C/AFT
Datalink Investment Analysis

Results

April 1999

Overview

- Introduction & Assumptions
- AOC Situation
- ATC Situation
- C/AFT Modeling Process
- Model Inputs
- Results
- Potential benefit of future datalink enhancements
- Conclusions

Introduction

- C/AFT airlines agree that future system capacity is a primary driver for global airspace system changes
- C/AFT proposes incremental operational enhancements that can be enabled by CNS technologies
- Datalink is primary candidate enabler for delay reduction
- A business case has not yet been developed that convinces airlines and ATS Service providers to equip with ATN

Assumptions

- This is not an alternatives analysis, datalink is the only enabler considered
- Analysis is performed for Cruise/Terminal Transition area capacity improvements in US NAS
- Based on airline point of view (airlines as an industry, not a single airline)
- Infrastructure readiness drives equipage
- Evaluates value of transitioning from Plain Old ACARS (POA) to VDL Mode 2
- Both AOC and ATC benefits considered

Airline Operations Control
Why the Need for Change?

- **ACARS Demand is Increasing**
  - New aircraft being delivered
  - New airline users entering service
  - New applications and non-airline users
- **ACARS is a Shared-Access System**
  - Based on non-discriminatory system of FCC frequencies
- **Spectrum Availability and Congestion**
  - Limited number of VHF frequencies
  - Interim ACARS expansion is short-lived and expensive

Airline Operations Control
Increasing U.S. Demand for Service

- **Growing number of ACARS aircraft in U.S.**
  - Today: Approx. 5600 U.S. + 1500 Non-U.S. = 7100
  - Future: Up to 1200 more over next 3 to 5 years
- **Potential new demand from new participants**
  - Civil: Large Scheduled (Regional), Cargo, & Business
  - Military: Non-Tactical Aircraft, Air National Guard
  - Estimated potential at more than 4500 additional a/c
- **Increasing number of data link applications**
  - Aircraft Performance
  - Crew Management
  - In-flight Operations

Spectrum Issues
Congestion and Availability

- New applications is the primary reason for increasing demand for ACARS
- New data link users entering service is the secondary reason for increasing demand for ACARS
- Many areas of US already already experiencing congestion on en route frequencies
- Other industries are looking and petitioning for available spectrum

Managing spectrum congestion and availability will be a growing and continuing concern for the airline industry.

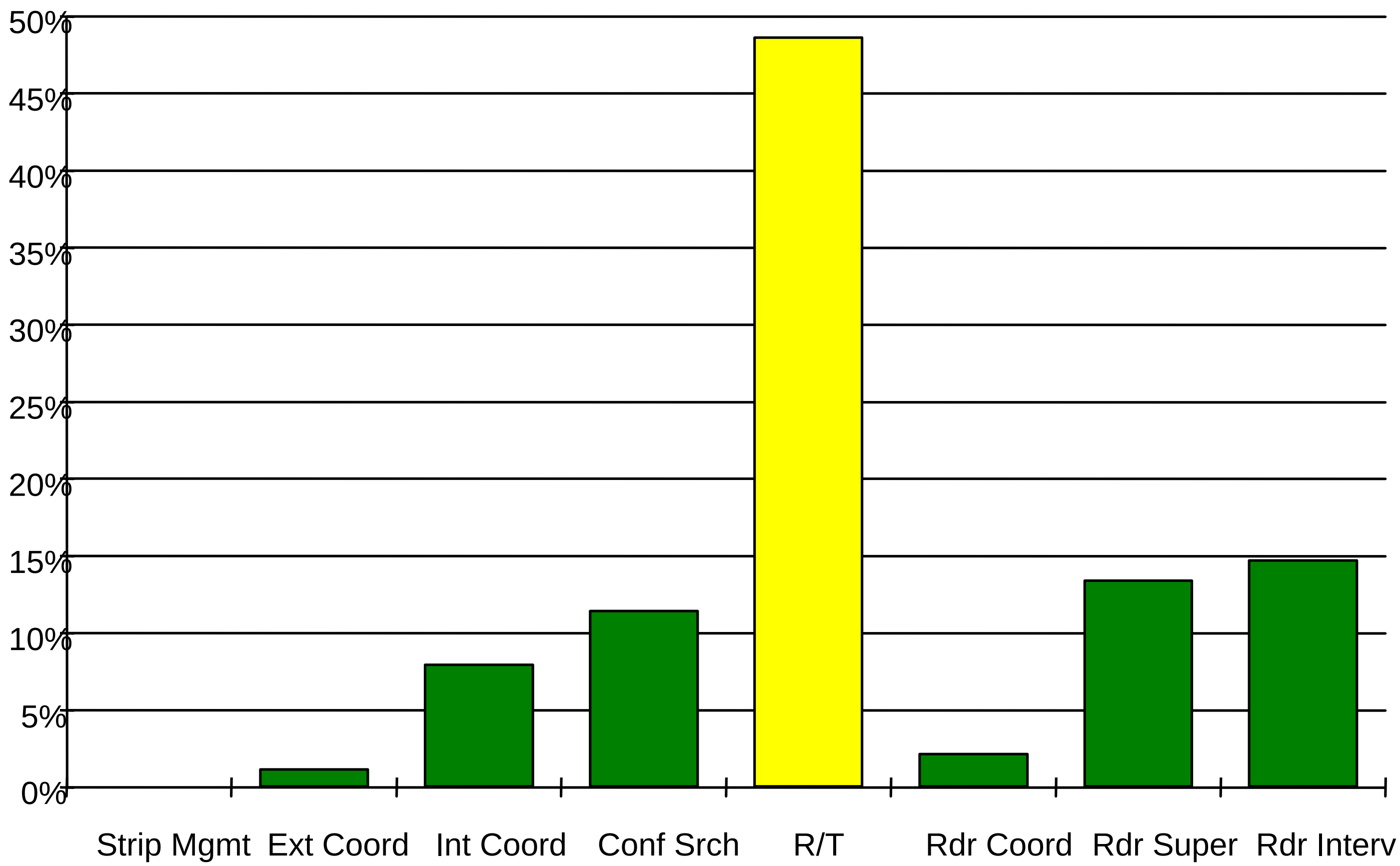
The Digital Solution (VDL-2)

- Migration of ACARS traffic to VDL-2 will effectively address projected frequency congestion
- Significant costs related to expanding interim ACARS capacity may be avoided
- ATC Data Link is a common element in most new applications related to ATC modernization and airspace management

ATC Situation

- American Airlines performed study of impact of delay on airline schedule
  - Without capacity improvements airline flight schedule critically impacted by year 2005
  - By reducing separations airline schedules can be maintained
- FAA study of Cruise/Terminal Transition area datalink indicates significant delay reduction possibilities
  - Reduce voice frequency congestion
  - Offload controller, allowing improved ATC services for increased sector productivity and efficiency
- FAA has funding approval for Builds 1 and 1a VDL Mode 2 CPDLC.
- PETAL-II trials in Europe underway to evaluate datalink operational issues

The First Step:
Controller Communications Workload

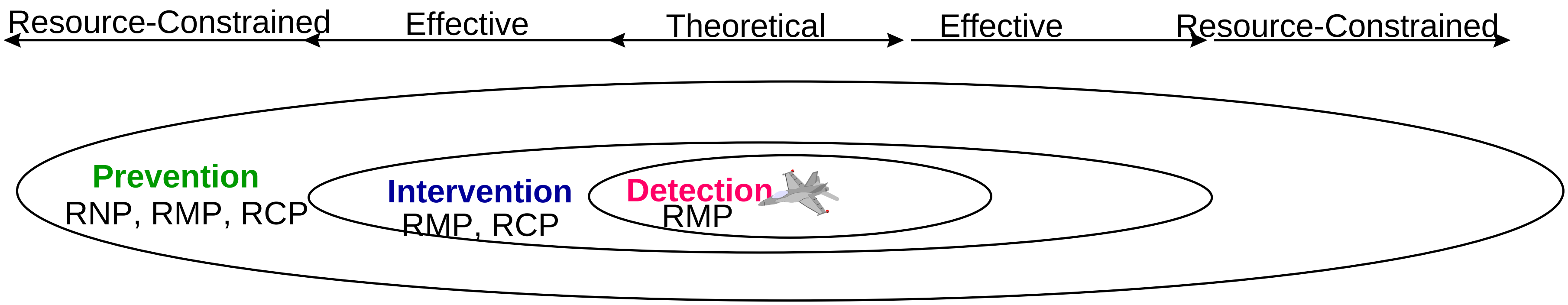


"SYSCO" Approximate Controller Workload Distribution

C/AFT Modeling Process
Transition Logic Diagrams

- C/AFT is proponent of incremental operational enhancements
- Transition Logic Diagrams
  - separate diagram for each phase of operation
  - developed for both capacity and efficiency
  - operational enhancements “enabled” by technology or procedural improvements
- C/AFT analysis focuses on capacity-related improvements
  - Reduced separations
  - Additional routes

Separation Rings



Display
Weather
Medium-Term Intent
Data Controller
Comm: g/g
Pilot
Flow Rates
Airspace Complexity

Sensor
Display
Short-Term Intent
Controller
Comm: a/g
Pilot
Closure Rate

Sensor
Display
Controller
Pilot

Required Element Performance

RxP = **f** (sensors, decision support, human)

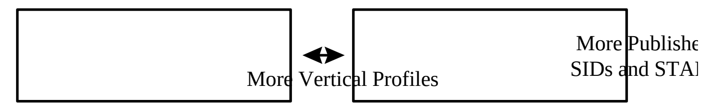
Required System Performance sets Separation Standard

RSP = **g** (RCP, RMP, RNP)

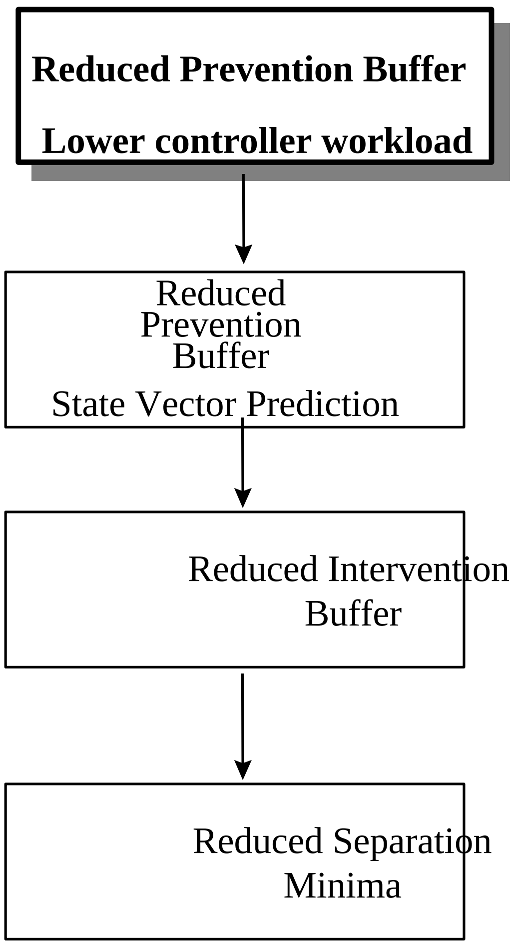
CNS/ATM Focus Team

5. Cruise/Terminal Transition Area Transitions

System-Level Capacity Effects



Airplane-Level Capacity Effects



Atlanta study baseline. Datalink 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 datalink for routine voice communications allowed reduction from 20 MIT to 5 MIT (62% delay reduction)

