

**Encouraging Technology Transition through Value Creation, Capture and Delivery Strategies: The Case of Data Link in the North Atlantic Airspace**

by

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Bachelor of Science in Aerospace Engineering  
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Submitted to the Engineering Systems Division  
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Master of Science in Technology and Policy

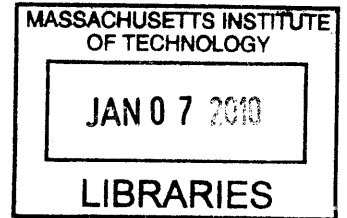
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## **Abstract**

This thesis studies the problem of data link in the NAT under a technology transition framework of value creation, capture, and delivery. Creating value through a new technology, such as data link, refers to designing competitive value propositions for stakeholders. Capturing value means recovering an investment in a technology through the value it creates. Delivering value refers to developing policies and business strategies to enable value capture. Realization of these concepts is necessary to guarantee technology transition.

Data was gathered from a survey of the two major stakeholder groups in the NAT, commercial operators and ANSPs. The survey covered five major research areas: 1) Perceived operational and coordination inefficiencies; 2) Opportunities to improve service; 3) Current and projected data link equipage and infrastructure in the NAT; 4) Value distribution of data link costs and benefits; and 5) Potential policy strategies to encourage data link adoption.

The study found that data link creates value for stakeholders through an understanding of the evolution of technology and stakeholder needs. Fuel penalties associated with flying suboptimal flight levels and routes is the largest inefficiency in the NAT. Data link, particularly through the FANS system, is seen as the enabling technology to improve efficiency of operations. Reducing separation is the data link application most valued by stakeholders. Coordination and harmonization issues threaten to limit the value created.

Data link diffusion (airborne equipage and ground infrastructure) is not always guaranteed as a result of value created due to improvements in technical performance. Value capture is limited due to unbalances in the distribution of data link costs and benefits. So far, data link operational benefits have been significant but have not yet translated into economic benefits given that such applications have not been implemented in the NAT. Delivering value from data link is more than balancing costs and benefits. Uncertainty in a number of issues needs resolution before the value created through data link could be fully captured and delivered. A combination of operational, financial and regulatory schemes may be necessary to leverage costs and benefits and ensure successful data link value delivery to all stakeholders.

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# Chapter 1

## Introduction

This thesis will discuss value creation, capture, and delivery strategies to promote technology transition in air transportation. These strategies will be studied through the case of data link in the North Atlantic (NAT) airspace. This chapter will provide an introduction to this topic. Section 1.1 will present the motivation behind this thesis work. Section 1.2 will explain the objectives of this study. Section 1.3 will show the research questions that this thesis is trying to answer. Section 1.4 will provide background material on the NAT concept of operations and data link technologies used in oceanic airspace. Section 1.5 will introduce the stakeholders participating in NAT operations and, finally, section 1.6 will depict a roadmap to outline the flow of the following chapters.

### 1.1 Motivation

The North Atlantic is the busiest oceanic airspace in the world (NAT SPG, 2005). The NAT Traffic Forecasting Group (TFG) projects a passenger demand growth from 76.4 million in 2007 to 136.7 million by 2020. Additionally, the group estimates traffic to growth from 442,500 flights in 2007 to 724,900 flights by 2020 (NAT TFG, 2008). With this level of growth, the NAT Aeronautical Communications Group (ACG) predicts that the High Frequency (HF) network infrastructure will experience congestion problems as

early as 2009 (NAT EFG, April 2008). Further, increases in fuel prices (averaging \$3 in April 2008) (U.S. DOT, June 2008), have placed a significant burden on the NAT airspace users.

## **1.2 Objectives**

The objectives of this study are:

- Identify strategies to improve efficiency of operations over the NAT airspace based on creating and capturing value from data link technologies.
- Evaluate policy measures to encourage data link adoption and ensure value delivery from data link to all stakeholders involved.

## **1.3 Research Questions**

This thesis will attempt to answer the following questions in the areas of data link value creation, capture, and delivery:

### Value Creation

- How do data link technologies create value for stakeholders?
- How does technology diffusion impact the creation of value from data link?
- How do stakeholder structures and synergies impact the creation of value from data link?

### Value Capture

- What are the elements that need to be in place in order to capture value from data link?

