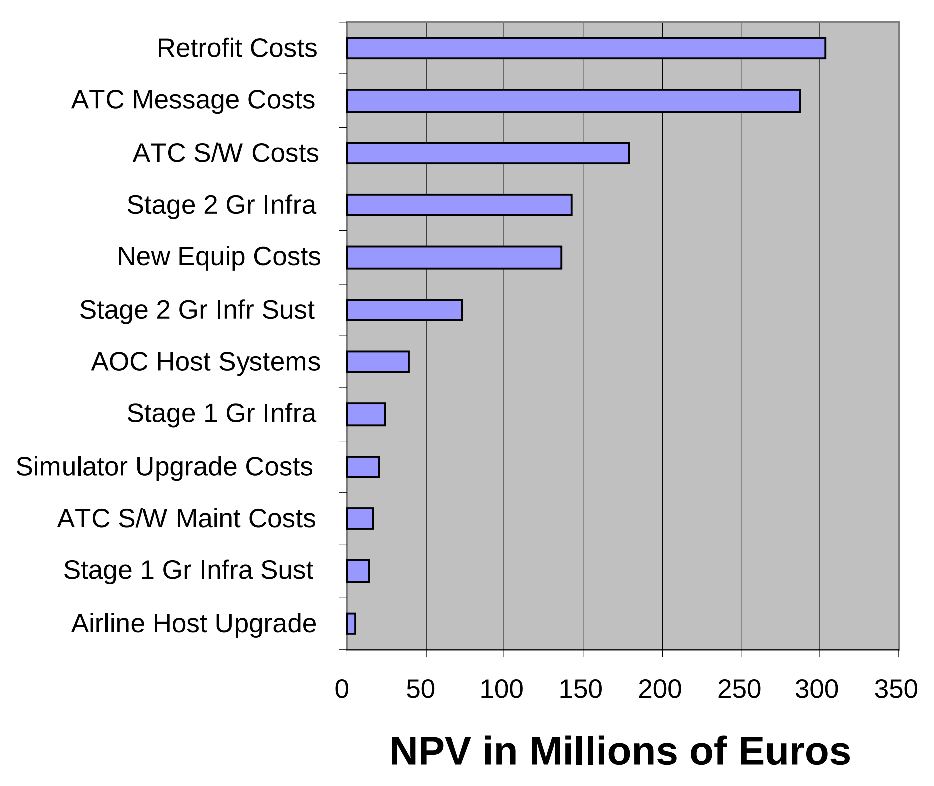


Figure 5.3.1-1. Full Data Link Costs by Category
Link2000+ Geographic Area

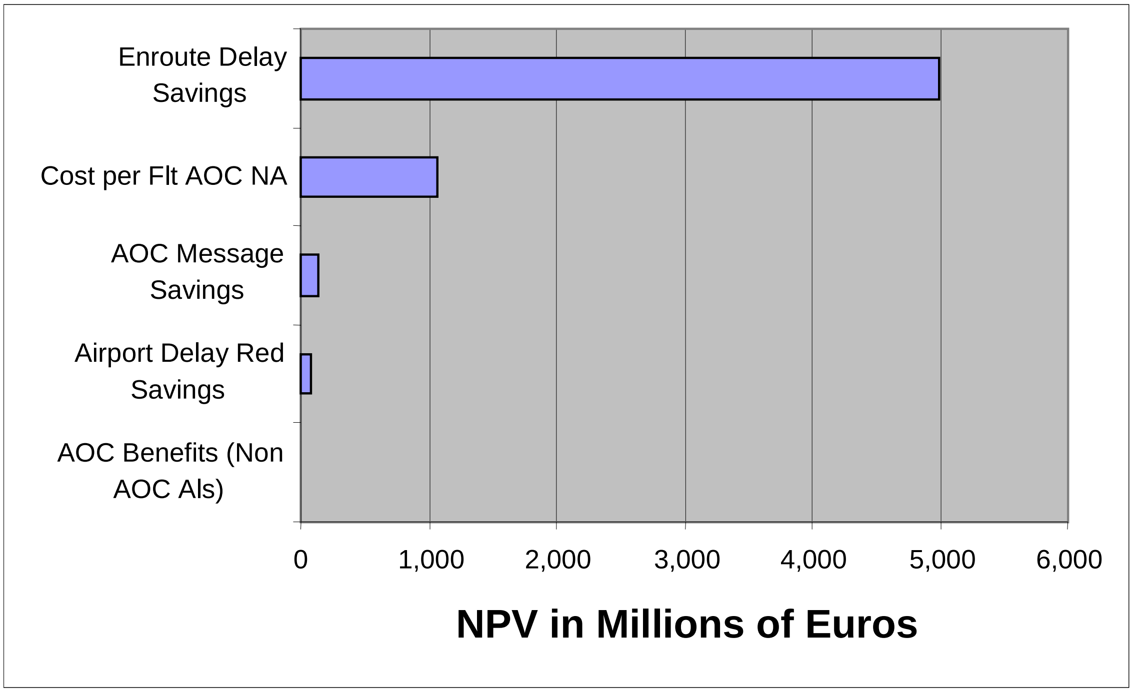


Figure 5.3.1-2. Full Data Link Benefits by Category Link2000+ Geographic Area

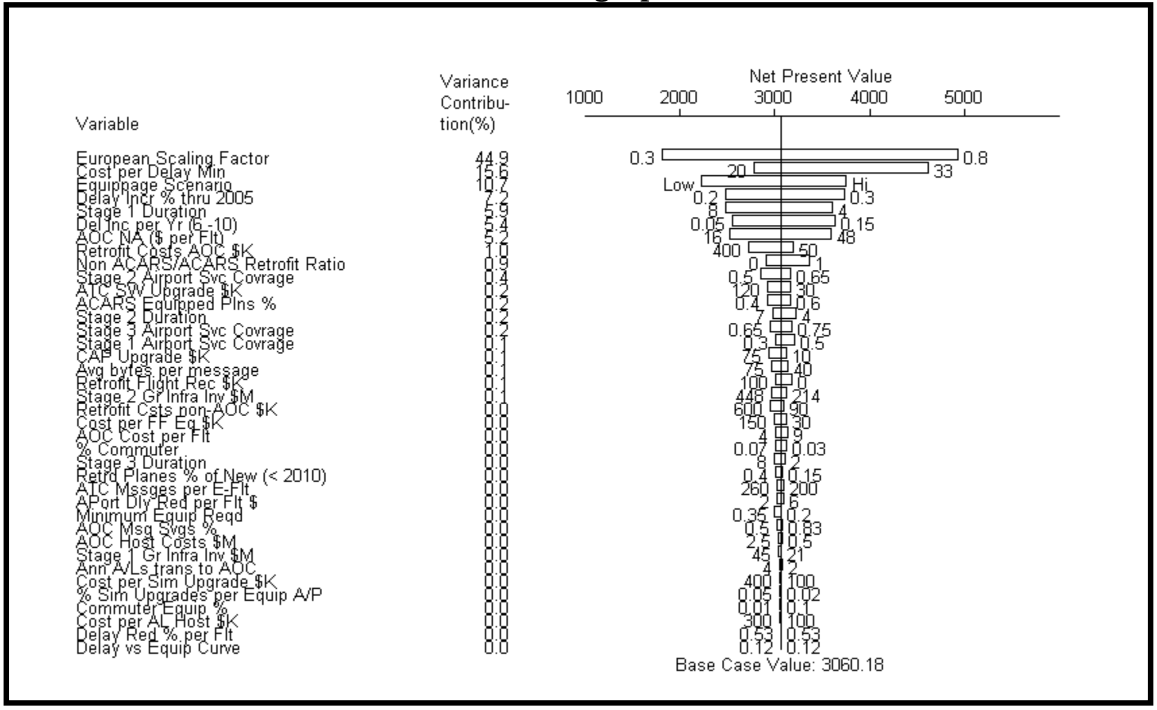


Figure 5.3.1-3. Full Data Link Deterministic Sensitivity Link2000+ Geographic Area, 2000-2020