C/AFT Modeling Process
Economic Model

- Determines
  - Costs
  - Benefits (converted to dollars)
  - Risk
  - Rules
- Builds Deterministic Sensitivity Analysis
  - Identifies influence of each uncertainty on NPV
  - Used to calculate overall risk and return
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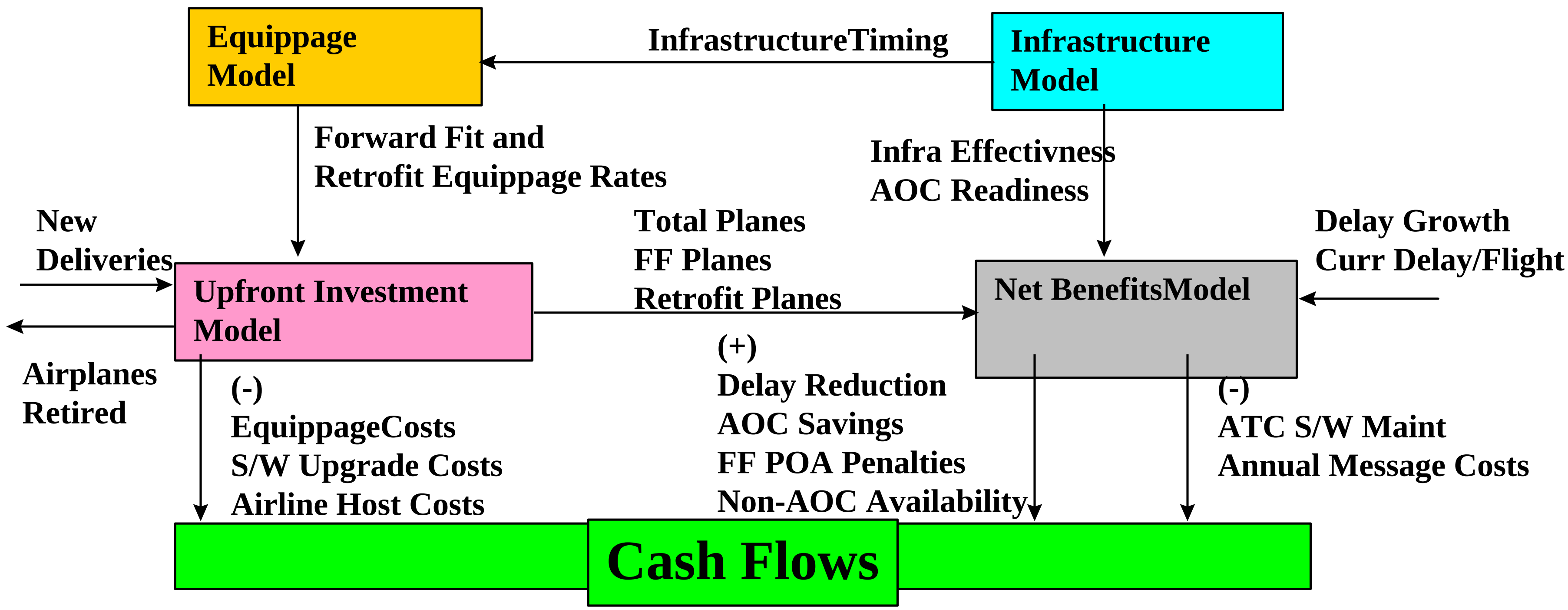
Datalink Influence Diagram

Datalink Investment Model



Model Inputs
Constants

- Start Year of Model 2000
- Final Year for Equipage = 2015
- Final Year for Benefit = 2020
- Discount Rate = 12%
- Inflation Rate = 3.5%
- Direct Operating Cost (DOC) per minute = $25
  - Does not include amortization of costs for ownership
- Percentage of Fuel-related DOC = 30%
- Fuel inflation rate = 5%

Model Inputs
Delay Growth

- Derived from Free Flight, Preserving Airline Opportunity, by Captain Russell Chew, Fig. 4
- Large range of this variable due to:
  - Russ' study was using conservative good weather day estimate
  - This represents delay over optimum (not schedule)
  - This takes into account unmet traffic growth due to capacity constraints

Variables	10	50	90
Delay Growth Per Year	2.5%	7%	11%

Model Inputs
Traffic Growth

- Number of planes at start of model: 5194 (from ATA)
- Number of planes in 2015:
  - Low estimate: 8054
  - Medium estimate: 8943
  - High Estimate: 9289

Model Inputs
Infrastructure

- Model includes both AOC and ATC Infrastructure
- CPDLC Builds have an associated “Delay Reduction Effectiveness” which represents the percentage of datalink-related delay that is affected with each build.
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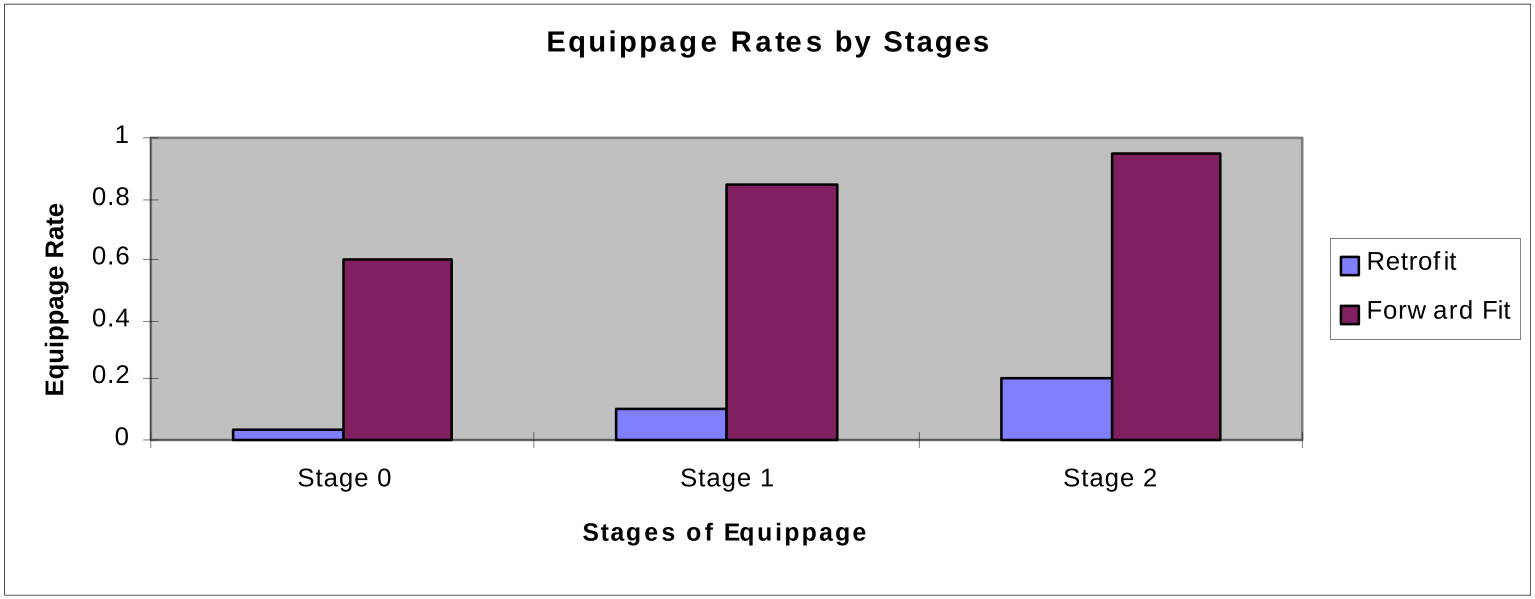
Model Inputs
Infrastructure

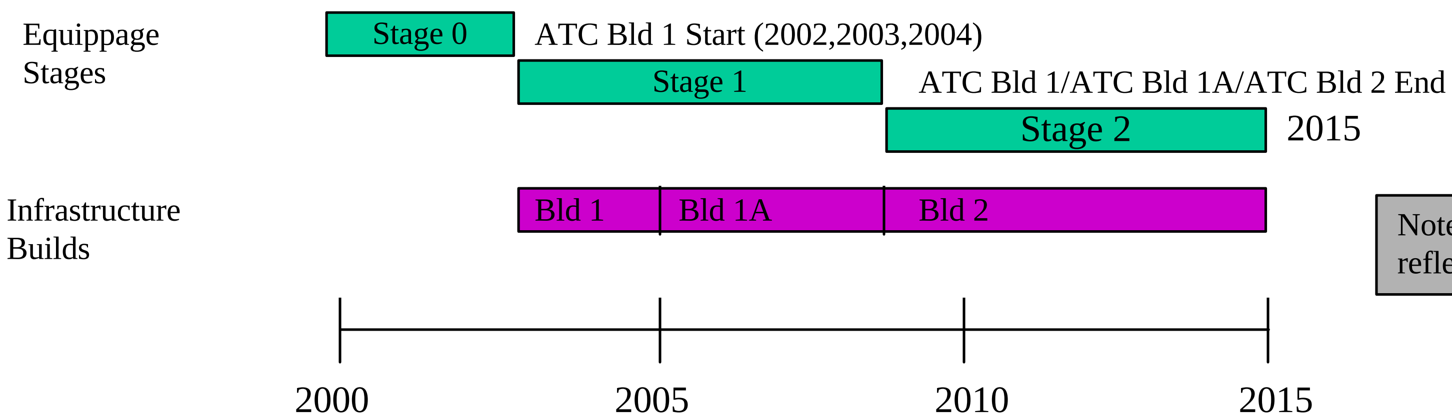
Variables	10	50	90
ARINC VDL-2 Infrastructure Readiness Year	2000	2001	2002
ATC Infrastrucutre			
Build 1 Start Yr	2002	2003	2004
Duration of Build 1 (years)	1	2	3
Duration of Build 1a (years)	2	3	4
Duration of Build 2	2	4	8
Build 1 Delay Reduction Effectiveness	0%	0%	0%
Build 1a Delay Reduction Effectiveness	50%	70%	85%
Build 2 Delay Reduction Effectiveness	70%	90%	95%

Model Inputs
Three Stages of Equipage

- **Stage 0**
  - tied to AOC infrastructure readiness
  - AOC benefits biggest driver (message cost reduction and penalty avoidance)
  - no ATC delay reduction benefits
  - high forward fit of VDL-2 equipment, low retrofit
- **Stage 1**
  - tied to ATC infrastructure readiness
  - both ATC delay reduction and AOC benefits
  - increased forward fit, low retrofit
  - ends when airlines equip more aggressively due to infrastructure maturity and realized benefits
- **Stage 2**
  - tied to ATC infrastructure maturity
  - both ATC delay delay reduction and AOC benefits
  - low change in forward fit, high retrofit

Model Inputs
Equipage





Note: All graphics reflect base case values

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Model Inputs
Equipage Timing Variables

Variables	10	50	90
Stage 0			
Stage 0 Start Yr		2000	
Stage 0 End Yr	Build 1 Start	Build 1 Start	Build 1 Start
Stage 1			
Stage 1 End Yr	Build 1a Start	Build 2 Start	Build 2 End
Stage 2			
Stage 2 End Yr		2015	

Model Inputs
Equipage Percentages

Variables	10	50	90
ACARS-equipped airplanes %	85%	90%	95%
Equipage Scenarios	**Low**	**Med**	**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%

Model Inputs
Costs

- **ATM Infrastructure costs not included**
- **Equipment costs assumes minimal avionics/flight deck impact: CMU, VDR, wiring**
- **Equipment Costs**
  - **Forward Fit and Retrofit for AOC**
  - **Software upgrade for ATC**
  - **Airline host or router upgrade for AOC**
- **ATC Message Costs**
  - **Who will pay?: FAA, airlines, or both**
  - **Multiplying Factor takes into account this uncertainty**

Model Inputs
Costs

Variables	10	50	90
Equipment Costs			
Retrofit	$ 50,000	$ 80,000	$120,000
Retrofit Installation costs	$100,000	$160,000	$240,000
Forward Fit	$ 30,000	$ 60,000	$100,000
ATC Upgrade	$ 10,000	$ 30,000	$100,000
Average host upgrade, all airlines	$100,000	$200,000	$300,000
Message Costs			
ATC Messages per equipped flight	200	229	260
Average bytes per message	40	56	75
Multiplying Factor on Message costs	0.0	0.5	1.0

Model Inputs
Costs

- Maintenance costs: 10% per year of ATC upgrade cost
- Message costs:
  - $.18 0-1Million Kbits;
  - $.14 1-4Million Kbits;
  - $.10 4-8;
  - $.06 8-15;
  - $.05 > 1