- What is the impact of risk and uncertainty as barriers for value capture?

### Value Delivery

- What policy strategies could be used to successfully deliver value from data link adoption to all stakeholders involved?

## 1.4 Background

This section will provide an introduction to the operations and data link technologies available in the NAT region.

### 1.4.1 North Atlantic Concept of Operations

The NAT airspace is divided into seven Flight Information Regions (FIRs) (Figure 1-1), each of which provides traffic crossing the NAT with communications, navigation, surveillance, and air traffic management. The International Civil Aviation Organization (ICAO) regulates the division of oceanic airspace among authorities of the participating countries (ICAO, April 1999).

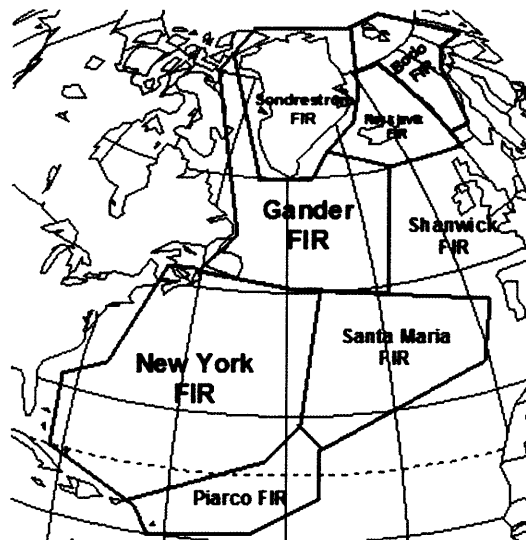


Figure 1-1: North Atlantic Flight Information Regions (Adapted from FAA, June 1999).

There are two major traffic flows between North America and Europe, one for eastbound and one for westbound flights. For each flow, traffic is divided into 4-7 nearly parallel tracks, known as the Organized Track System (OTS). The exact location of these tracks is updated twice a day according to wind and meteorological conditions (ICAO, April 1999). When flying along the OTS, operators need to maintain a certain track, flight level, and speed as determined by the air traffic controller (Williams, 2005). This rigidity penalizes airline fuel efficiency. Figure 1-2 shows an example of west bound tracks.

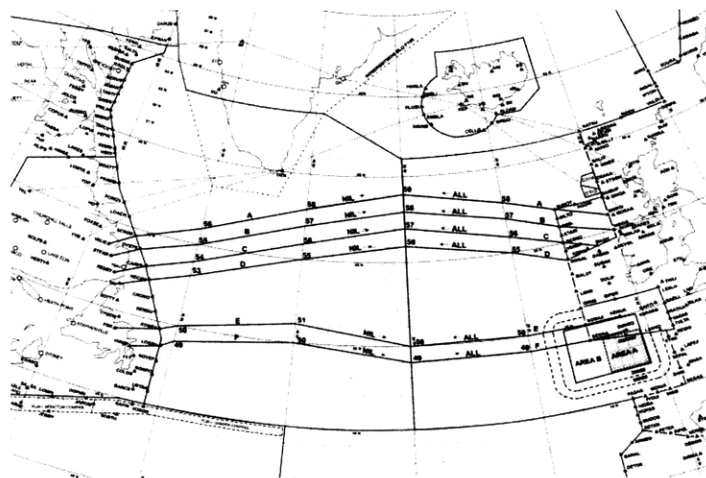


Figure 1-2: Example of a West-Bound Organized Track System  
(Adapted from NAT SPG, 2005)

Most of the NAT airspace is out of the range of VHF and radar. The majority of communications take place using High Frequency (HF) voice, which is subject to disruption, atmospheric effects, ambiguity in accents, frequency congestion, and a third party relay between pilots and controllers (ICAO, April 1999). One position report using HF voice is usually done every 10 degrees of longitude or, roughly, once every hour.

Due to the lack of surveillance and timely controller intervention capability, safety in the NAT is maintained by imposing large longitudinal (10 minutes) and horizontal (60 NM or 1 degree of latitude) separation standards (Figure 1-3).