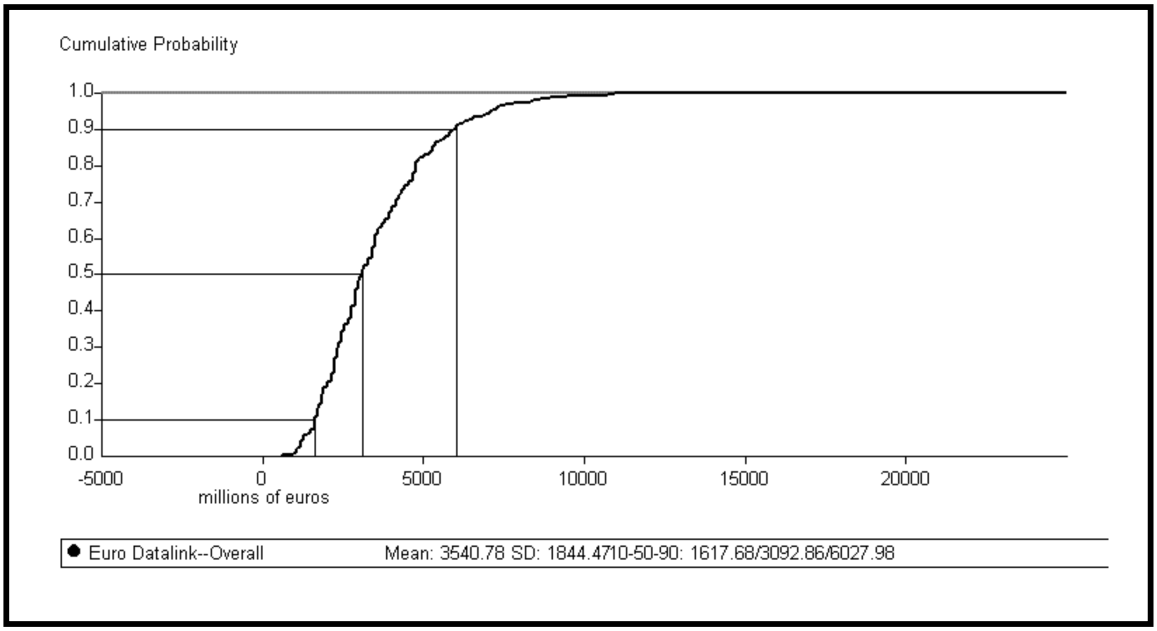


Figure 5.3.1-4. Full Data Link Cumulative Probability Distribution
Link2000+ Geographic Area, 2000-2020

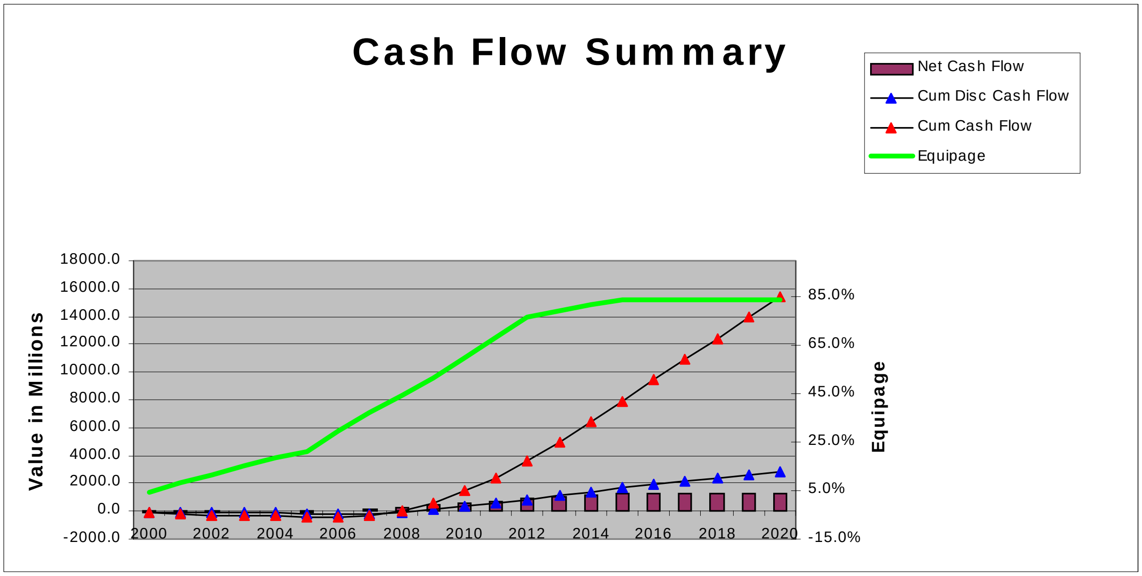


Figure 5.3.1-5. Full Data Link Cash Flow Summary
Link2000+ Geographic Area, 2000-2020

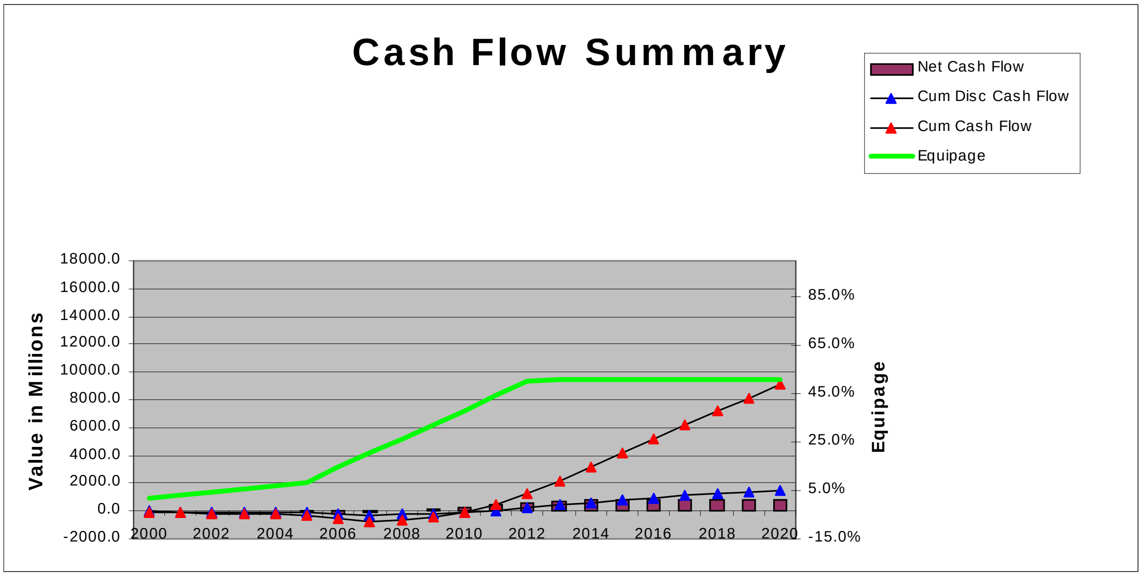


Figure 5.3.1-6. Full Data Link Retrofit Cash Flow Summary
Link2000+ Geographic Area, 2000-2020

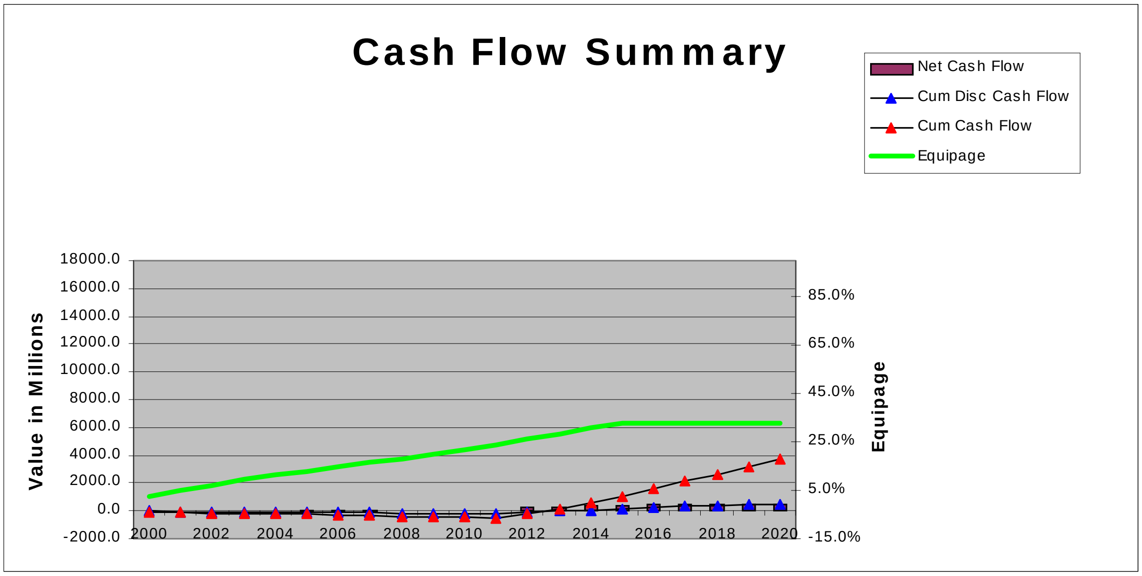


Figure 5.3.1-7. Full Data Link Forward Fit Cash Flow Summary
Link2000+ Geographic Area, 2000-2020

5.3.2 ATC Only

The ATC-Only Data Link case includes ATC benefits only and uses the full equipage levels of Appendix E. Figures 5.3.2-1 and 5.3.2-2 show a breakdown of the NPV of costs and benefits by category. Retrofit equipage and ATC message costs are still the dominant cost factors, and en route delay savings is the dominant benefit factor in this case.

Figure 5.3.2-3 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 1886.99 million Euros. The most sensitive variables are the European Scaling Factor and the cost per delay minute, each of which contributes 39.7% to the variance. The next most significant variable is the Delay Increase Percent through 2005, which contributes 6.3%.

The cumulative probability distribution shown in Figure 5.3.2-4 shows that the expected value is 2012.05 million Euros, there is a 10% chance the project outcome will be below 77.69 million Euros, a 50% chance it will be below 1574.56 million Euros and a 90% chance it will be below 4595.42 million Euros. There is some chance for a negative NPV in this case.

Figure 5.3.2-5 shows the cash flows for the ATC-only 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 2011, at the earliest, and the long-term benefit potential is much lower than in the Full Data Link case. In addition, there is much less long-term benefit potential in both the retrofit only and forward fit only cases.