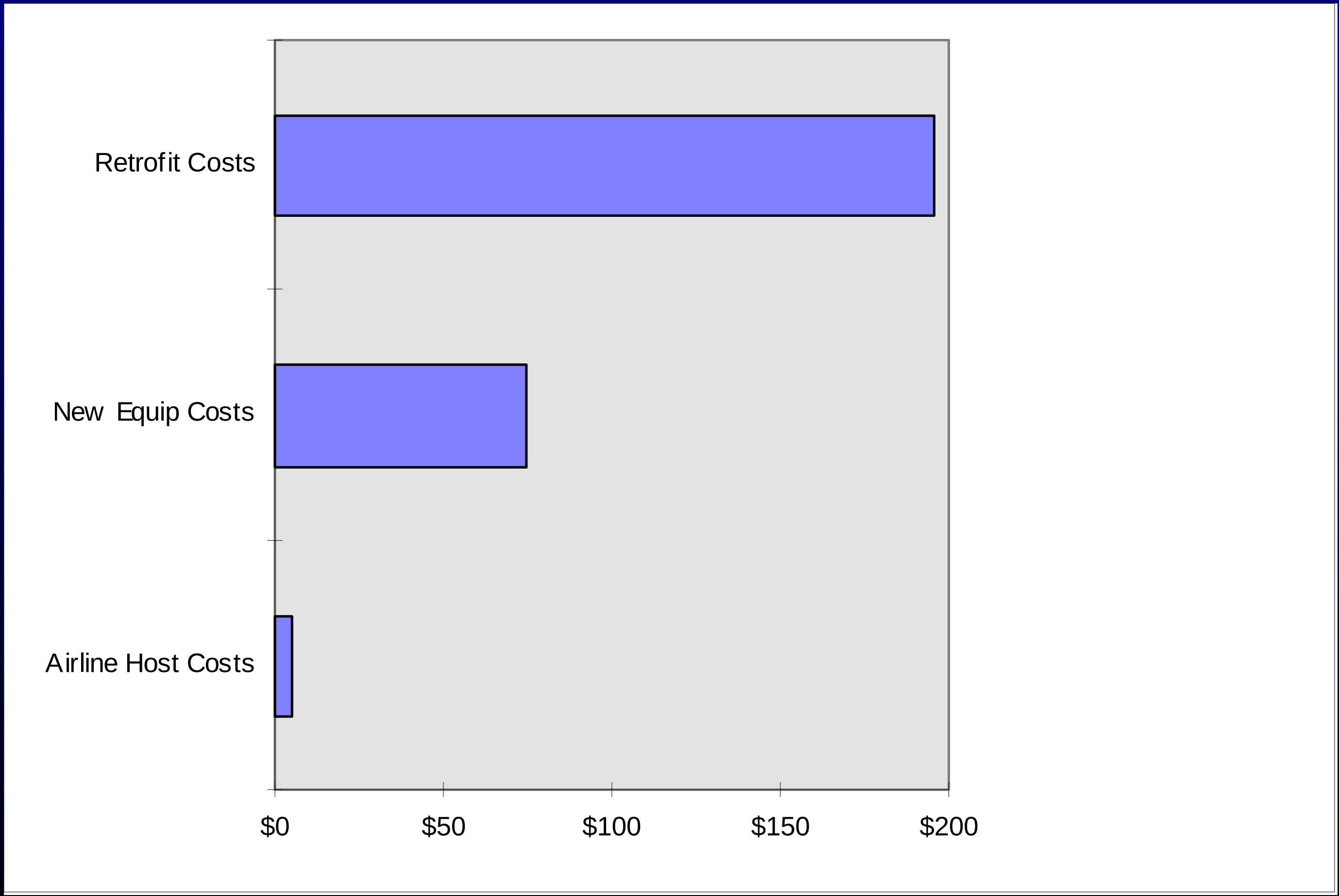
Model Inputs
AOC Benefits

- **AOC Non-Availability Avoidance**
  - Cost to an airline of not having full ACARS capability
    ($16, $32, $48 per flight)
- **AOC message cost reduction**
  - per-bit savings and message length reduction (discount factor 0.67, 0.8, 0.86)
- **AOC Penalty Avoidance for VDL-2 equipage**
  - per-Kilobit penalty (3%, 5%, 10% increase per year)
  - Monthly surcharge ($900, $1000, $1100 per month)

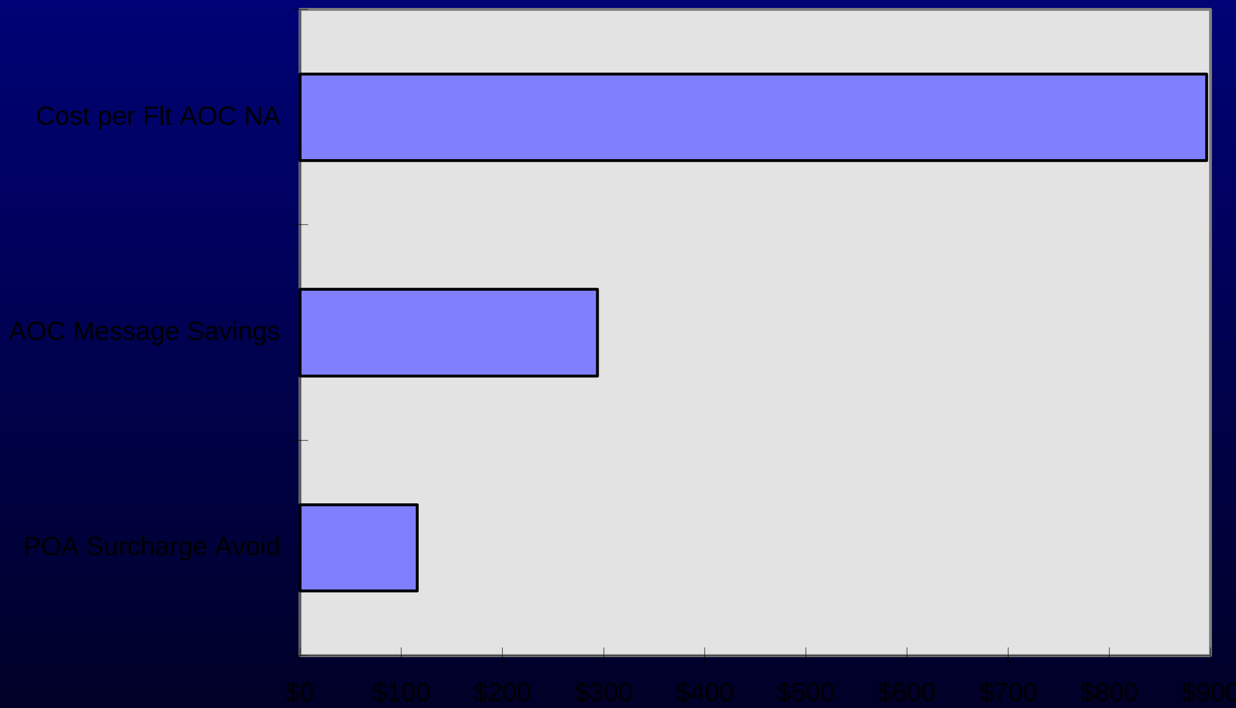
Model Outputs
AOC Only

- Let's look at AOC only scenario
- AOC-only scenario uses Stage 0 equipage rates only:
  - Forward Fit per Year 25%, 60%, 75%
  - Retrofit per Year 2%, 3%, 4%

AOC Only
(Stage 0 Equipage Rates)
Cost by Category

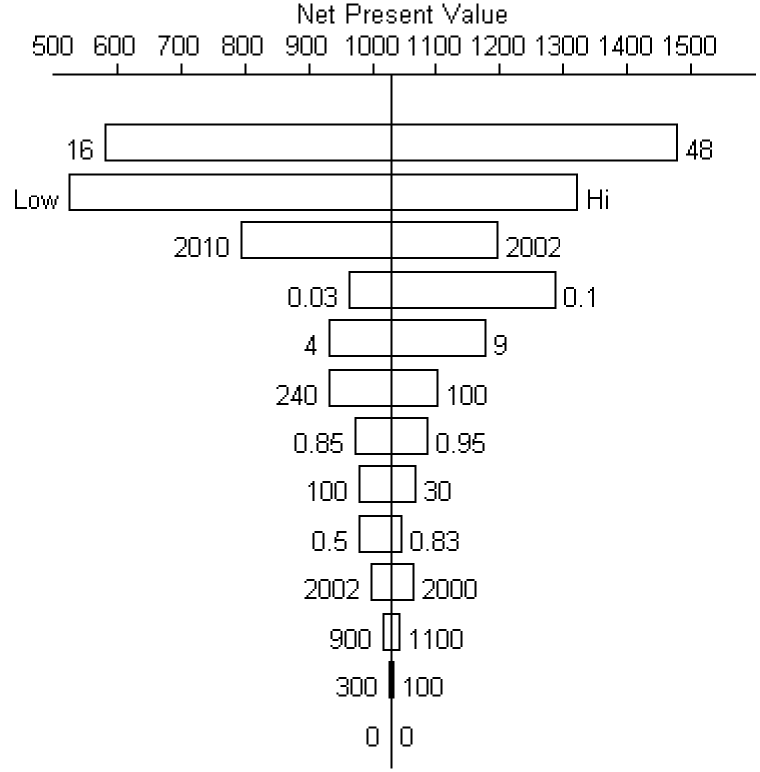


AOC Only
(Stage 0 Equipage Rates)
Benefit by Category



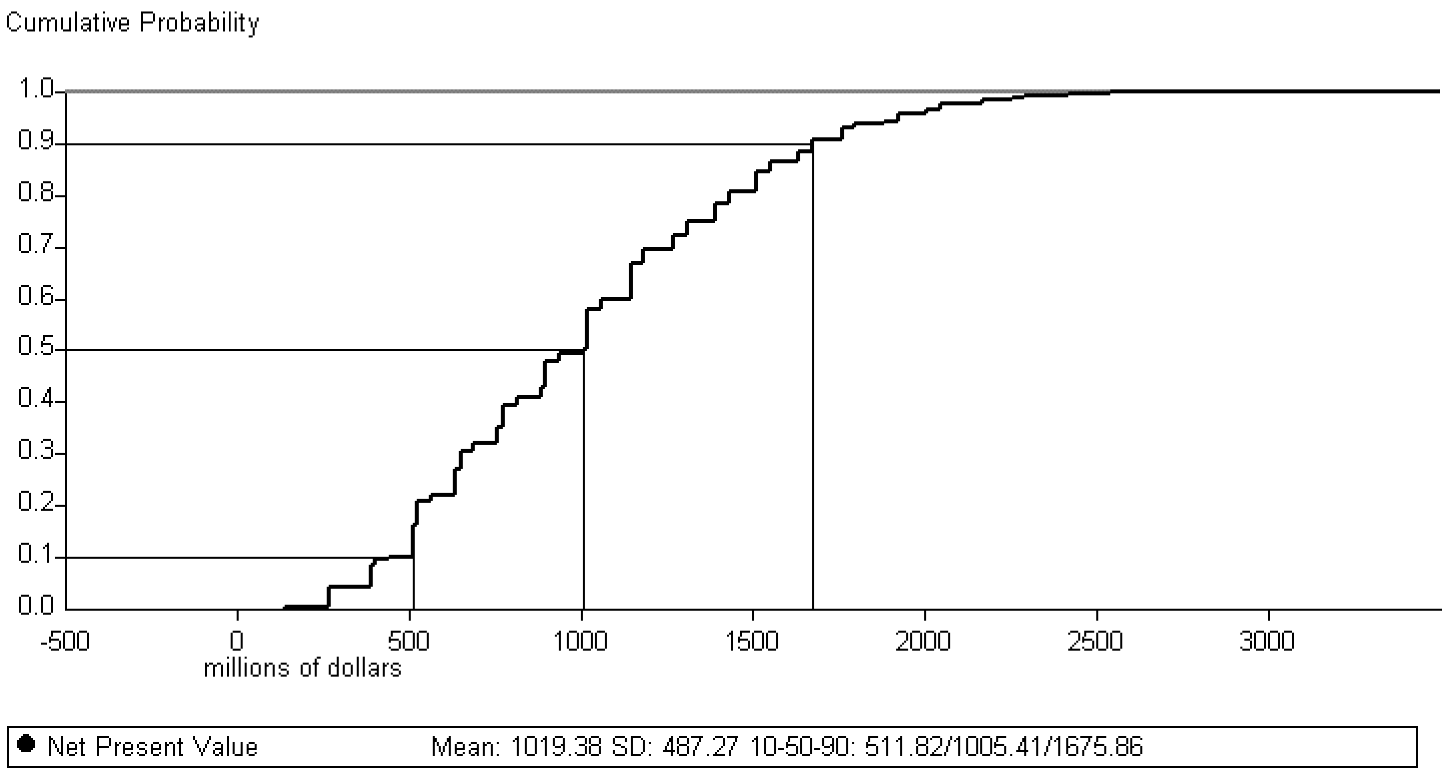
AOC Only
(Stage 0 Equipage Rates)
Deterministic Sensitivity

Variable	Base Case	Variance Contribu-tion(%)
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



Base Case Value: 1029.73

AOC Only
(Stage 0 Equipage Rates)
Cumulative Probability Distribution



AOC Only
(Stage 0 Equipage Rates)
Value of Perfect Information and Control

Selected Chance Variables	VOPI	VOPC
Equippage Scenario	0.0	$360M
AOC NA Strt Yr	0.0	177
AOC NA ($ per Flt)	0.0	425
AOC Cost per Flt	0.0	148

Value of Perfect Information: The value you should be willing to pay to know the outcome of an uncertainty before you make the investment decision.