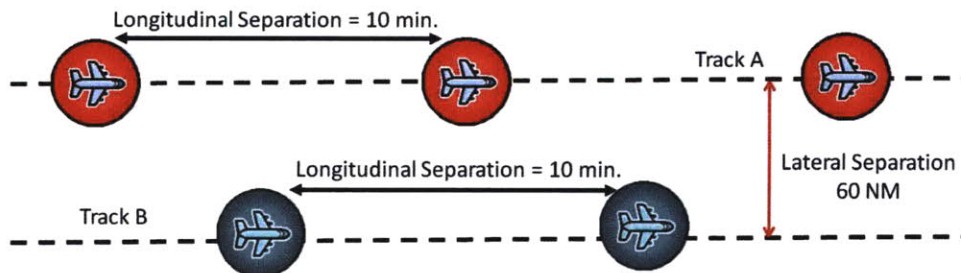


Figure 1-3: North Atlantic Lateral and Longitudinal Separation Standards

### 1.4.2 Data Link Technologies in Oceanic Airspace

#### FANS-1/A

Boeing's version of FANS is known as FANS-1 while Airbus' version is known as FANS-A. Both versions combined are known as FANS-1/A and meet Boeing's System Requirements and Objectives (SR&O) and Airbus' System Objectives and Requirements (SO&R). The FANS-1/A system has three main functionalities (NAT SPG, May 2001):

- a) ATS Facilities Notification (AFN): used to initiate logon between aircraft and ATS facility.
- b) Controller Pilot Data Link Communication (CPDLC): enables direct data link communication between pilot and ATS facility using either pre-defined or free text message formats. Used to conduct clearances, requests, acknowledgements, negotiations, and other communications.
- c) Automatic Dependent Surveillance - Contract (ADS-C): enables automatic report of position, velocity, intent, and other information via a contract established between aircraft and ATS facility. Contracts can be based on a reporting rate (periodic contract); requested when a determined event, such as altitude change, occurs (event contract); or when demanded by ATS unit (demand contract).

#### SATCOM Voice (SatVoice)

SATCOM voice could provide a secondary communication method in case of poor HF conditions, offering a direct communication channel between pilots and controllers.

Trials have been conducted to validate procedures, availability, integrity, reliability, security, and technical issues (Inmarsat, October 2007).

### FMC-WPR

System allows automatic or semi-automatic position reporting via the Flight Management Computer (FMC). Used as an alternative to ADS-C reports for aircraft not equipped with FANS-1/A. FMC-WPR does not follow the same message format of the ADS-C reports available through FANS-1/A (Dimock, 2001).

### HFDL

Only data link communication capability in the North Pole, where SATCOM availability degrades. Approved for use with FMC-WPR position reports, but pending approval with ADS-C and CPDLC. HFDL can be used as a data link medium by aircraft not equipped with SATCOM or as a fully compatible complement to SATCOM (ARINC Incorporated, 2003).

### ADS-B

An aircraft carrying ADS-B Out equipage is capable of transmitting position and other state information to air traffic control and other aircraft equipped with ADS-B In. In addition to broadcasting information, an aircraft carrying ADS-B In equipage is capable of displaying traffic situational awareness using a cockpit display. Three data link technologies support ADS-B: Mode-S 1090 Extended Squitter, VHF Data Link (VDL) Mode 4, and Universal Access Transceiver (UAT).

### AIDC

The ATS Inter-facility Data Communications is used to exchange information for notification, coordination, and transfer of control between ATS facilities (Mizoguchi, 2001).



## ANSP Oceanic Automation Systems

Oceanic automation reduces controller workload by improving surveillance, conformance monitoring, and coordination with other ATS units. Common functionalities of oceanic automation systems include: integration of oceanic flight data processing, 4D trajectory modeling, conflict predicting and reporting, aircraft situation display, FANS-1/A capabilities, AIDC, electronic flight strips (Addison, 2006).

## Oceanic Clearance Delivery (OCD)

OCDs allow exchange of messages for pilots to request oceanic clearances and controllers to deliver them by exchanging text messages. SITA and ARINC provide data link service through ACARS network. OCDs are available in Shanwick, Gander, and Santa Maria Oceanic Centers (NavPortugal, 2007).

## **1.5 Stakeholder Description**

Due to time and resource constraints, the work done in this thesis will focus on the two major stakeholder groups: commercial operators and Air Navigation Service Providers (ANSPs). Both of these groups have a large stake in terms of level of influence, operations conducted, and services provided; however, it is important to acknowledge that other stakeholders exist in the NAT and that all groups impact each other. Other NAT stakeholders include satellite operators, communication service providers, business and military aviation, and the traveling public. Figure 1-4 shows these groups and their interactions.