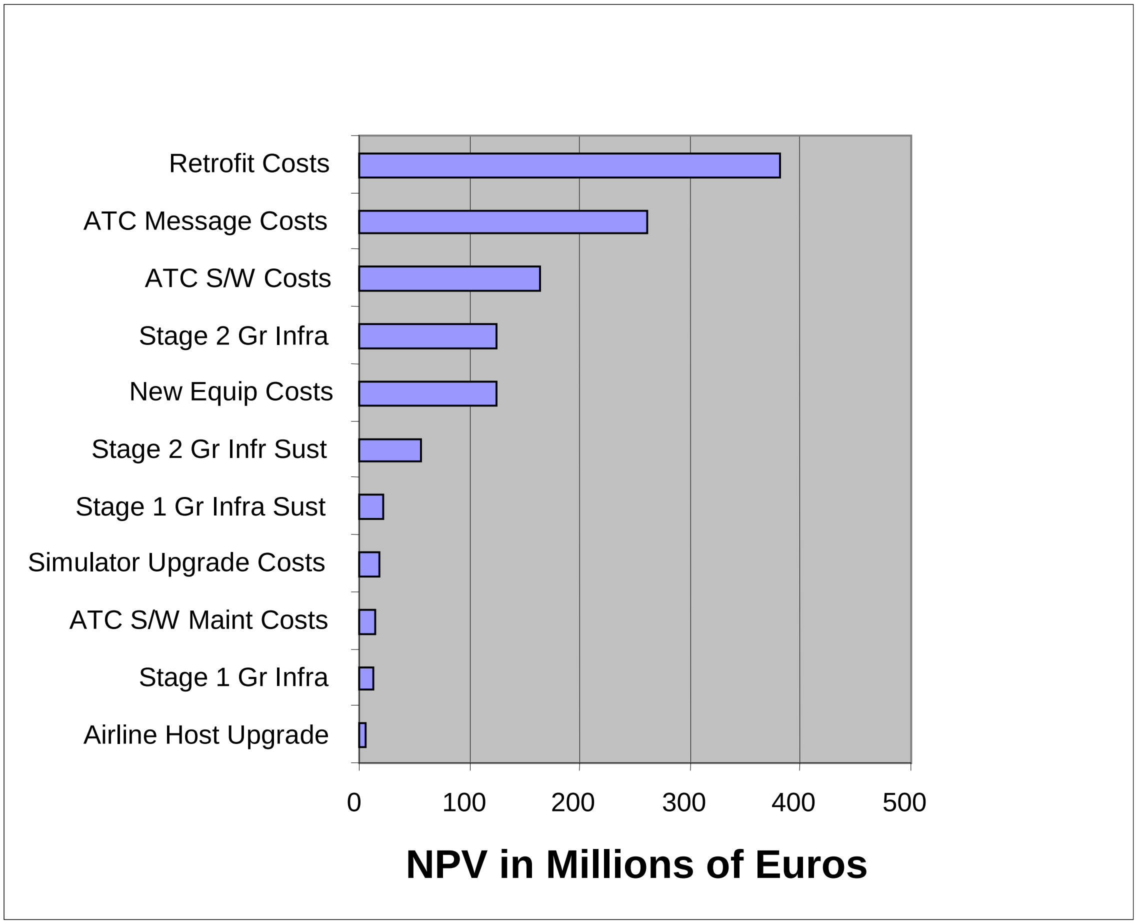


Figure 5.3.2-1. ATC-Only Costs by Category

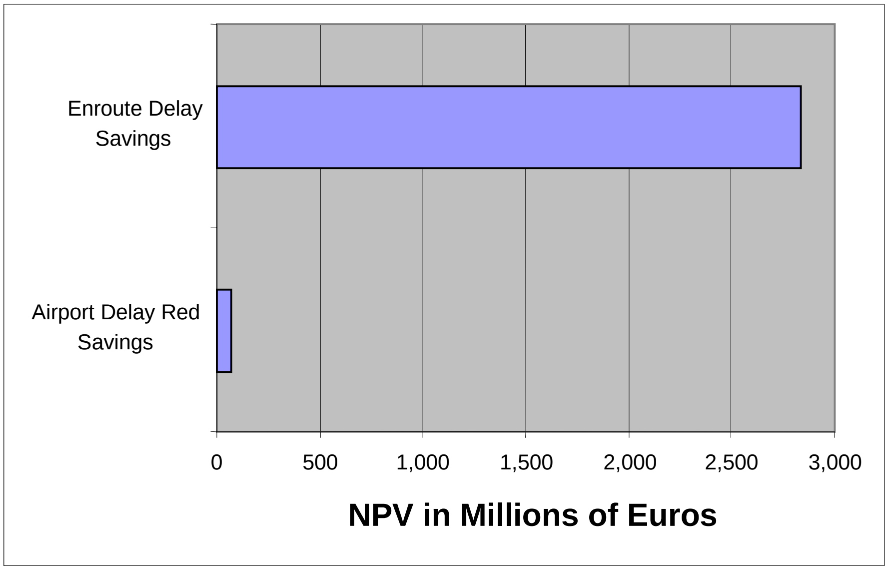


Figure 5.3.2-2. ATC-Only Benefits by Category

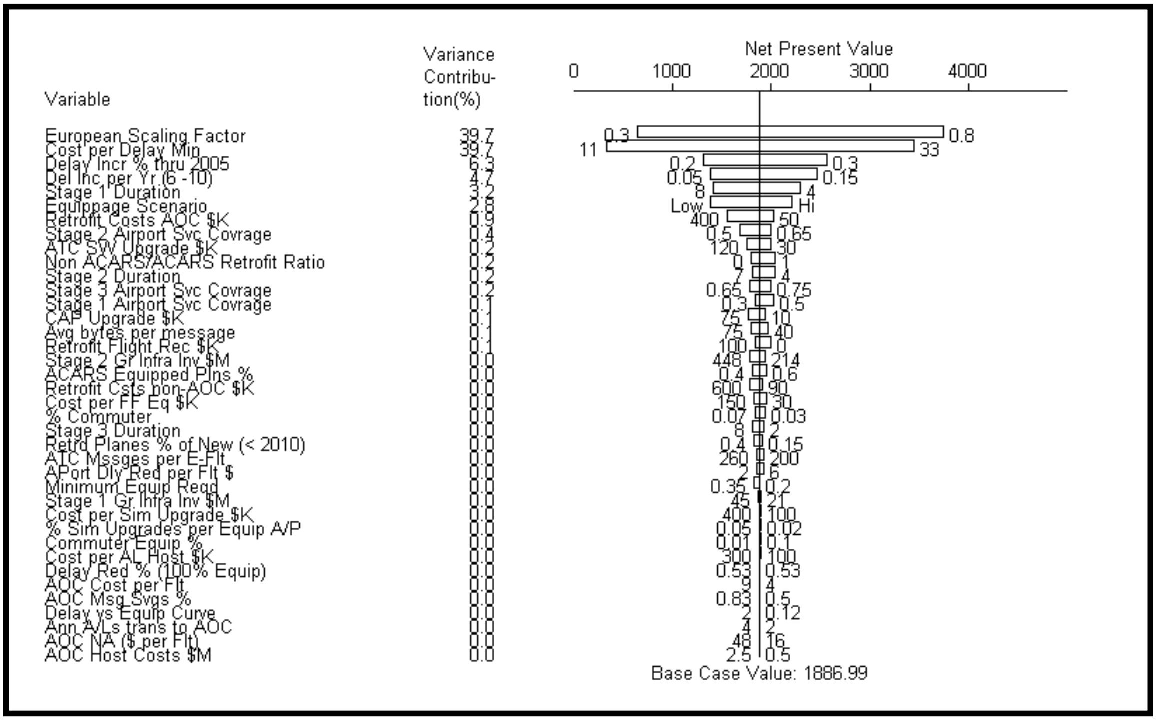


Figure 5.3.2-3. ATC-Only Deterministic Sensitivity

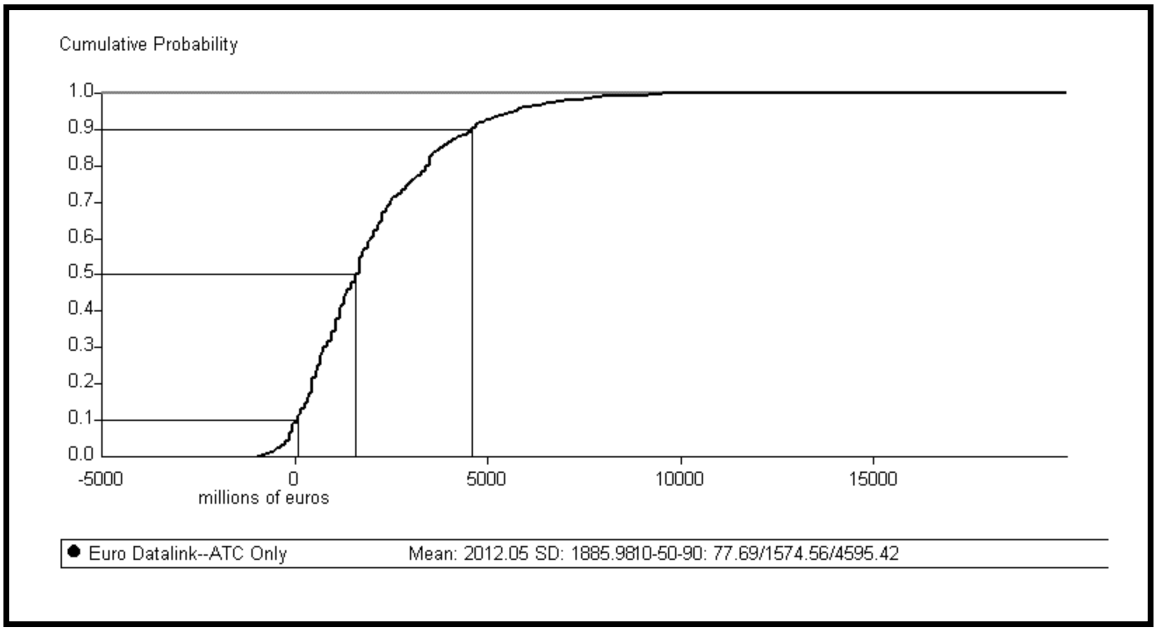


Figure 5.3.2-4. ATC-Only Cumulative Probability Distribution

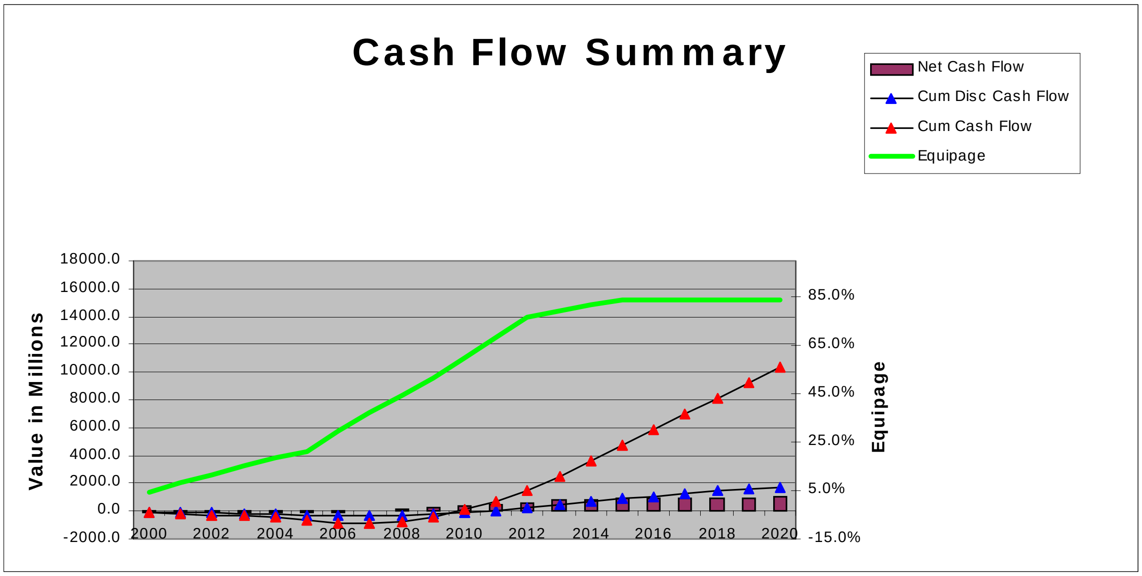


Figure 5.3.2-5. ATC-Only Cash Flow Summary
Link2000+ Geographic Area, 2000-2020

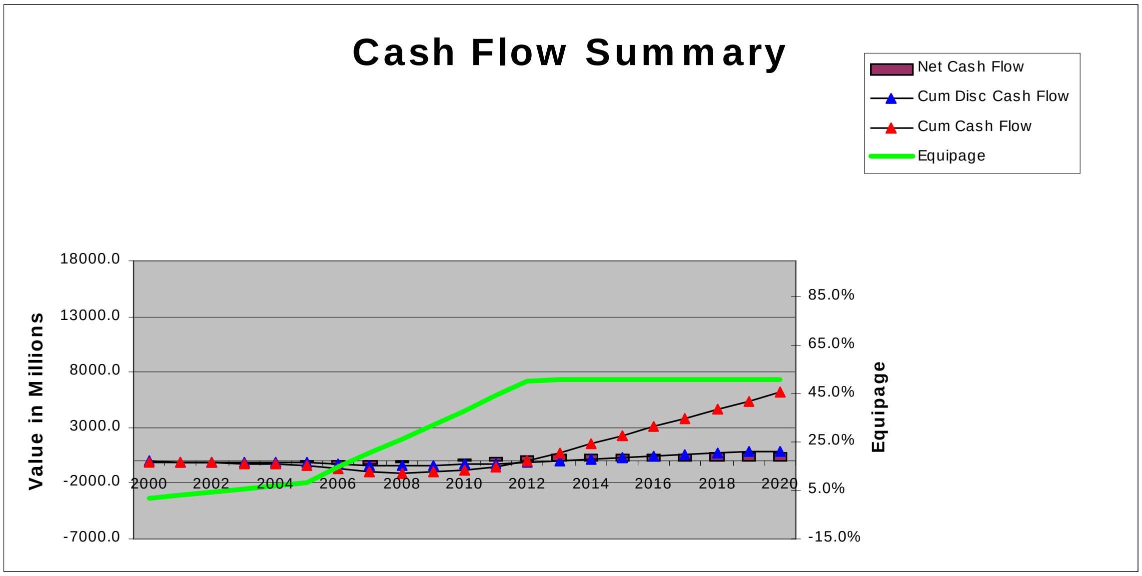


Figure 5.3.2-6. ATC-Only Retrofit Cash Flow Summary
Link2000+ Geographic Area, 2000-2020

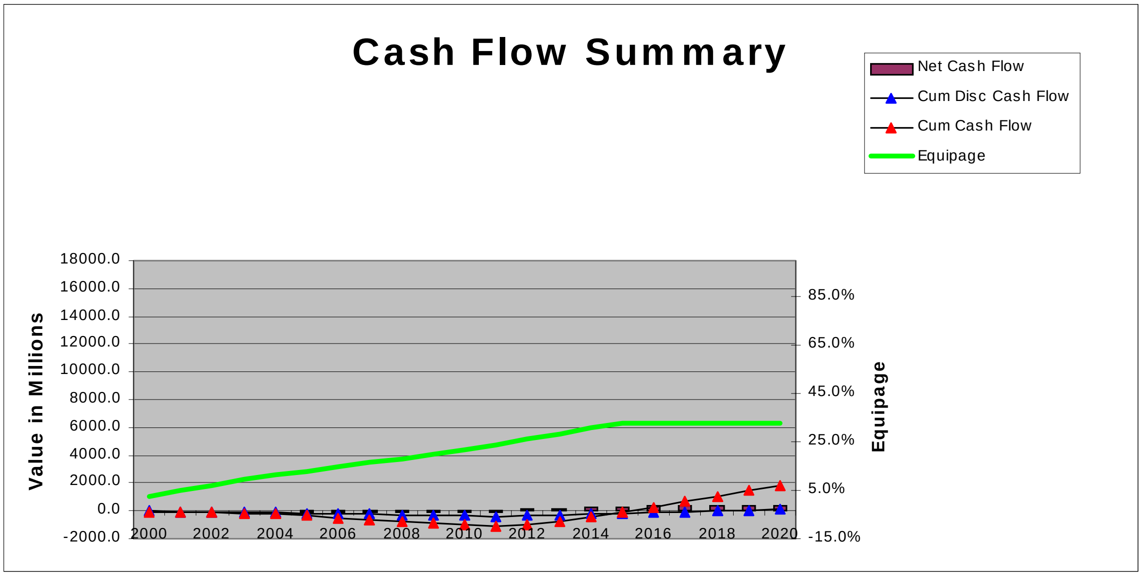


Figure 5.3.2-7. ATC-Only Forward Fit Cash Flow Summary
Link2000+ Geographic Area, 2000-2020

5.3.3 AOC Only

Figures 5.3.3-1 and 5.3.3-2 show a breakdown of the NPV of costs and benefits by category for the AOC-only data link case. Equipage costs are the dominant cost factors and AOC non-availability avoidance is the primary benefit factor.

Figure 5.3.3-3 shows the deterministic sensitivity of the variables included in the AOC-only analysis. In this case, the base case NPV (all variables at their 50% value) is 707.26 million Euros. The most sensitive variables are the AOC non-availability benefit which contributes 67.2% of the variance, retrofit costs (13.4%), and equipage scenario (10.9%).

The cumulative probability distribution shown in Figure 5.3.3-4 shows that the expected value is 632.03 million Euros, there is a 10% chance the project outcome will be below 77.50 million Euros, a 50% chance it will be below 617.59 million Euros and a 90% chance it will be below 1262.58 million Euros. In this case there is a more significant chance of a negative NPV.

Figure 5.3.3-5 shows the cash flows for the AOC-only 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 negligible negative cash in these scenarios, but there is also much less long-term benefit potential than in the full data link and ATC-only cases.