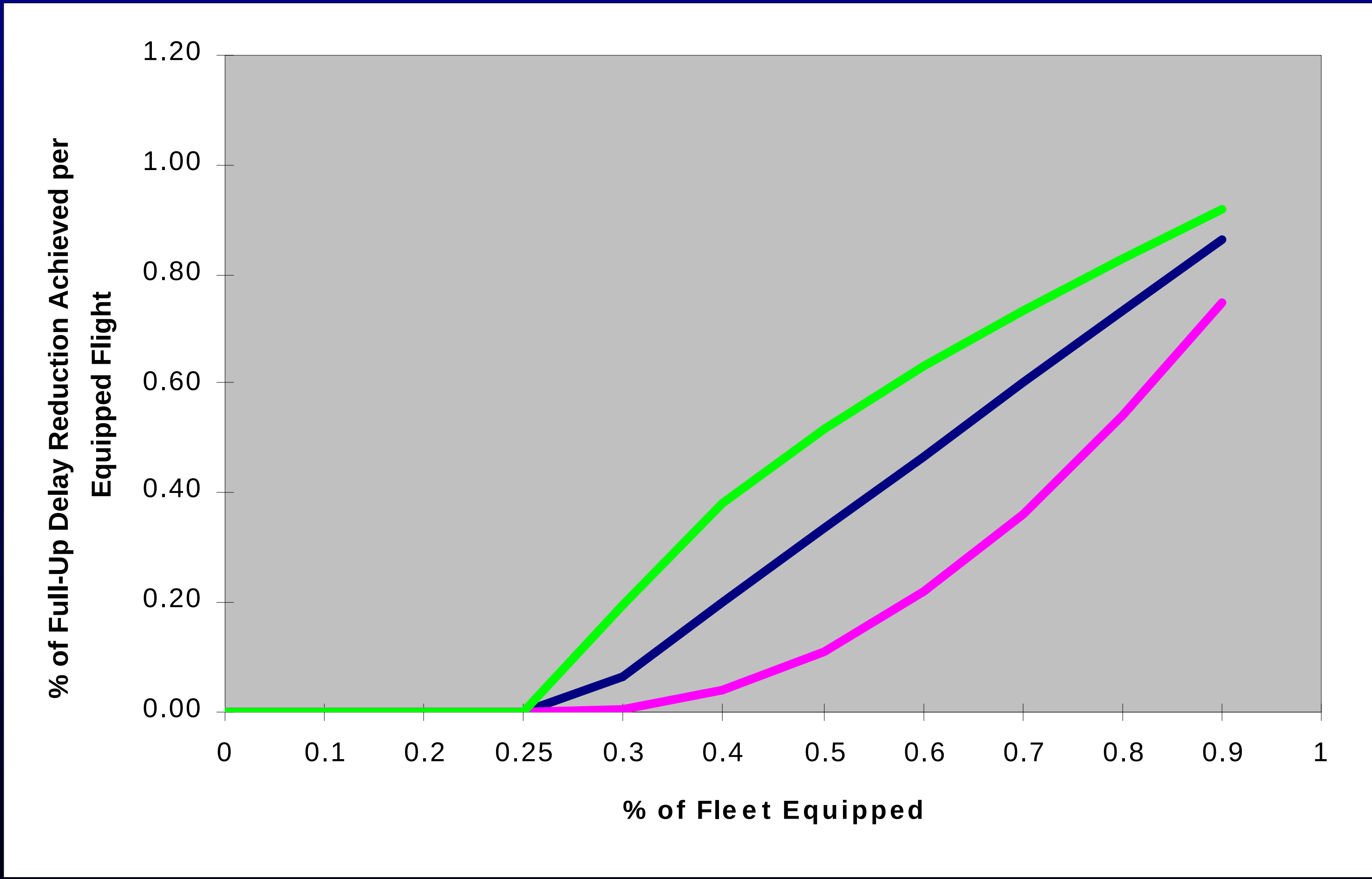
Value of Perfect Control: The value you should be willing to pay to ensure that the outcome of an uncertainty comes out to the most favorable outcome for your decision.

Note: These calculations assume a 25% chance of the 10th percentile event occuring, a 50% chance of the 50th percentile event occuring, and a 25% chance of the 90th percentile event occuring.

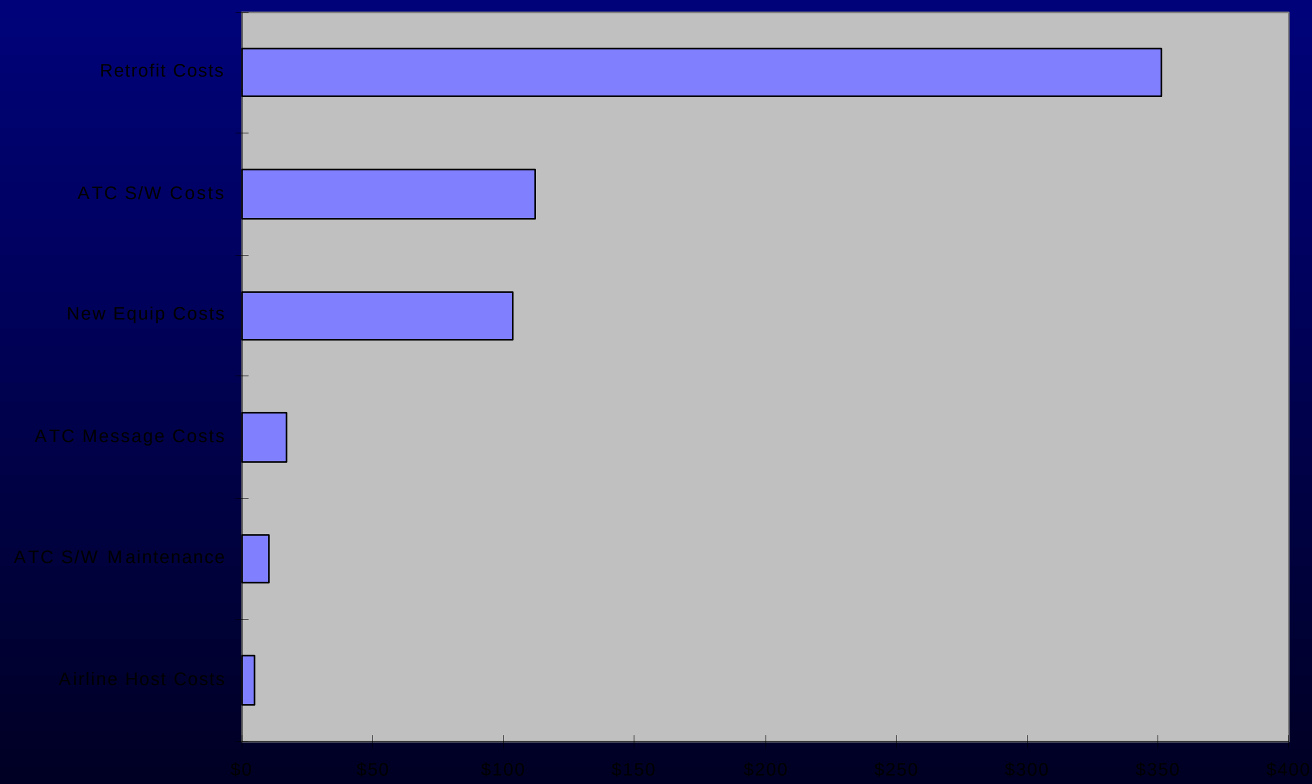
Datalink Model
ATC Benefits

- Delay reduction benefits applied to <u>all</u> airplanes, not just those equipped
- ATC Delay Reduction Benefit
  - Based on Atlanta study; scaled study benefits
  - Assigned delay reduction % to each FAA Build
- Uses the following formula:
  - Atlanta NAS-wide benefits * discount factor * annual delay growth
    - Atlanta NAS-wide benefits = 11,491,387 minutes saved in Cruise/Terminal Transition phase of flight
    - Discount Factor = 30%, 50%, or 80% of Atlanta-study benefits
    - Annual Delay Growth = 2.5%, 7%, 11% per year