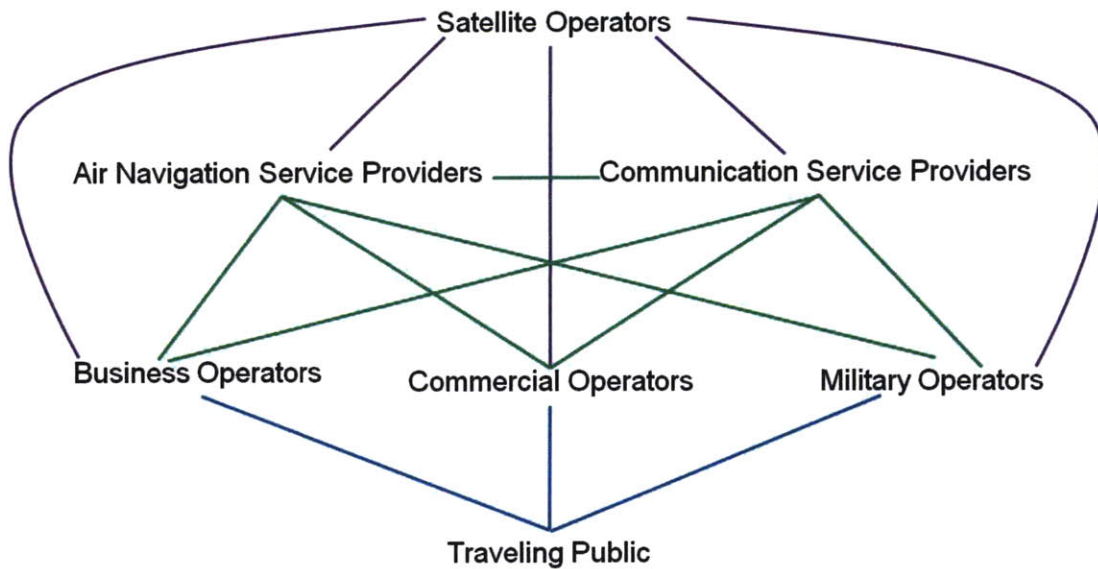


Figure 1-4: NAT Stakeholder Groups.

## 1.6 Thesis Roadmap

This thesis will use a technology transition framework to describe strategies to create, capture, and deliver value from data link to all stakeholders. This chapter provided an introduction to the NAT Concept of Operations and data link technologies used in oceanic airspace. Chapter 2 will describe the literature review that contributed to shape the technology transition framework. Chapter 3 will introduce the methodology used to conduct a survey of the two major NAT stakeholder groups. Chapters 4, 5, and 6, respectively, will analyze how value derived from data link can be created, captured, and deliver to all stakeholders involved. Figure 1-5 shows the interaction among these different elements. Finally, Chapter 7 will provide a synthesis of main findings.