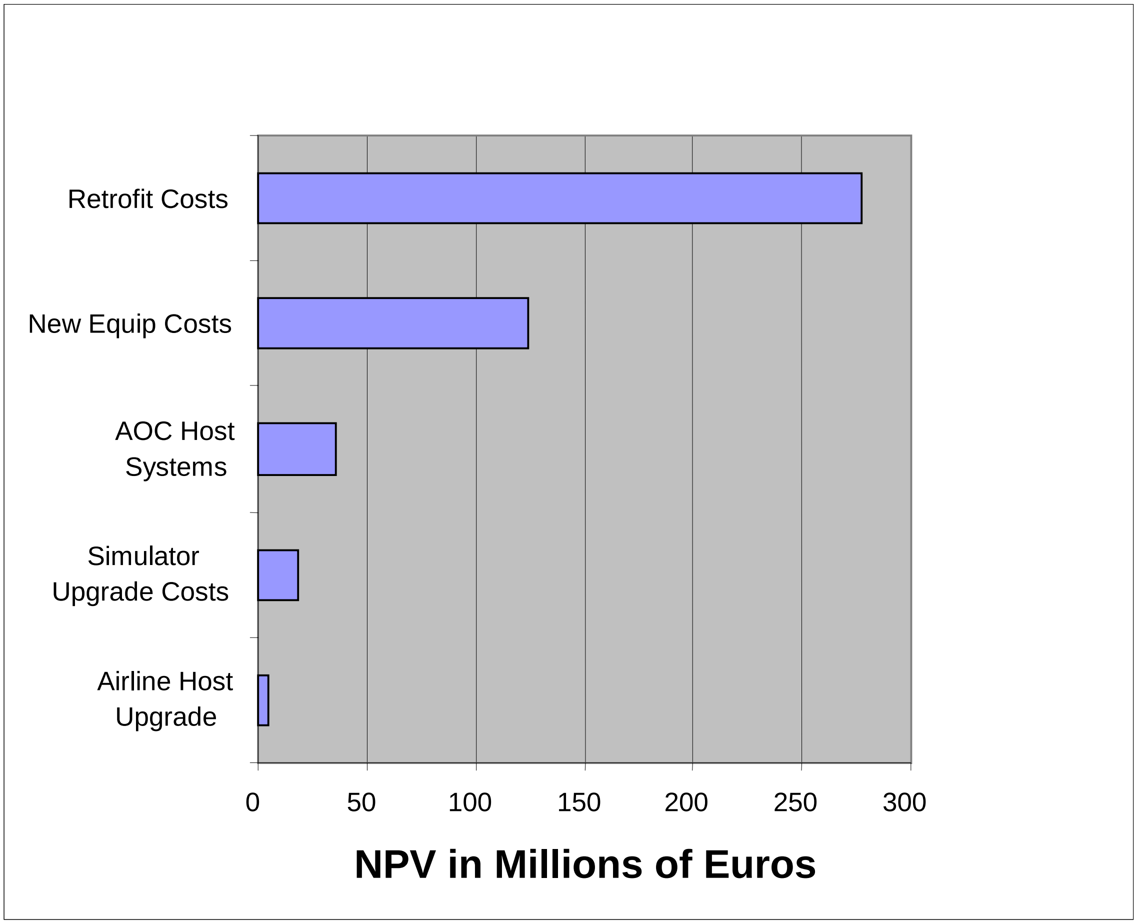


Figure 5.3.3-1. AOC-Only Costs by Category

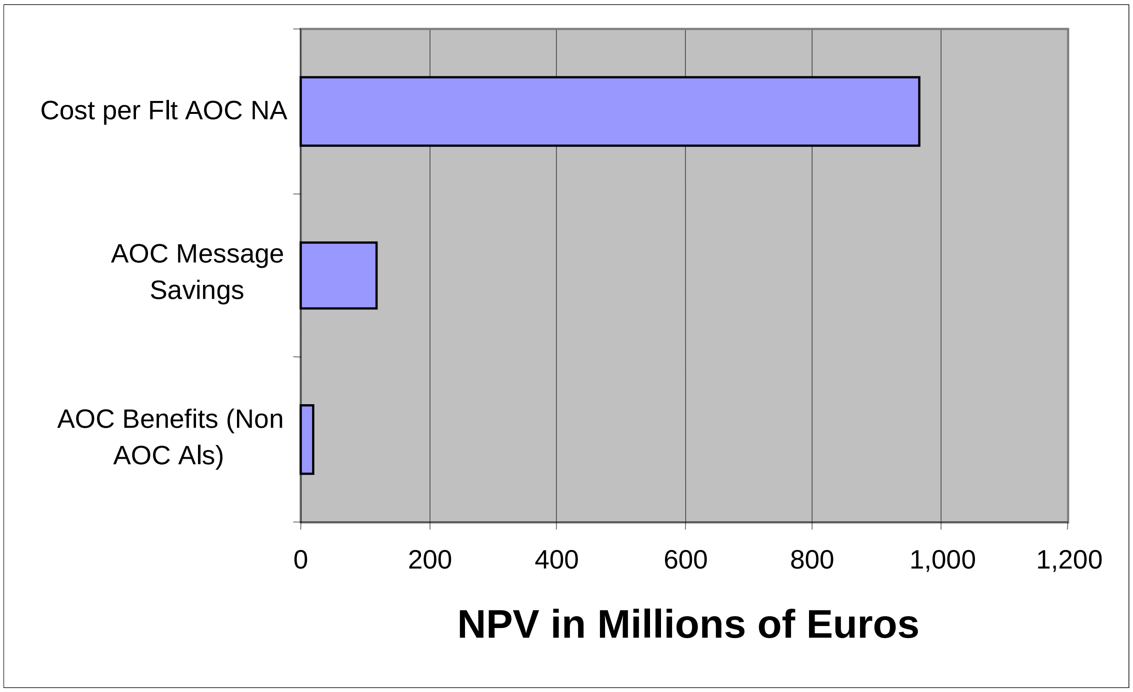


Figure 5.3.3-2. AOC-Only Benefits by Category

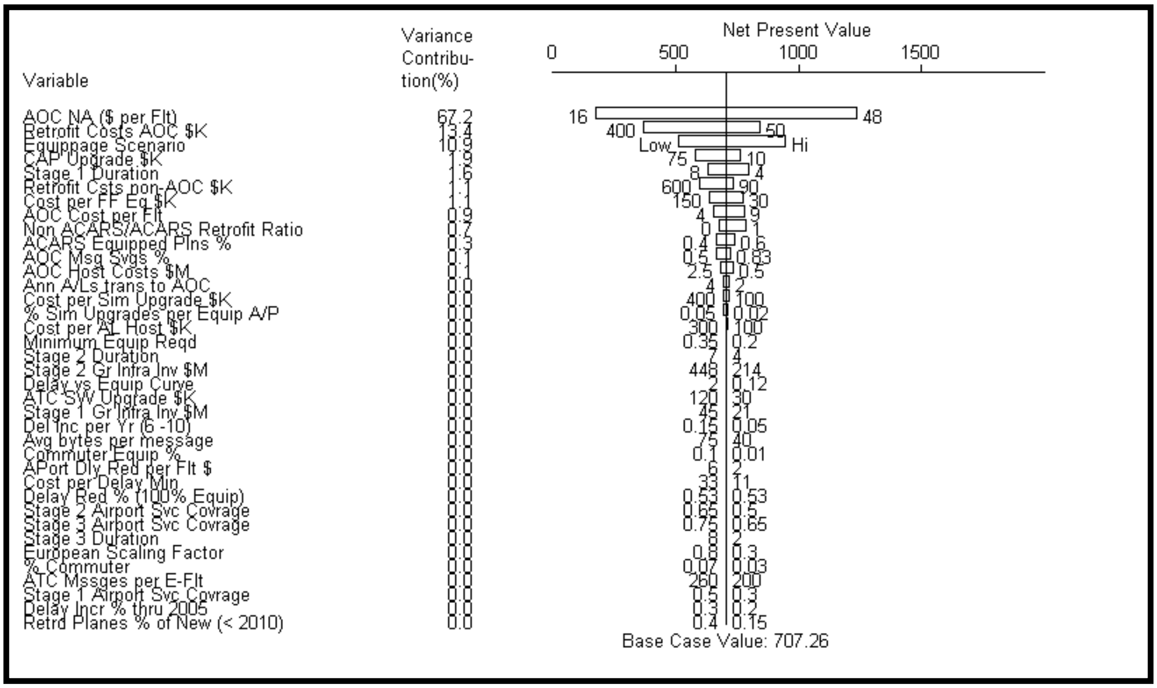


Figure 5.3.3-3. AOC-Only Deterministic Sensitivity
LINK2000+ Geographic Area, 2000 - 2020