Model Inputs
Delay vs. Equippage Curve



Full Datalink
Costs by Category



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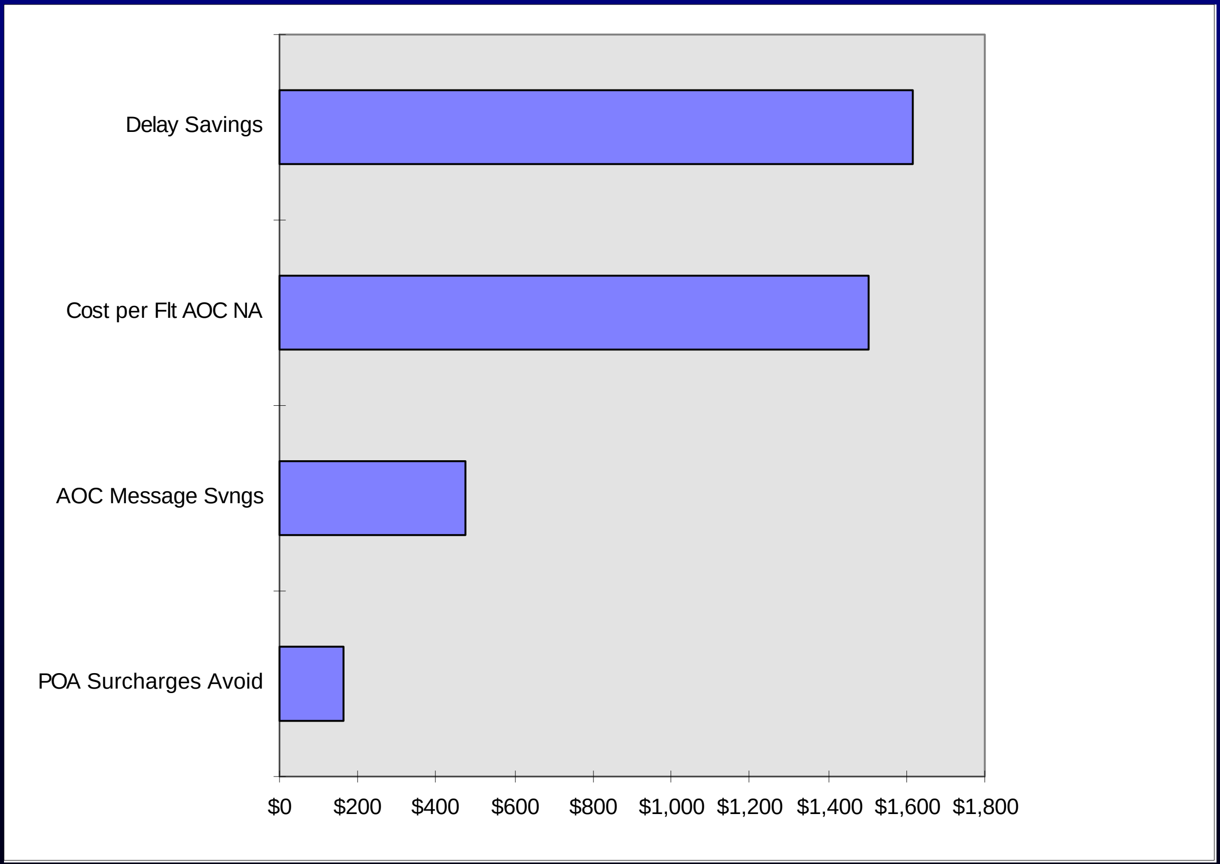
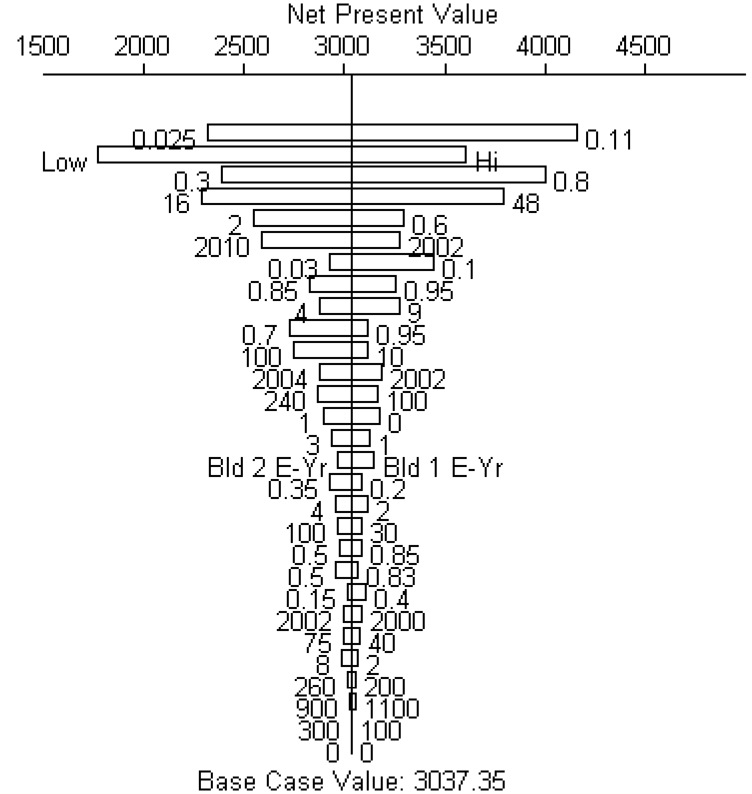
Full Datalink
Benefit by Category



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



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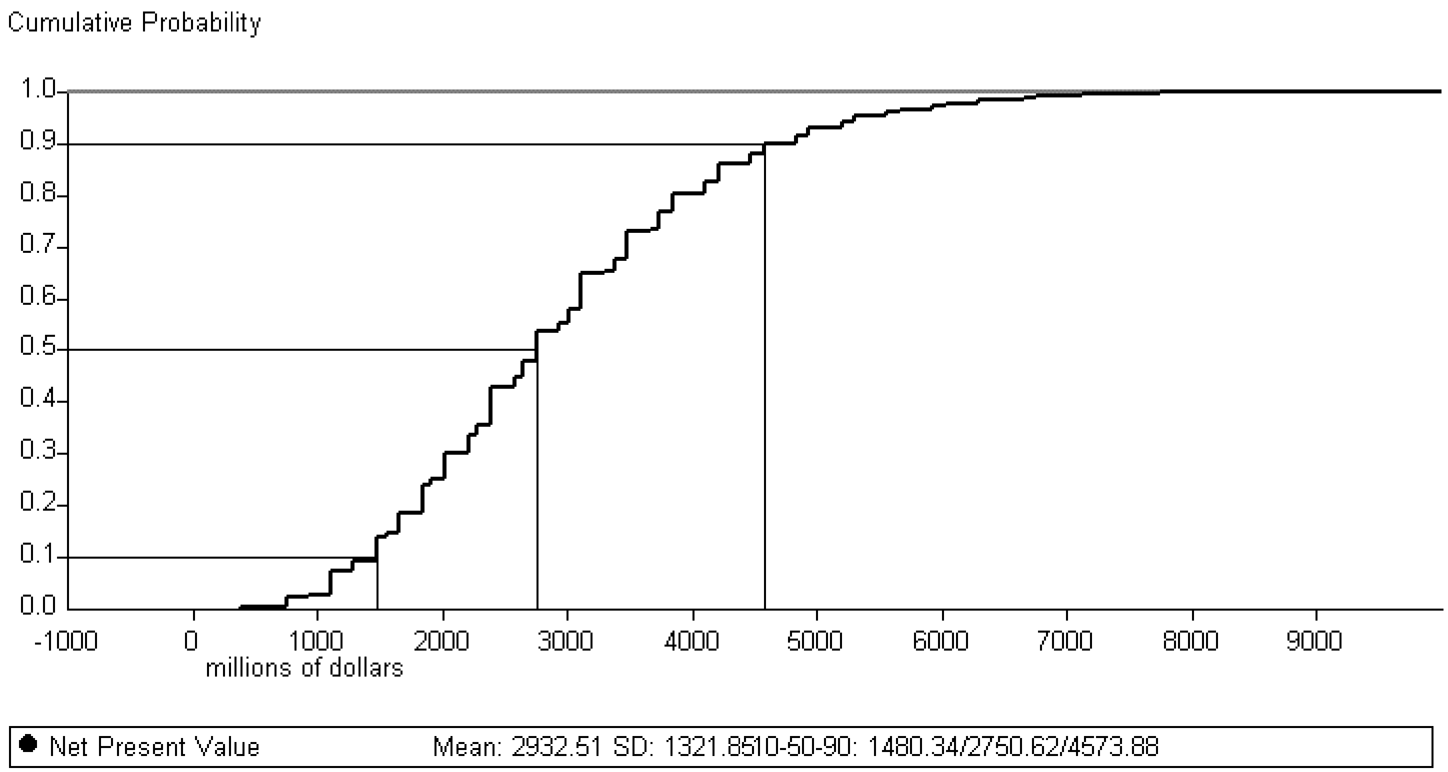
Full Datalink
Cumulative Probability Distribution



Full Datalink

Value of Perfect Information and Control

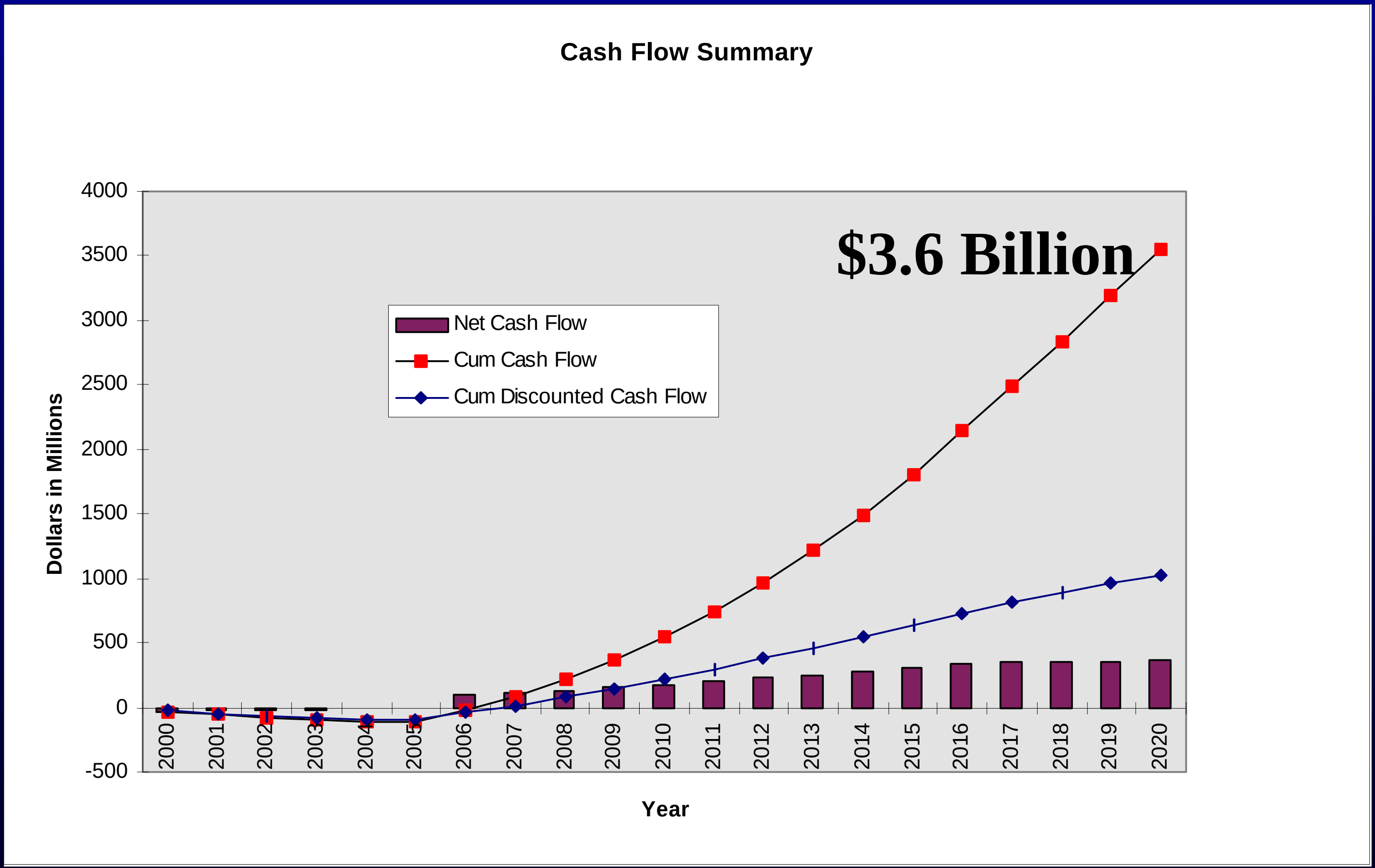
Selected Chance Variables	VOPI	VOPC
Equippage Scenario	0.0	$787M
Delay Incr % per Yr	0.0	981
ATC Build 1A Eff %	0.0	50
Atlanta Discount Factor	0.0	846
AOC NA Strt Yr	0.0	282
Delay vs. Equip Curve	0.0	353
AOC NA ($ per Flt)	0.0	691

Value of Perfect Information: The value of knowing the outcome of an uncertainty before you make the investment decision.