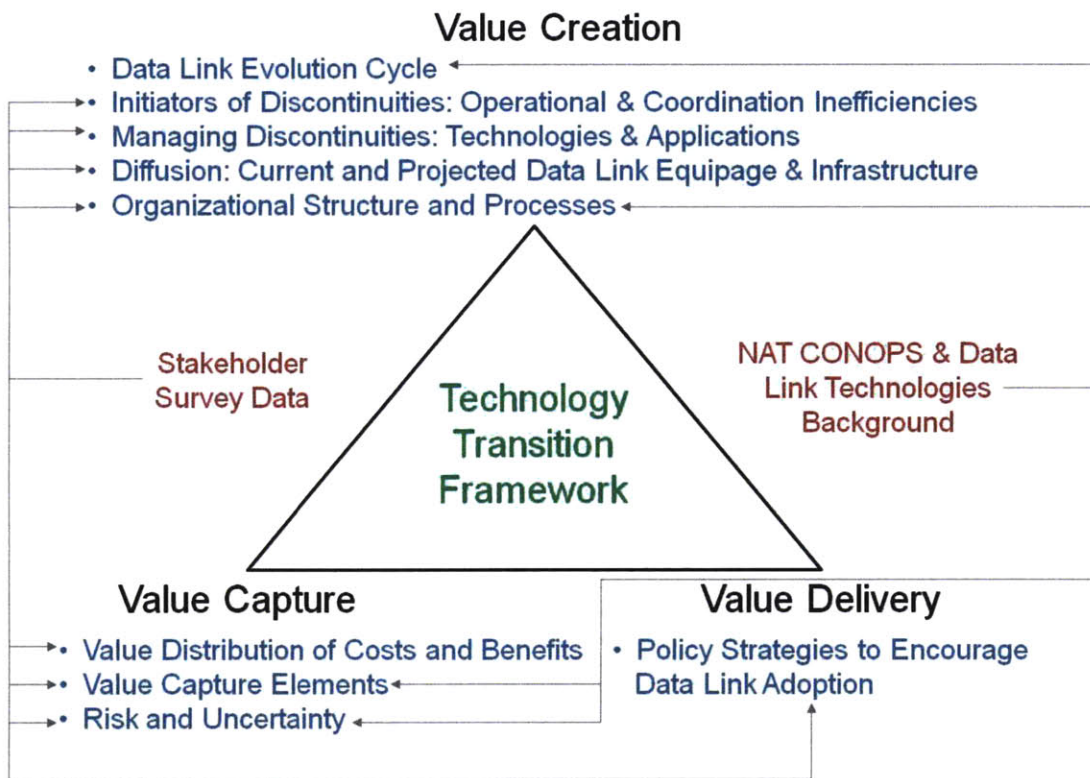


Figure 1-5: Thesis Roadmap.

## **Chapter 2**

# **Technology Transition Framework**

This chapter introduces the key concepts that will be used throughout the thesis to understand the case of data link in the North Atlantic. Section 2.1 reviews the contributions of this thesis and the type of literature covered. Section 2.2 details the analysis framework in terms of value creation, capture, and delivery concepts and, finally, section 2.3 summarizes key ideas from this chapter.

### **2.1 Literature Review**

Previous work has been done in identifying some of the elements of value creation, capture, and delivery discussed in this chapter with application to the case of data link over the North Atlantic. So far, past research tends to focus on isolated components of the data link case. For example, studies have been conducted to identify potential new services and benefits derived from data link but have not addressed issues which need resolution before such benefits can be realized; including uncertainty, technical limits, coordination, or implementation strategies. The contribution of this thesis is to analyze the case of data link in the North Atlantic under a framework of technology transition by integrating strategies to create, capture and deliver value to all stakeholders.

The literature review conducted to shape the skeleton of the conceptual model covered research in the areas of business and management, economics, public policy, transportation, strategy, and administrative science. The studies reviewed included topics in technology transition life-cycles; economics of technology evolution and diffusion; coordination of multinational infrastructure projects; management and dynamics of discontinuous innovation; failure of high-technology markets; network properties and effects; equilibrium models; organizational environments; and business models, technology platforms, and standards.

Although the fields covered in the literature review are diverse, some of the concepts found can be applied to study technology transition in air transportation. The literature is particularly helpful in setting up a framework for value creation by understanding how technology and stakeholder needs evolve. Similarly, value capture is understood through complementary assets or services, network effects, and standard tipping. Finally, value delivery is studied by evaluating approaches to balance the value distribution of costs and benefits.

At the same time, due to inherent differences in the fields reviewed, some of the concepts found in the literature cannot be directly translated to air transportation studies, particularly in the areas of management strategy, business models, and organizational environments. For example, under management strategy literature, uniqueness or control of knowledge generated by an innovation is an important strategy for value capture. However, the concept of uniqueness is not applicable to the problem of data link in the NAT studied in this thesis. Similarly, value chain dynamics, market competition, and the creation of platforms and ecosystems to capture value do not adapt to explain technology transition in air transportation. Unlike the problem of one firm striving to remain competitive, the field of air transport needs to deliver global solutions based on core values of safety and efficiency to all stakeholders involved.