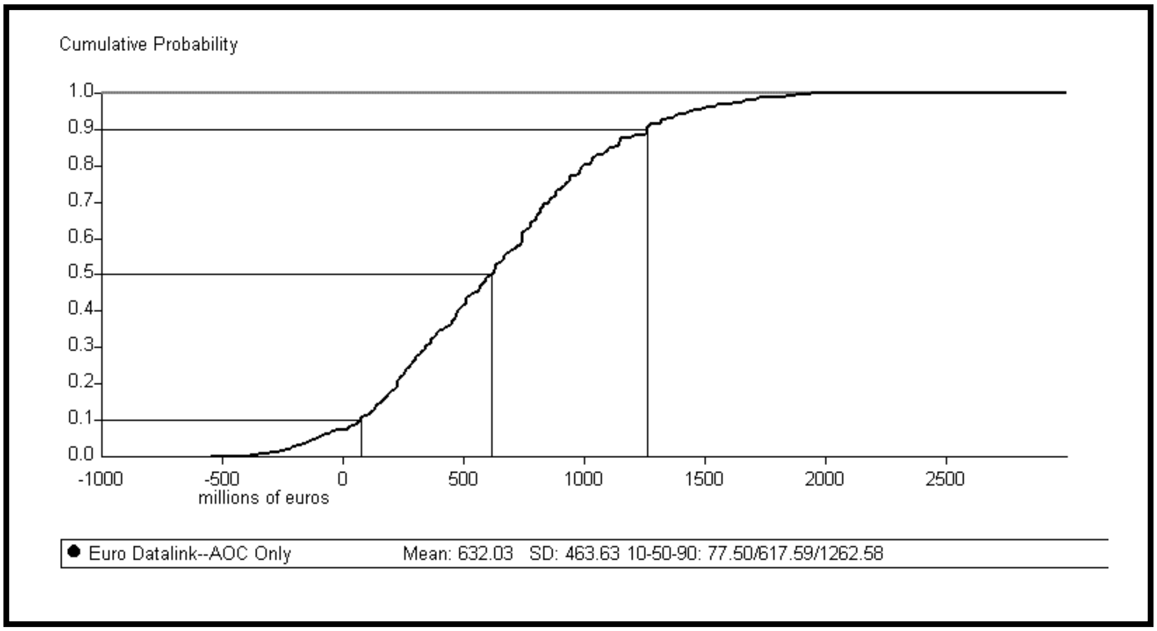


Figure 5.3.3-4. AOC-Only Cumulative Probability Distribution LINK2000+ Geographic Area, 2000 - 2020

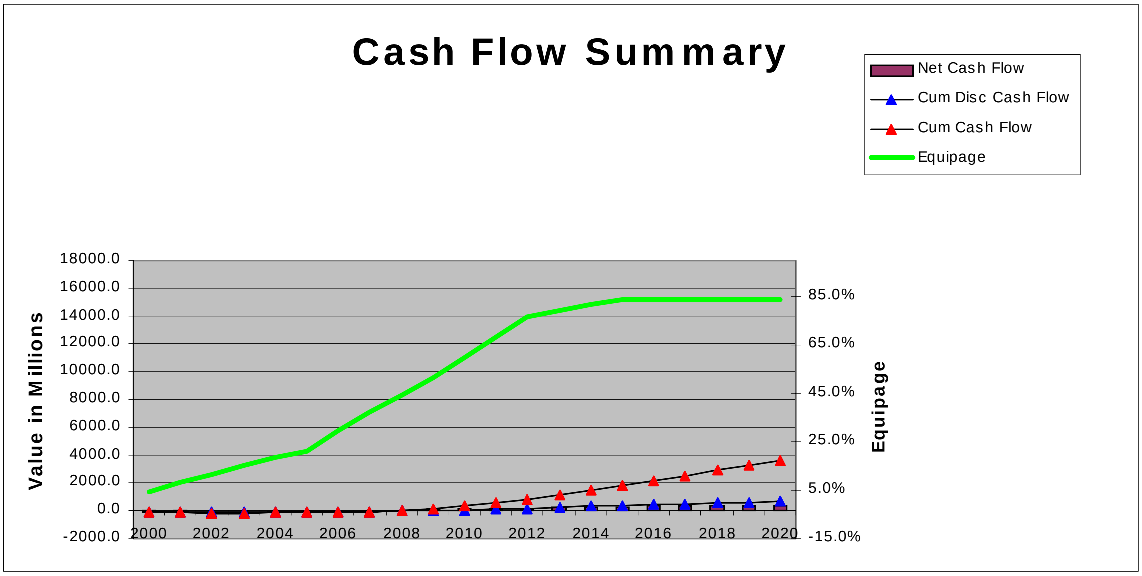


Figure 5.3.3-5. AOC-Only Cash Flow Summary LINK2000+ Geographic Area, 2000 - 2020

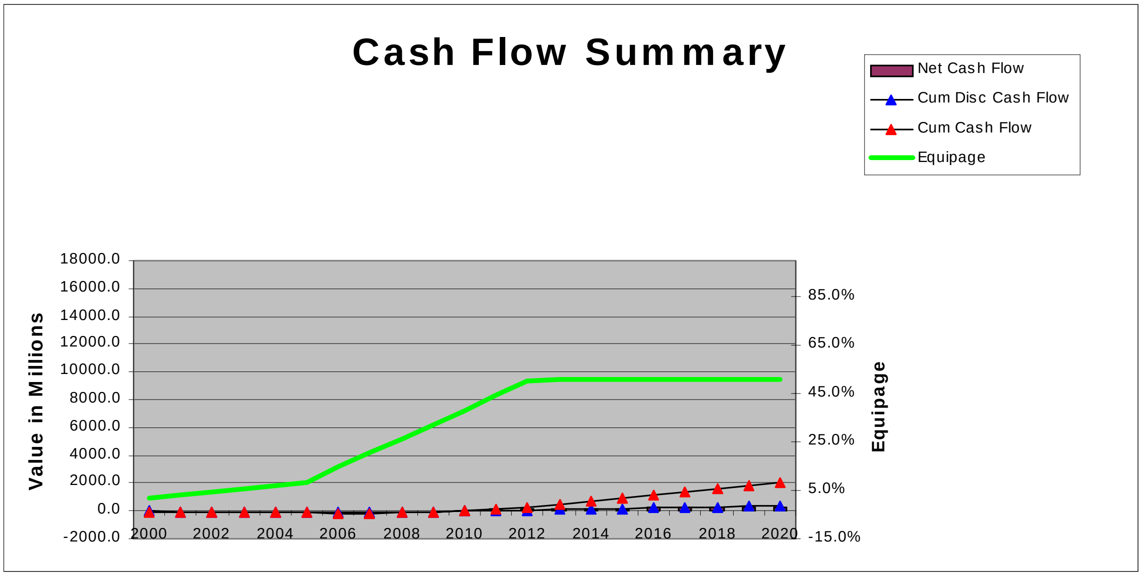


Figure 5.3.3-6. AOC-Only Retrofit Cash Flow Summary LINK2000+ Geographic Area, 2000 - 2020

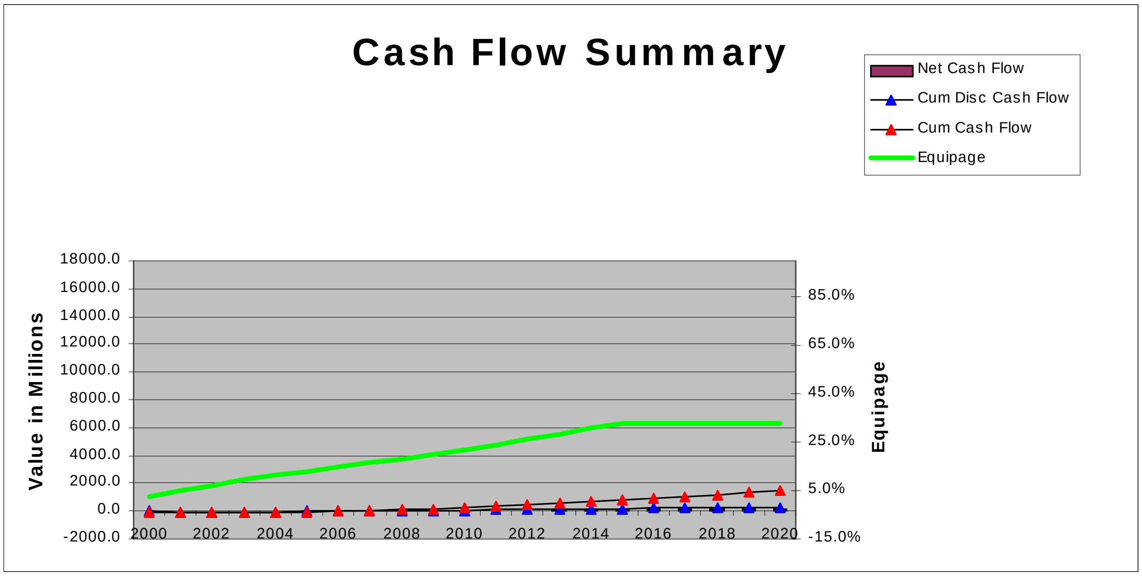


Figure 5.3.3-7. AOC-Only Forward Fit Cash Flow Summary LINK2000+ Geographic Area, 2000 - 2020

6. Conclusions

Table 6.0-1 summarizes the results for the three data link scenarios: Overall, which includes AOC and ATC; ATC-Only; and AOC-only. The table shows the expected NPV (from the cumulative probability distributions), the total benefits and costs, the benefit/cost ratio, the break-even year, and the Internal Rate of Return for each scenario. (Note that the break-even year and IRR are computed on base case values, while the other three columns are computed on probabilistic values.)