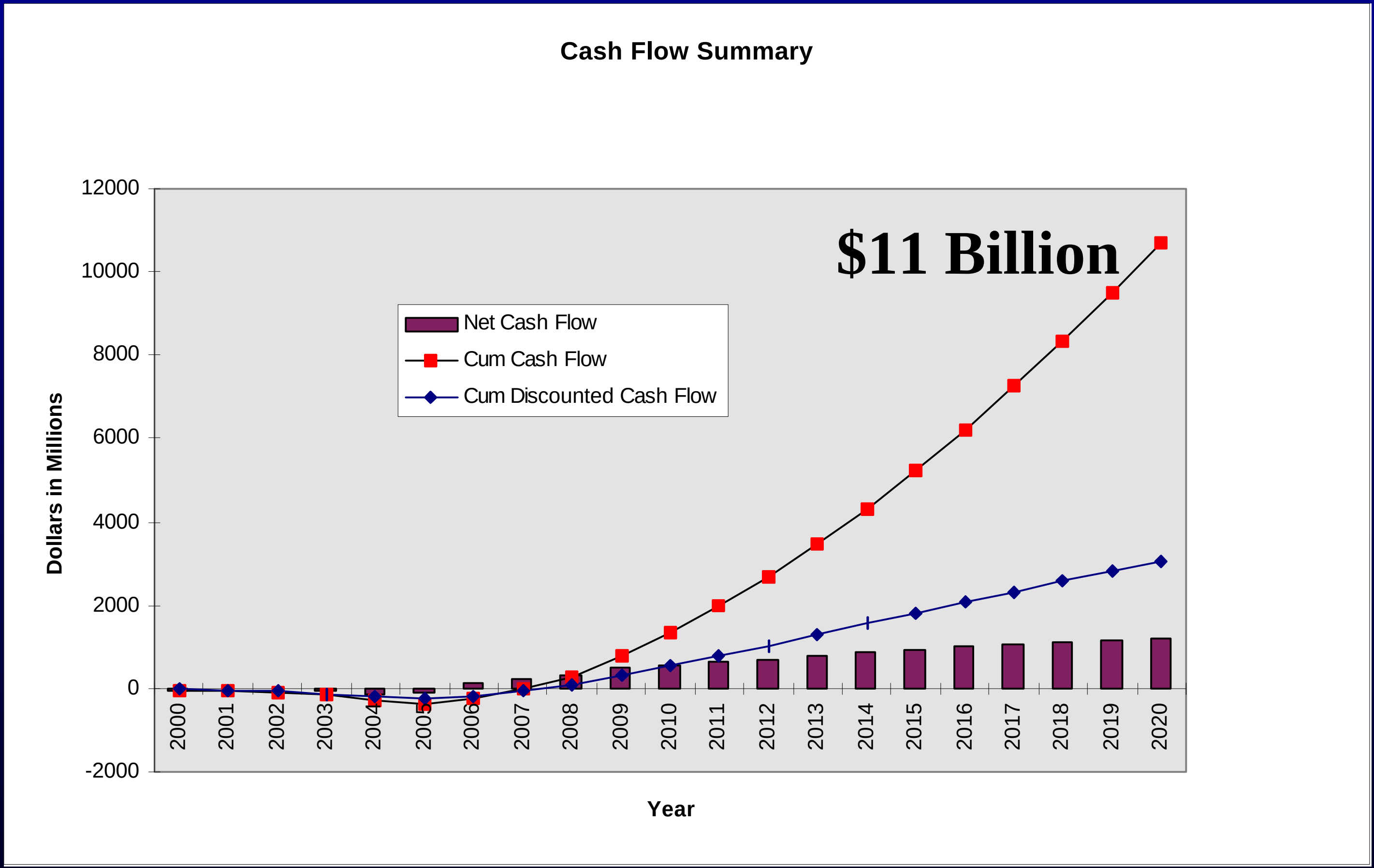
Value of Perfect Control: The value you of ensuring that the outcome of an uncertainty comes out to the most favorable outcome for your decision.

Note: These calculations assume a 25% chance of the 10th percentile event occurring, a 50% chance of the 50th percentile event occurring, and a 25% chance of the 90th percentile event occurring.