## 2.2 Analysis Framework: Data Link Value Creation, Capture, and Delivery

### 2.2.1 Value Creation

Christensen describes two types of technology evolution. The most common type of transition is one of sustained development, which leads to continuous improvements in performance while fully exploring the potential of existing architectures (Henderson and Kim, 1990). The second type is one of disruptive transition, which completely redefines performance trajectories (Christensen, 1997) and requires altering the current mode of behavior of the services enabled by the innovation (Moore, 1999). Disruptive technologies also open the possibility to achieving completely new applications (Henderson and Kim, 1990). In fact, the traditional life cycle of a technology is characterized by four key phases. The first is an era of ferment and discontinuity, characterized by constant experimentation with different technical approaches. The second is a phase where a dominant design emerges, achieving more legitimacy based on the value it generates for stakeholders. The third is a phase of incremental innovation where the technology is “fine tuned” to generate more value. Finally, the fourth phase is reached when a technology reaches maturity (McGahan, 2004). This technology life cycle can be seen in Figure 2-1.

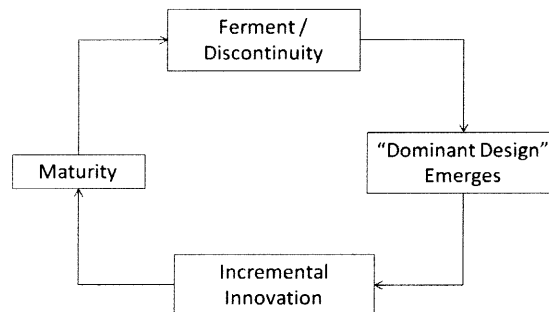


Figure 2-1: Technology Life Cycle (Adapted from Davis, 2008).

Ensuring technology transition in air transportation through all phases of the life-cycle, particularly when a technology is disruptive, requires having a strategy to address how the technology can be used to **create, capture, and deliver** value to stakeholders

(Henderson, 2004). Malinen describes value creation as “designing competitive value propositions” for stakeholders (Malinen, 2006). This implies understanding both technological change and the evolution of stakeholder needs (Davis, 2008).

An S-curve framework is frequently used to describe the path followed by technology development, showing the relationship between level of effort and improvement in performance. As technical limits are approached, an effect of diminishing returns is observed, yielding to a level-off in performance metrics (Utterback, 1994). At this point, a new technology usually replaces the current one. At first, transitioning into a new technology may appear less efficient and more costly than the current technology. However, after a period of ferment, the new technology is expected to outperform the current one (Foster, 1986). Figure 2-2 shows the technical life cycle described as an S-curve.

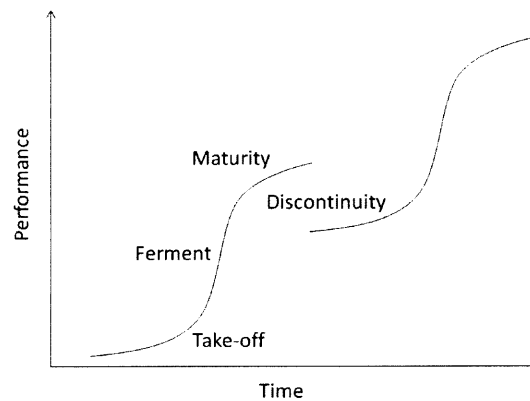


Figure 2-2: Technology Life Cycle as an S-Curve (Adapted from Davis, 2008)

The second component of value creation is understanding the evolution of the technical needs of stakeholders. A framework of technology diffusion is useful to study the “acceptance and spread of a new technology,” as proposed by Loch and Huberman (1999). According to their work, technology diffusion may be initially received by stakeholders with inertia or resistance to change. This is because the disruptive technology creates uncertainty for users and producers and may even destroy existing competencies, calling for the adoption of new procedures and methods. Throughout this thesis, uncertainty is understood as “the extent to which future states of the environment can be anticipated or accurately predicted” (Tushman and Anderson,

1986). Secondly, a new technology may not be entirely compatible at the beginning with the existing systems of which is part and may disrupt cooperation within the existing network. A third source of uncertainty is the organizational environment in which technologies operate, often characterized by conflicting stakeholder interests and perceptions. Technical superiority of a new technology may not guarantee diffusion in itself (Loch and Huberman, 1999). In other words, a technical S-curve may not necessarily translate into a diffusion S-curve (Davis, 2008), as shown in Figure 2-3. Other factors that increase inertia include: a large base of user population of current technology, small network externality benefits, large performance advantage of current technology, and uncertainty in the benefits provided by the new technology. Such sources of uncertainty need to be resolved in order to overcome resistance and promote technology transition (Loch and Huberman, 1999).