Scenario	NPV (Millions of Euros)	Benefits (NPV, Millions of Euros)	Costs (NPV, Millions of Euros)	Benefit/ Cost Ratio	Breakeven Yr*	IRR*
Overall	3541	4101	876	4.7	2009	44%
ATC Only	2012	2672	840	3.2	2011	32%
AOC Only	632	1118	543	2.1	2008	35%

Table 6.0-1. Data Link Scenario Summary
LINK2000+ Geographic Area, 2000 – 2020

The Benefit/Cost ratio and break-even year suggest that the greatest benefit is achieved in the Overall case, thus equipage for both AOC and ATC operations. The benefit for ATC-only, however, is sufficiently high to justify the investment. The lower benefit/cost ratio for AOC-only suggests that it is not the best investment of the three alternatives.

From these data the following conclusions can be drawn:

- There is a strong business case for airlines to equip with ATS data link for future delay reduction
- The real-time simulations and fast-time validation performed provide solid basis for estimating relationship between delay reduction and capacity
- The maximum benefit is derived from combining AOC and ATC
- The break-even year is constrained by infrastructure implementation (stage 1 duration)
- The NPV can be significantly increased by accelerating equipage rate and infrastructure implementation. (Delays in infrastructure cost approximately 250 million Euros per year)
- There is minimal investment risk for ATS data link (probability of negative NPV is small)
- **ATN VDL Mode 2 data link is a strategic, long-term investment.**

Note: Results of a European model are different from the C/AFT US data link investment model primarily because delay growth in Europe is higher than the US. [14] The US model assumed a 7% delay increase per year in the base case throughout the 20 years. The European model assumes a 25% delay increase in years 1-5, 10% years 6-10, and no increase in delay years 11-20.

7. List of Acronyms

ACARS	Airline Communication Addressing and Reporting System
AOC	Airline Operational Control
ATA	Air Transport Association
ATC	Air Traffic Control
ATFM	Air Traffic Flow Management
ATM	Air Traffic Management
ATN	Aeronautical Telecommunication Network
ATS	Air Traffic Services
C/AFT	CNS/ATM Focused Team
CMU	Communication Management Unit
CNS	Communication Navigation Surveillance
CPDLC	Controller-Pilot Data Link Communication
D/L	Data Link
DOC	Direct Operating Cost
FANS	Future Air Navigation System
FMS	Flight Management System
HLTA	High Level Traffic Areas
HMI	Human Machine Interface
NAS	National Airspace System
NPV	Net Present Value
PETAL	Preliminary EUROCONTROL Test of Air/Ground Data Link
R/T	Radio/Telephony
SARPS	Standards and Recommended Practices (ICAO)
SID	Standard Instrument Departure
STAR	Standard Terminal Arrival Route
VDL	Very High Frequency Data Link

8. References

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Appendix A – Full Influence Diagram

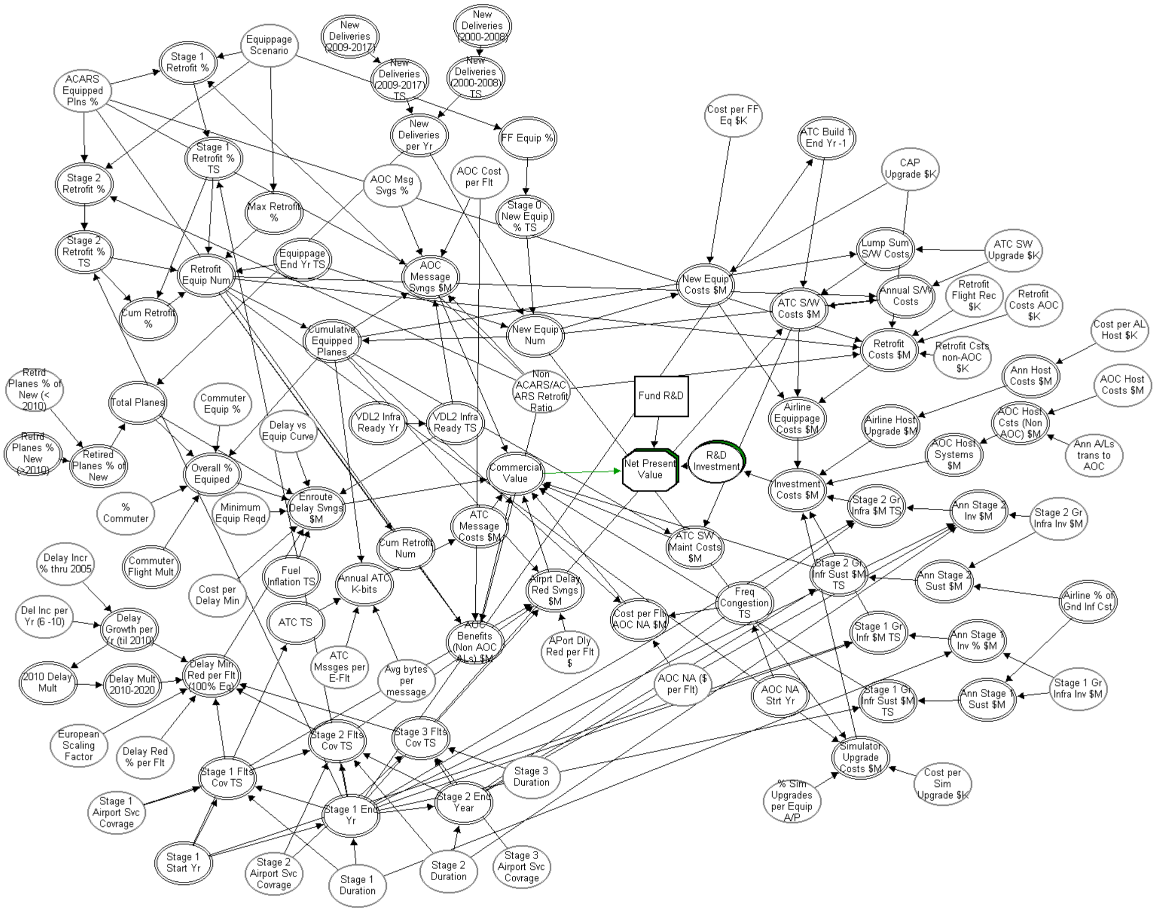

Figure A-1. Full Influence Diagram

Appendix B – Constants

Constants	Value	Source
Start Year of Model	2000	C/AFT consensus
Final Year for Equippage	2015	C/AFT consensus
Final Year for Benefits	2020	C/AFT consensus
Discount Rate	12%	IATA
Inflation Rate	2%	EUROCONTROL
Fuel percent of DOC	15%	IATA, 1997 AETF
Fuel inflation rate	5%	Airline consensus

Table B-1. Constants

Appendix C – Traffic & Delay Growth Assumptions

Constants	Value	Source
Stage 1 Number of 70+ seats Airplanes (jetliners) - European-registered (ECAC) in 1999. (Aircraft types falling into this category: Avro RJ and BAe 146 series, BAC 1-11, Fokker jet series, Airbus A319, 320, 321, Boeing 727, 737, 757, MD80, Airbus A300, 310, 330, 340, Boeing 747, 767, 777, DC10, MD11, Lockheed L-1011 Tristar.)	4443	EUROCONTROL
Average Flights per year per airplane for 70+ seat airplanes	1560	EUROCONTROL. IATA and airlines have validated this data.
Number of flights/year of commuter (up to 70 jetliners) airplanes	2200	EUROCONTROL. IATA and airlines have validated this data.
New Deliveries Passenger Airplanes through 2008 core Europe	210/year	Boeing Current Market Outlook. Concurrence by Airbus.
New Deliveries Passenger Airplanes after 2008 core Europe	240	Boeing Current Market Outlook. Concurrence by Airbus.

Table C-1. Traffic Growth Constants

	Traffic Growth			
Variables	10	50	90	Source
Number of commuter airplanes as percent of commercial	3%	5%	7%	Calculated as number of Stage 1 European 70+ airplanes divided by Stage 1 commuter airplanes. (183/3864)
Retired Passenger Airplanes as % of New until 2010	15%	22%	40%	Used data from US analysis. Note: After 2010 will equal new deliveries.

Table C-2. Traffic Growth Variables

	Delay Growth			
Variables	**10**	**50**	**90**	**Source**
Delay Growth Per Year per flight (in do-nothing case). Until 2005.	20%	25%	30%	EUROCONTROL - Average ATFM Delay variation 1997/1998 - First Performance Review Report. Will modify this based on FAP results. No trade-off between delay and unsatisfied demand. This is delay growth if we want to satisfy demand.
Delay Growth Per Year per flight (in do-nothing case). 2005 - 2010	5%	10%	15%	C/AFT consensus. Note: After 2010 delay growth will be capped at 2010 levels.