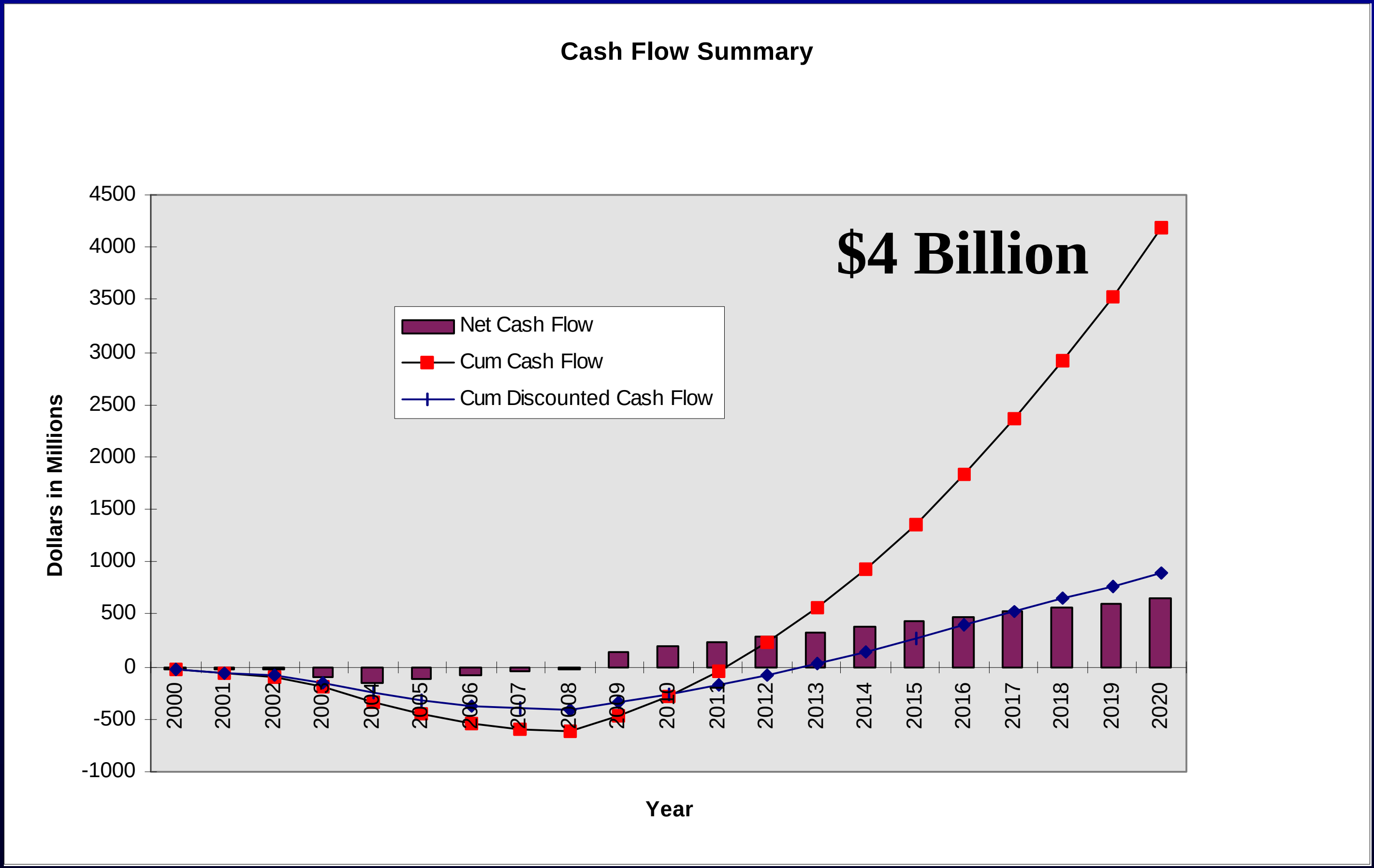
AOC Only--Cash Flow Summary



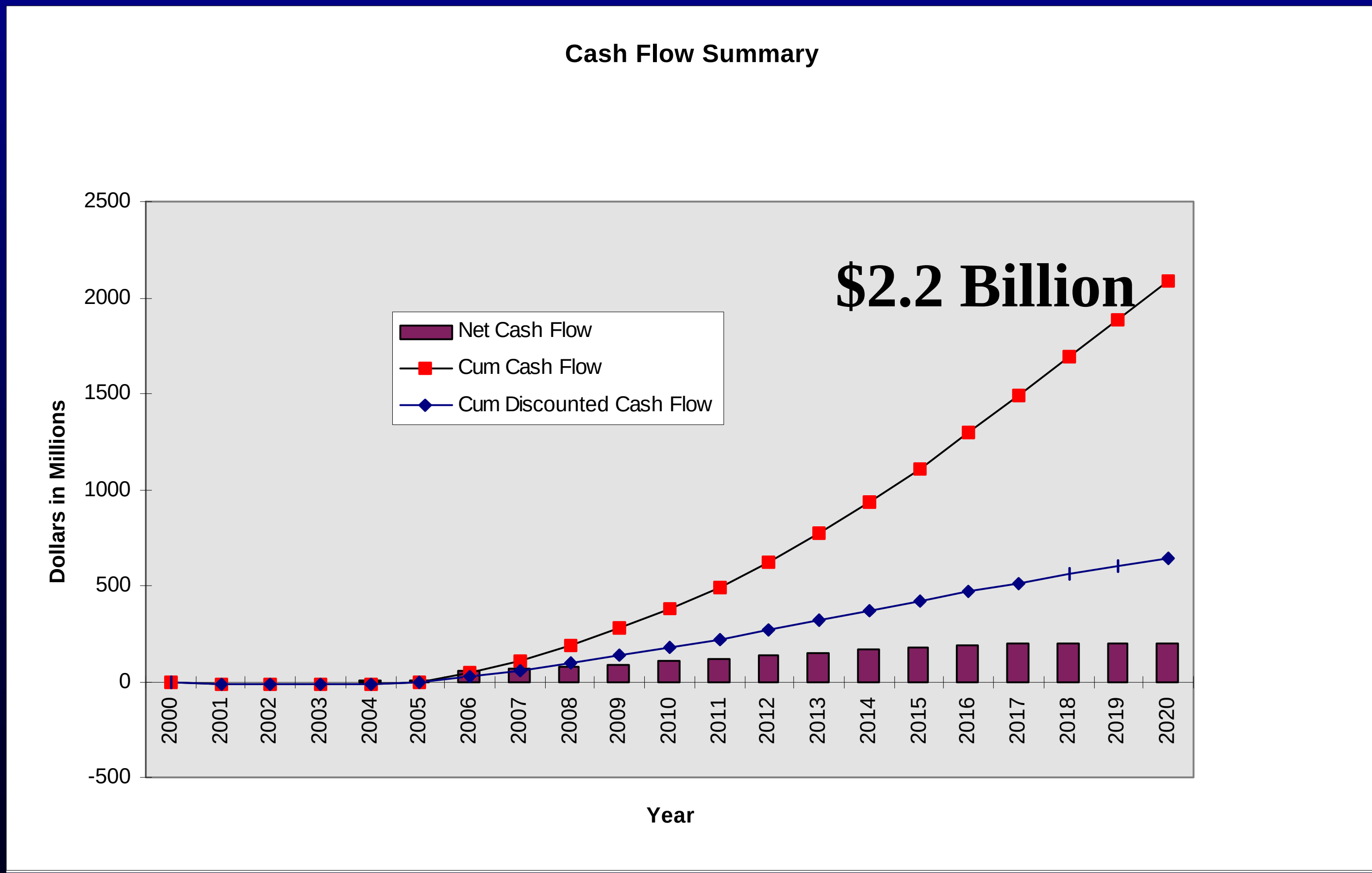
Full Datalink--Cash Flow Summary



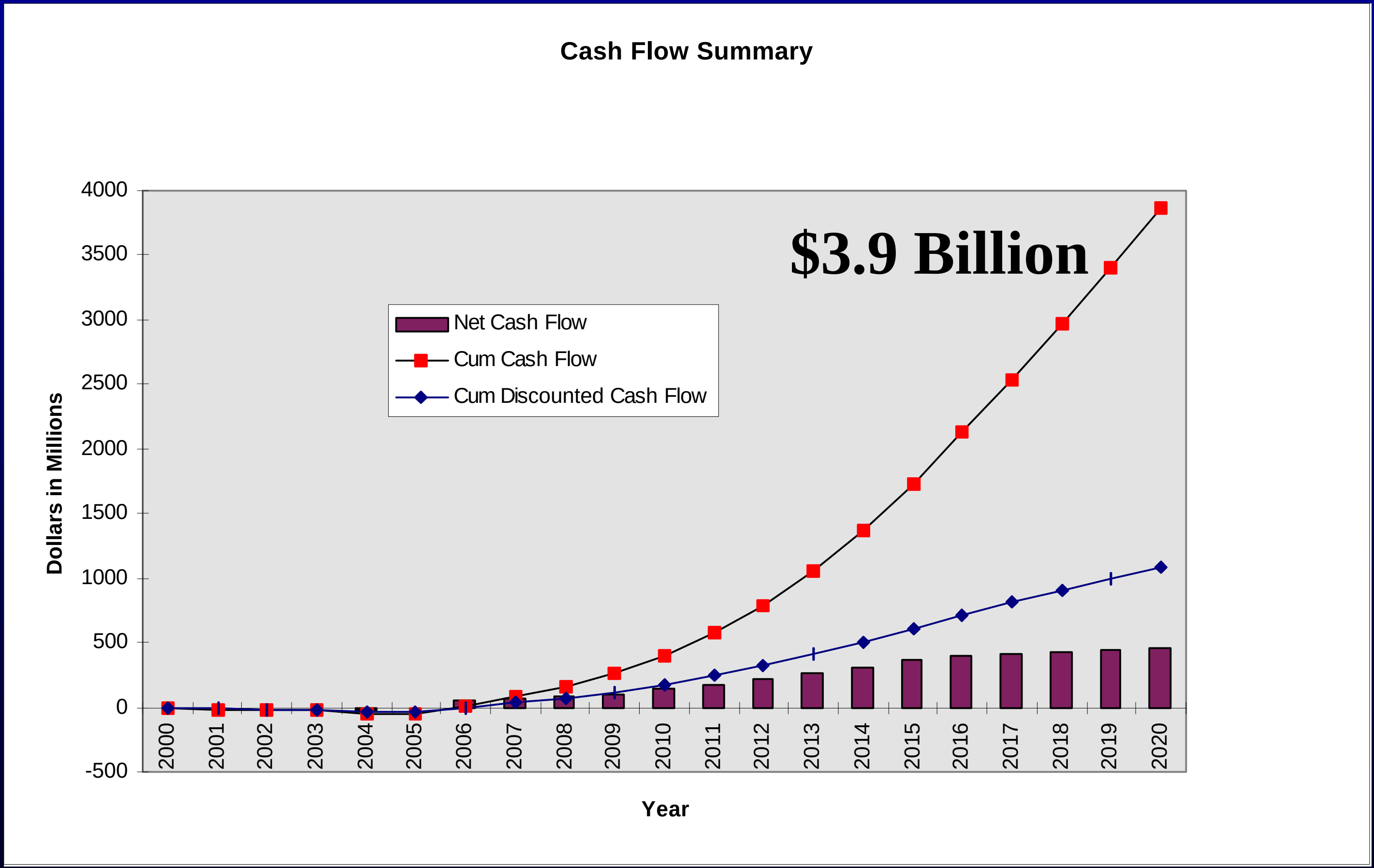
ATC Only -- Cash Flow Summary



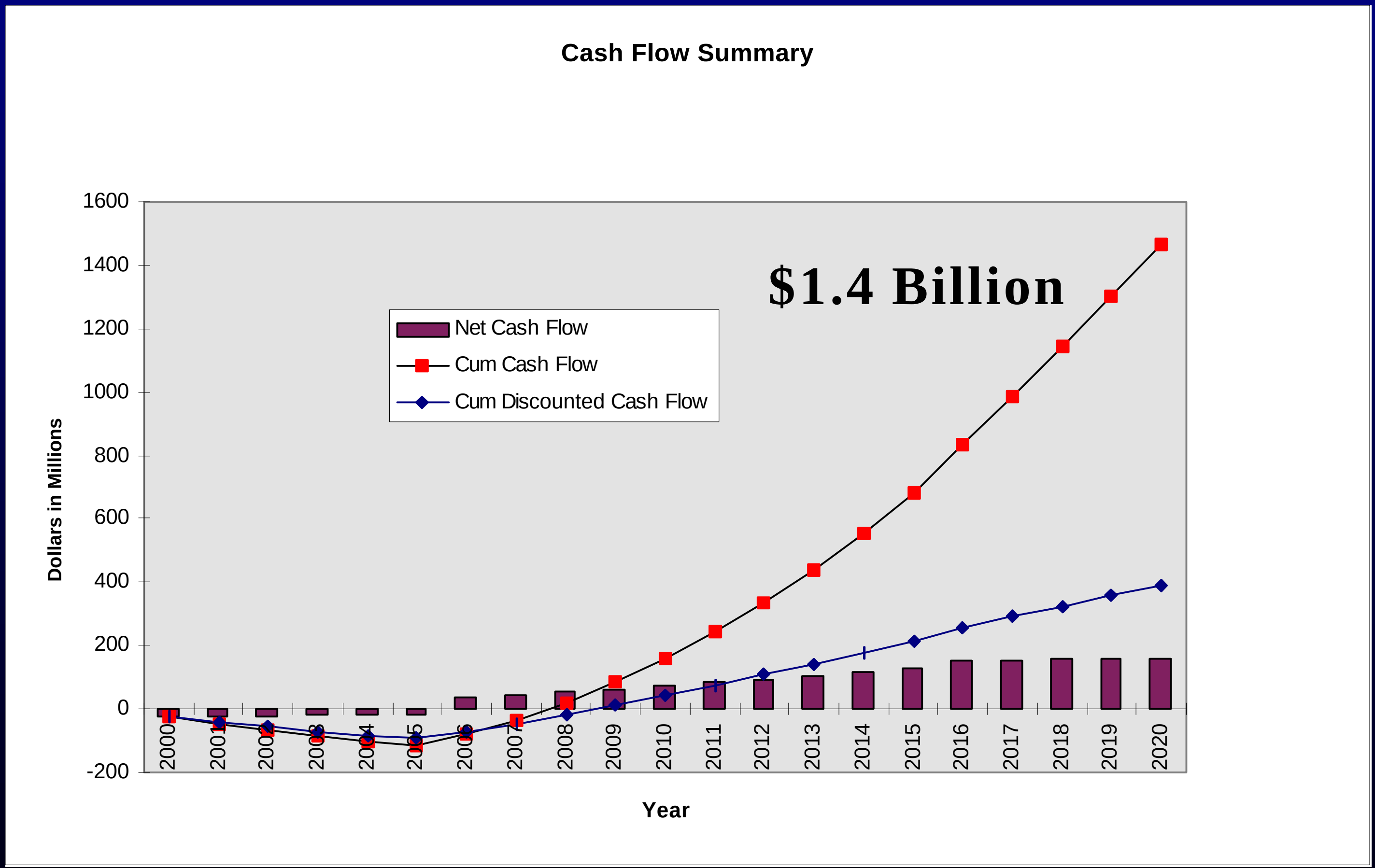
AOC Only FF
Cash Flow Summary



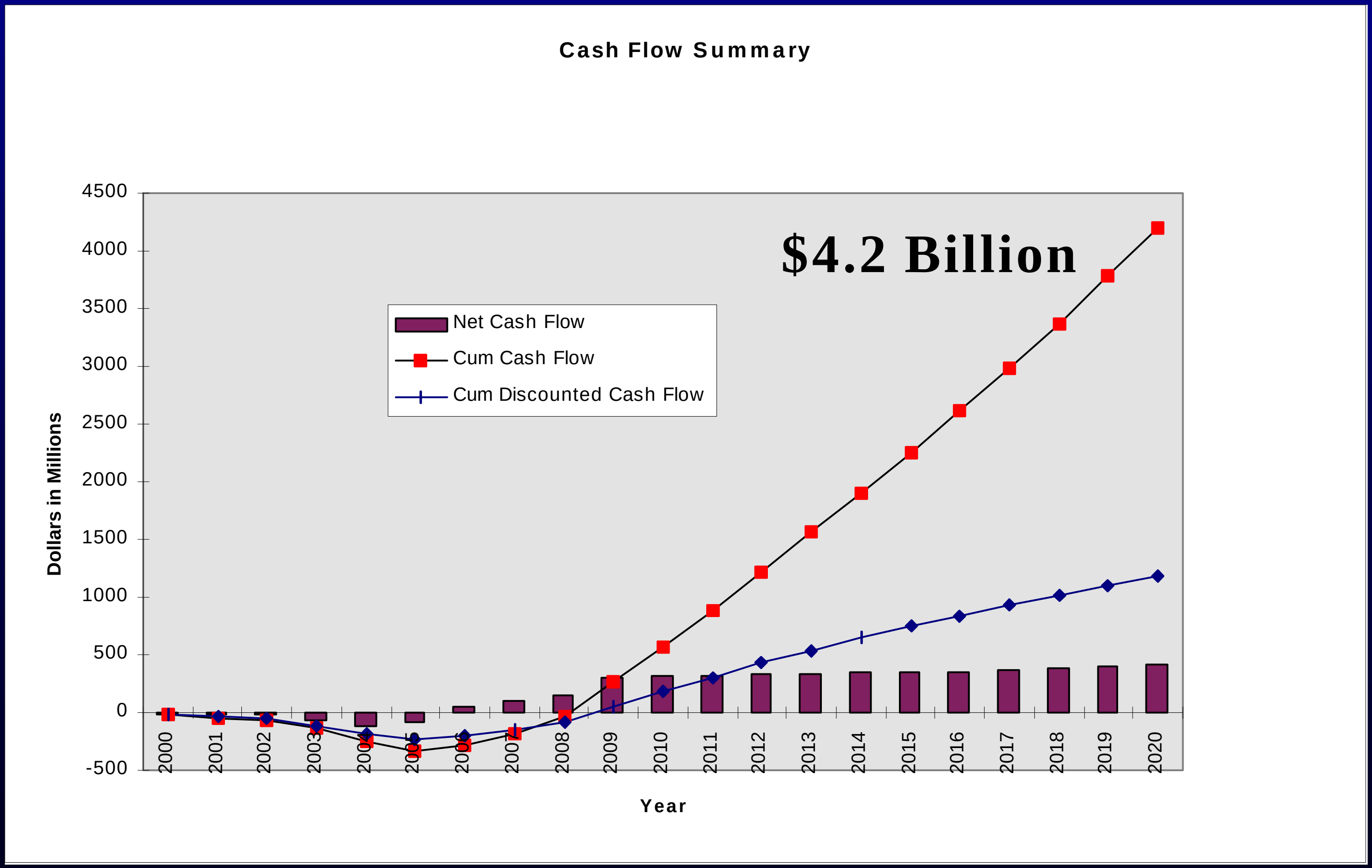
Full Datalink FF--Cash Flow Summary



AOC Only Retrofit
Cash Flow Summary



Full Datalink Retrofit
Cash Flow Summary



ROI's for Datalink Scenarios

Scenario	End Equippage %*	Expected NPV	Expected Productivity Net Expected Benefit / 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

Conclusions

- 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.
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Conclusions

- 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.
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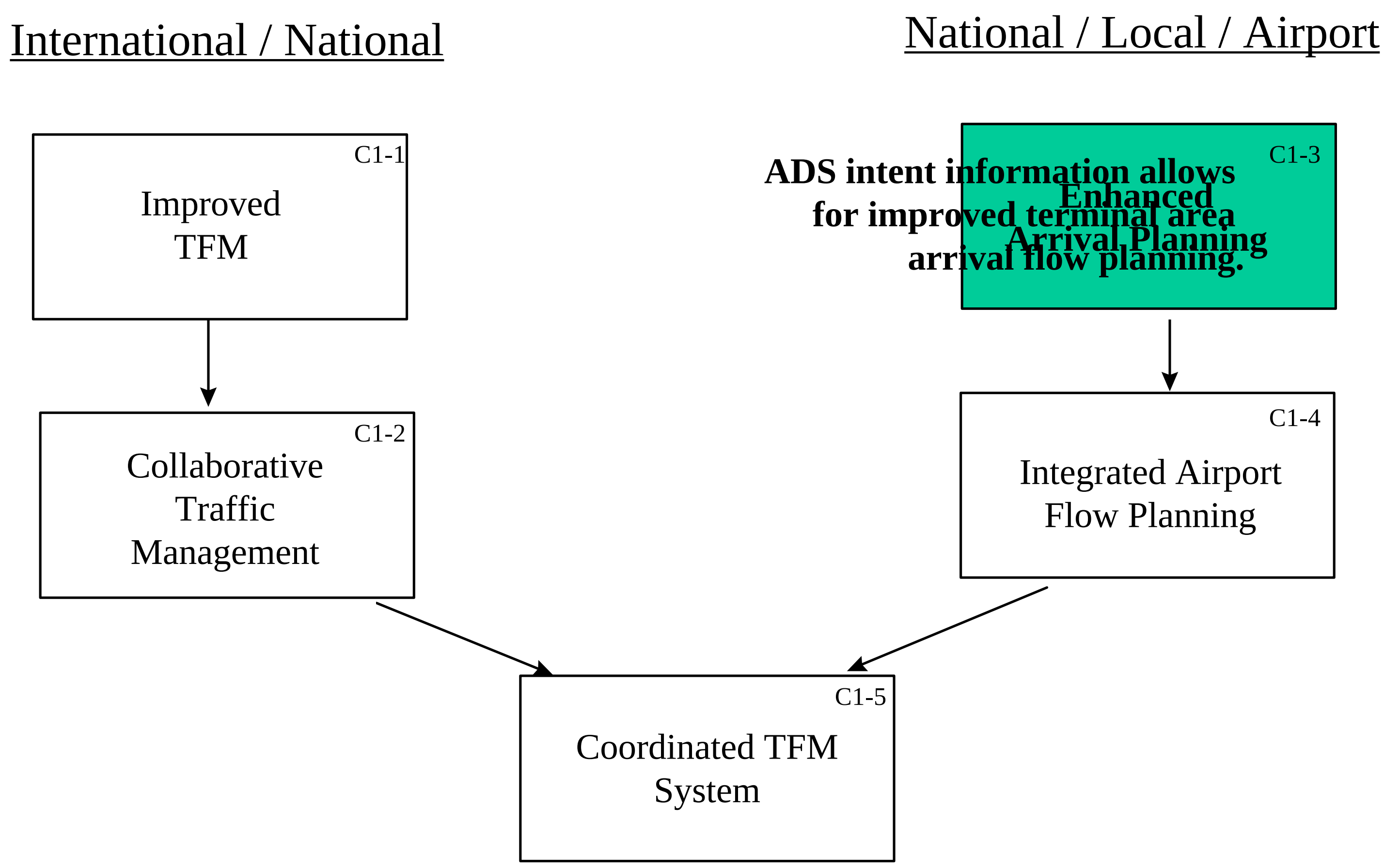
Conclusions

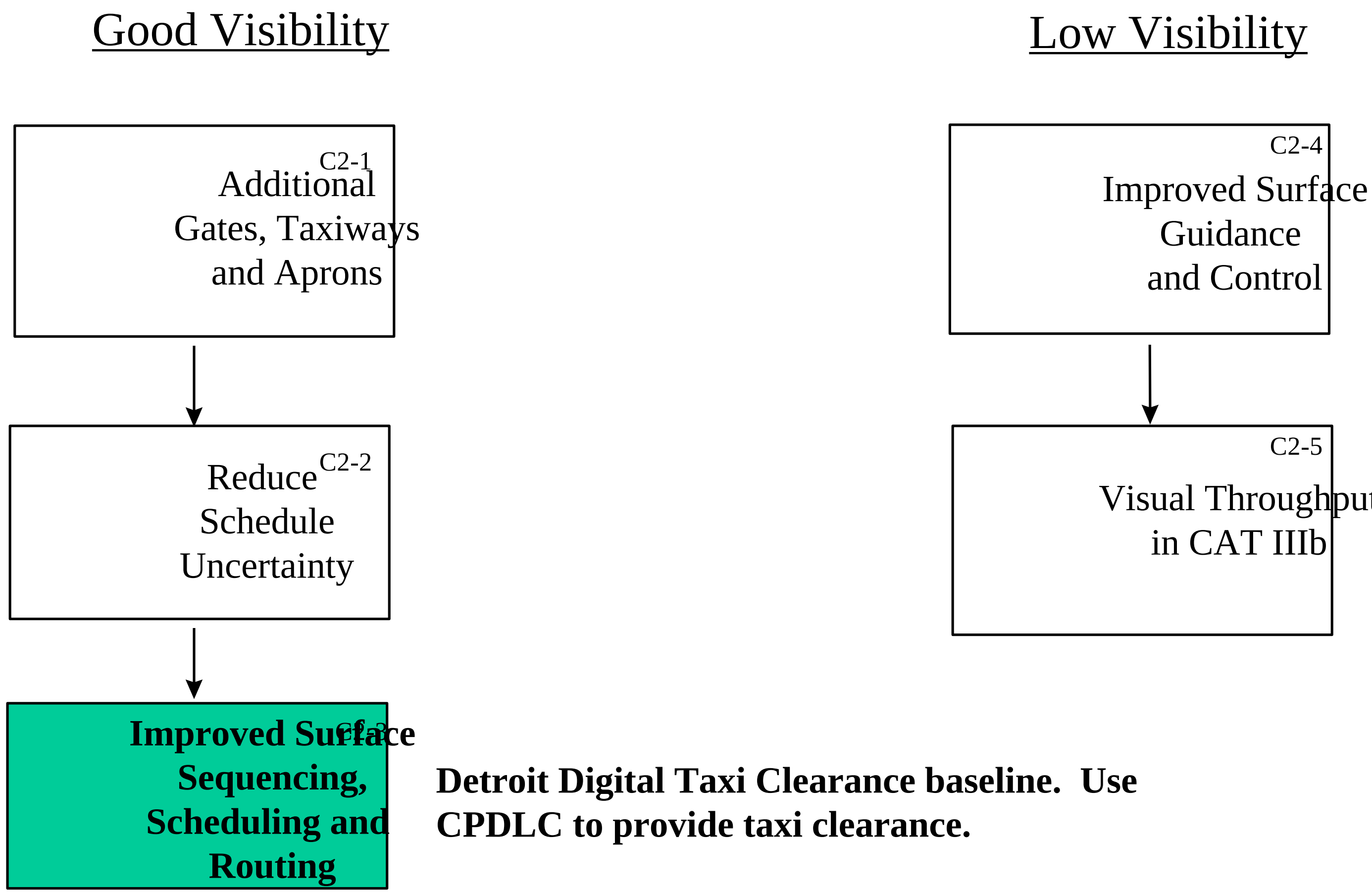
- Retrofit equipage will be driven by ATC
  - ATC delay reduction benefits are highly dependent on equipage levels, thus providing an incentive for airlines to retrofit.
  - AOC frequency congestion constraints may be sufficiently alleviated by forward fit equipage, thus providing little incentive to 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.**

Potential Benefit of Future Datalink Enhancements

1. Planning Capacity Transitions

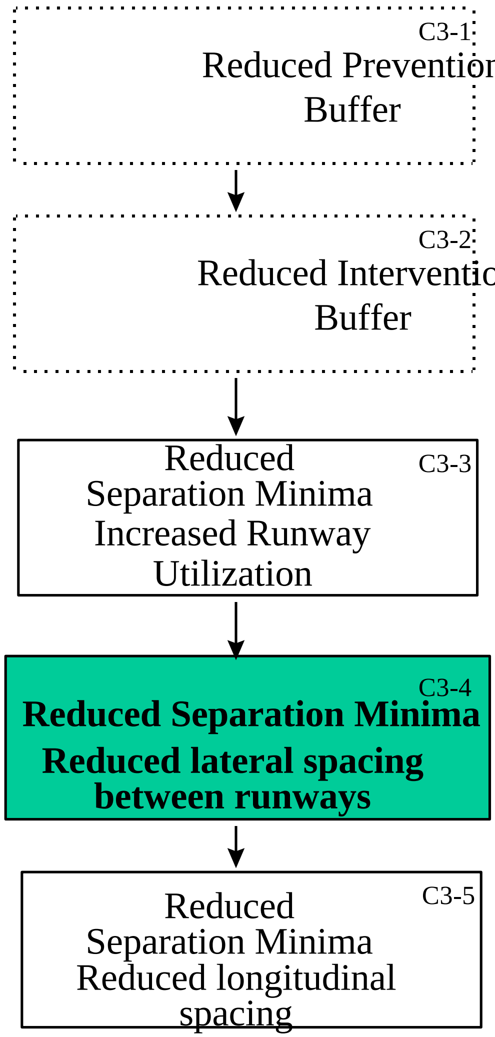


2. Surface Capacity Transitions

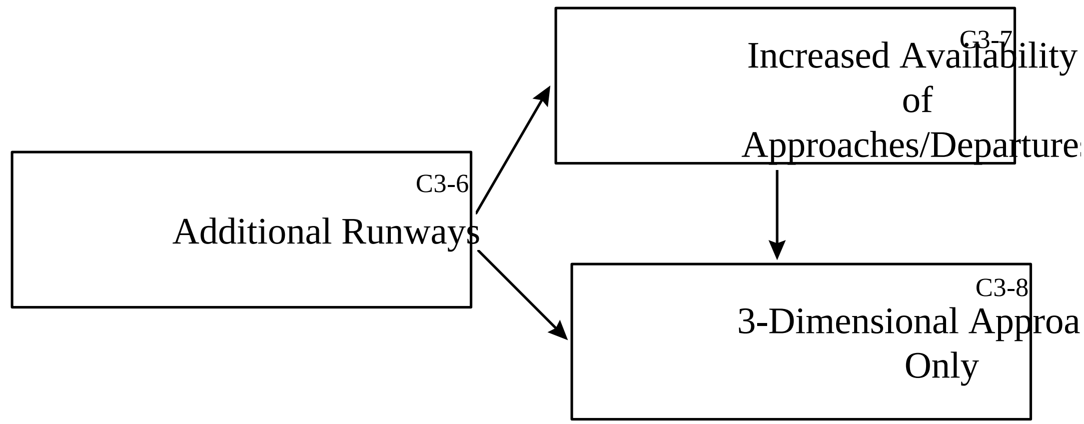


3. Final Approach / Initial Departure Capacity Transitions

Airplane-Level Capacity Effects



System-Level Capacity Effects



Use ADS to reduce lateral separation for independent operations to 2500’.

4. Approach / Departure Transition Capacity Transitions

Airplane-Level Capacity Effects

System-Level Capacity Effects

C4-1 Reduced Prevention Buffer

C4-2 Reduced Intervention Buffer Ground Vectoring

C4-3 **Reduced Intervention Buffer Ground Guidance with A/C trajectories**

Use ADS with CTAS for more efficient sequencing.

C4-4 **Reduced Intervention Buffer A/C Guidance**

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

C4-5 **Reduced Separation Minima**

TBD

C4-6 More Transitions

C4-7 Increased Availability Existing Transitions

CNS/ATM Focus Team

5. TMA Arrival/Departure Capacity Transitions

System-Level Capacity Effects

C5-5 More Vertical Profiles ⟷ C5-6 More Publ SIDs and S

Airplane-Level Capacity Effects

C5-1
Reduced Prevention Buffer
Lower controller workload

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

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C5-2
Reduced Prevention Buffer
State vector prediction

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

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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

6. En-Route Capacity Transitions (Procedural Separations)

Airplane-Level Capacity Effects

C6P-1
Reduced Prevention Buffer

C6P-2
Reduced Intervention Buffer

C6P-3
Reduced Separation Minima
50/50 Horizontal

C6P-4
Reduced Separation Minima
30/30 Horizontal

ADS used to provide position data to ATC.

C6P-5
Reduced Separation Minima
15NM radius

TBD

C6P-6
Reduced Separation Minima
< 15NM radius

TBD

System-Level Capacity Effects

C6P-7
More Flight Levels

C6P-8
More Published Routes

6. En-Route Capacity Transitions (Radar Separations)

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 Comm Workload)**	**Atlanta study baseline. Data Link 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**