Table C-3. Delay Growth

Appendix D – Infrastructure Assumptions

Constants	Value	Source
Stage 1 start	2000	
VDL-2 Infrastructrure Readiness Year	2001	ARINC/SITA

Table D-1. Infrastructure Constants

	Defintion of Stages and Stage Dates			
Stage 1	DCL and ATIS Messages in HTLA's of Core Europe + airline AO			
Stage 2	Area-Wide Messages in HTLA's of Europe			
Stage 3	Area-Wide Messages in additional HTLA's of Europe			
Variable	**10**	**50**	**90**	**Notes**
Stage 1 duration	4	6	8	C/AFT consensus
Stage 2 duration	4	6	7	C/AFT consensus
Stage 3 duration	2	4	8	C/AFT consensus

Table D-2. Infrastructure Stages

	Infrastructure Effectiveness			
Variable	**10**	**50**	**90**	**Notes**
Stage 1 Percent of 70+ seat Flights Covered by Airport Services	30	35	50	EUROCONTROL. (CFMU 1997).
Stage 2 Percent of 70+ seat Flights Covered by Airport Services	50	60	65	EUROCONTROL.
Stage 3 Percent of 70+ seat Flights Covered by Airport Services	65	70	75	EUROCONTROL
Stage 2 Percent of 70+ seat Flights Covered by EnRoute Services	Stage 2 Airport Services + 15%	Stage 2 Airport Services + 15%	Stage 2 Airport Services + 15%	EUROCONTROL. Based on STATFOR (Statistics and Forecasts).
Stage 3 Percent of 70+ seat Flights Covered by EnRoute Services	Stage 3 Airport Services + 15%	Stage 3 Airport Services + 15%	Stage 3 Airport Services + 15%	EUROCONTROL

Table D-3. Infrastructure Effectiveness

Appendix E – Equipage Rate Assumptions

	Equipage Scenario			
Variables	10	50	90	Source / Notes
Percentage of airplanes that are ACARS-equipped	40%	50%	60%	SITA. Note: 1752 airplanes using SITA network right now.
Commuter Equipage Percent	1%	5%	10%	SITA. Current level of equipage for European commuters, relative to commercial.
Non ACARS/ACARS Retrofit Ratio	0%	20%	100%	C/AFT consensus. Conversion factor used to determine retrofit rates of non-ACARS airplanes relative to ACARS-equipped airplanes.
Max Retrofit Total (over life of model)	50%	75%	90%	C/AFT consensus.
Stage 1 Retrofit % per yr of ACARS baseline	2%	3%	4%	C/AFT consensus. Retrofit for Stage 1 will be small due to limited benefits. Expressed as a percentage of the airplanes that are ACARS-equipped.
Stage 2 & 3 Retrofit % per yr of ACARS baseline	10%	15%	25%	C/AFT consensus. Retrofit in Stages 2 & 3 will increase due to AOC and ATC benefits. Other reasons are non-related retrofit (e.g. 8.33). Expressed as a percentage of the airplanes that are ACARS-equipped.
Forward Fit % per yr	50%	60%	75%	C/AFT consensus. Forward Fit with VDL-2 percentages are high because of the need to increase AOC capacity.

Table E-1. Equipage Population and Equipage Rates

Appendix F – Non-Recurring Cost Assumptions

	Airborne Equipment Costs (ACARS Baseline)			
Variable	**10**	**50**	**90**	**Notes**
Retrofit (AOC VDL-2, including Service Bulletin)	$ 50,000	$ 150,000	$ 400,000	Airline consensus
Forward Fit (AOC VDL-2, including Master Change)	$ 30,000	$ 90,000	$ 150,000	Airline consensus
ATC Software Upgrade	$ 30,000	$ 70,000	$ 120,000	Airline consensus

Table F-1. Airborne Equipment Costs, ACARS Baseline

	Airborne Equipment Costs (non-ACARS Baseline)			
Variable	**10**	**50**	**90**	**Notes**
Retrofit (AOC VDL-2, including Service Bulletin)	$ 90,000	$ 190,000	$ 600,000	Airline consensus

Table F-2. Airborne Equipment Costs, non-ACARS Baseline

	Flight Data Recorder and CAP Upgrades (both baselines)			
Flight Data Recorder Upgrade	$ 0	$ 70,000	$ 100,000	Airline consensus.
CAP Upgrade	$ 10,000	$ 30,000	$ 75,000	Airline consensus. Assume VDL-2 equipped airplanewith Flight Management System (FMS) connection, and that this is required in Europe only. Assume that non FMS airplanes are those that will not equip with VDL-2.

Table F-3. Airborne Equipage Costs, Both Baselines

Constants	Value	Source
Current number of datalink AOC airlines whose host computers are based in European airspace	32	SITA

Table F-4. Airline Host Costs Constant -- Number of AOC hosts

	Airline Host Costs (ACARS Baseline)			
Variable	**10**	**50**	**90**	**Notes**
Average host/router upgrade, per airline	$ 100,000	$ 200,000	$ 300,000	Airline & ARINC/SITA consensus

Table F-5. Airline Host Costs (ACARS Baseline)

	Airline Host Costs (non-ACARS Baseline)			
Variable	**10**	**50**	**90**	**Notes**
Average AOC infrastructure costs	$.5M	$1.5M	$2.5M	SITA, reflects costs of: host system, applications, training, etc on ground.
Number of airlines implementing AOC host systems per year	2	3	4	SITA.

Table F-6. Airline Host Costs (non-ACARS Baseline)

	Training Simulator Upgrade (both baselines)			
Variable	**10**	**50**	**90**	**Notes**
Average Cost of simulator upgrade	$ 100,000	$ 240,000	$ 400,000	KLM
Number of simulators to be upgraded as percentage of total number of airplanes	2%	3%	5%	Airline consensus.

Table F-7. Training Simulator Upgrade (Both Baselines)

Appendix G –Benefit and Recurring Cost Assumptions

AOC Non-Availability Avoidance (Both Baselines)				
Benefits	**10**	**50**	**90**	**Notes**
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 Yr of AOC Non-Availability Problems		2003		SITA

Table G-1. AOC Non-Availability Avoidance (Both Baselines)

AOC Lower Message Costs (ACARS Baseline)				
Benefits	**10**	**50**	**90**	**Notes**
Current average AOC cost per flight segment	$ 4	$ 6	$ 9	Airline consensus.
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. These rates would apply to incremental traffic on higher speed data link.

Table G-2. AOC Lower Message Costs (ACARS Baseline)

AOC Applications to Airlines Not Currently Using ACARS AOC				
Benefits	**10**	**50**	**90**	**Notes**
Per flight AOC benefit	4	6	9	Airline consensus. Assuming that the benefit is equal to the current average AOC cost per flight segment.

Table G-3. AOC Applications to Airlines Not Currently Using ACARS AOC

Cost of Delay per Minute				
Cost of Delay per Minute	$ 20	$ 22	$ 33	IATA and Eurocontrol

Table G-4. Cost of Delay per Minute

Airport Delay Reduction				
Benefits	**10**	**50**	**90**	**Notes**
Cost Avoidance of late flight or missed connection ($/equipped and airport covered flight)	$2	$4	$6	KLM. Reduced turn-around time.

Table G-5. Airport Delay Reduction

Enroute Delay Reduction				
Benefits	**10**	**50**	**90**	**Notes**
% Delay savings per flight (assume 100% equipage).		53%		Based on preliminary results from L2KBC simulation.
European Discount Factor (Delay Red % (100% equip))	30%	50%	80%	C/AFT consensus. Discounts the delay savings per flight because of uncertainty in the relationship between controller workload reduction and delay reduction.
Delay minutes per flight (1999)		5.7		EUROCONTROL -- Medium-term Capacity Shortfalls 2003-2005 -- EEC Note No. 16/99
Minimum Equipage Required	20%	25%	35%	ATC benefits don't start until this percent equipage is achieved. Estimate based on NASSIM and DPAT results
Delay Reduction vs. Equipage Curve				Using curve based on L2KBC simulation results.

Table G-6. En Route Delay Reduction

Ground Infrastructure Sustaining Costs (route charges)				
Benefits	**10**	**50**	**90**	**Notes**
Stage 1. Total implementation cost of ground infrastructure (millions of Euros)	21	30	45	EUROCONTROL.
Stage 2. Total implementation cost of ground infrastructure (millions of Euros)	214	298	448	EUROCONTROL.
Total annual recurring cost of ground infranstructure (Annual Data Link Sustaining) includes communication costs. This is applied to ALL flights (not just those equipped) in a "covered" area.	10% of total implementation cost	10% of total implementation cost	10% of total implementation cost	EUROCONTROL. Starts at beginning of Stage and implementation is spread over Stage duration. Sustaining costs from stage end and beyond.

Table G-7. Ground Infrastructure Sustaining Costs

Constants	Value	Source
Average cost per ATC kilobit (annual)		
up to 1 Million Kbits per year	$0.28	SITA/ARINC
1 - 4 Million Kbits per year	$0.24	
4 -8 Million kbits per year	$0.16	
8 - 15 Million Kbits per year	$0.08	

Table G-8. Recurring Cost Constants -- Average Cost per ATC Kilobit

	ATC Message Costs			
Variable	**10**	**50**	**90**	**Notes**
ATC Messages per equipped fli	200	229	260	FAA JRC charts
Average bytes per message	40	56	75	FAA JRC charts

Table G-9. ATC Message Costs

	ATC S/W Maintenance Costs	
ATC SW Maintenance	10%/year of ATC Software Upgrade Cost, starting 2nd year	Airline consensus

Table G-10. ATC Software Maintenance Costs