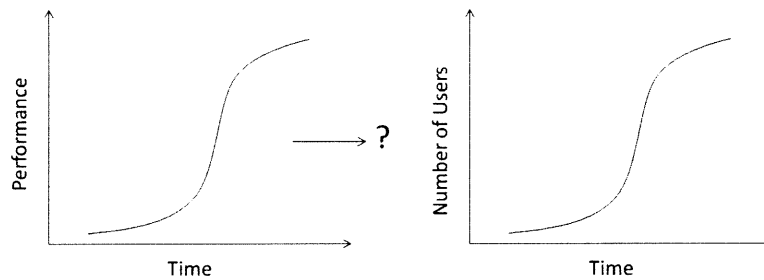


Figure 2-3: Relationship between S-Curve and Diffusion Curve  
(Adapted from Davis, 2008).

Another way to understand technology diffusion in air transport is to look at market segmentation dynamics. Under this framework, adopters are classified in five main categories: innovators, early adopters, early majority, late majority and laggards. Very few adopters fall under the category of innovators. However, their endorsement is fundamental to reassure stakeholders that the technology works. They would often invest in a new technology with the purpose of exploring new properties. Early adopters also buy into a technology early on in the life-cycle but, unlike innovators, they tend to seek specific benefits from it. Approximately one third of the adopters belong to the third category, the early majority. Members of this segment will wait to see how a technology is benefiting others before deciding to adopt it. A strong baseline of proven benefits and the infrastructure to support the technology are necessary to encourage this



group to invest. Another third of the adopters usually belongs to the fourth category, the late majority. This group will usually wait until the technology becomes an established standard and will try to maintain the status quo unless change is necessary. Finally, the last segment is represented by the technology laggards. Stakeholders in this category are not interested in adopting a new technology if given the choice. This group is not particularly worth pursuing with targeted incentives (Moore, 1999). Figure 2-4 shows this segmentation of market adopters.

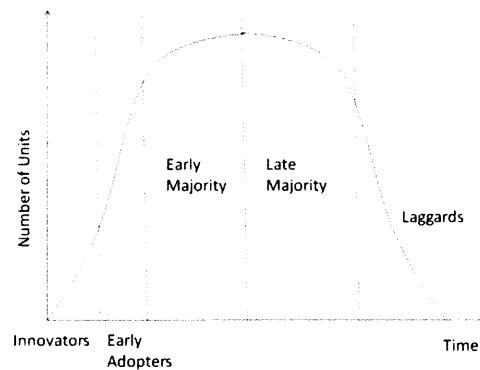


Figure 2-4: Rogers' Market Dynamics – Basic Segmentation (Adapted from Davis, 2008)

In order to create a high-tech market, groups in the bell-curve have to be captured from left-to-right, focusing first on getting the endorsement of innovators, then early adopters and so on before moving on to the groups on the right of the curve (High-Tech Market Model). This is important in order to stimulate the momentum necessary to create a bandwagon effect and encourage technology transition. In reality, transition between groups is not as smooth and incentives are often used to re-create momentum (Moore, 1999). Losses in momentum create cracks in the bell curve that could prevent transition into the next market segment. The first of these gaps occurs between innovators and early adopters when a technology does not readily translate into a new major benefit through a compelling application that generates intrinsic value for stakeholders. A second gap is identified between the early majority and the late majority. In order to bridge this gap, technology has to become increasingly easier to use and gain more relative value for stakeholders (Moore, 1999).

The larger and most problematic loss of momentum occurs as a chasm between the early adopters and the early majority (Figure 2-5). The danger of the chasm is that it is not

properly recognized most of the time. It occurs because the reasons for the early adopters and the early majority to invest in a new technology are fundamentally different. By betting on a new technology, the early adopter is trying to gain a business advantage in front of the competition through a radical discontinuity of the status quo, even if this means bearing with some of the glitches associated with innovation. In contrast, the early majority is interested in technical evolution to improve operations instead of radical change. When adopting innovation, the early majority wants to see the new technology already fully integrated with existing systems. In order to cross the chasm, additional incentive strategies or the development of different competencies are necessary (Moore, 1999).

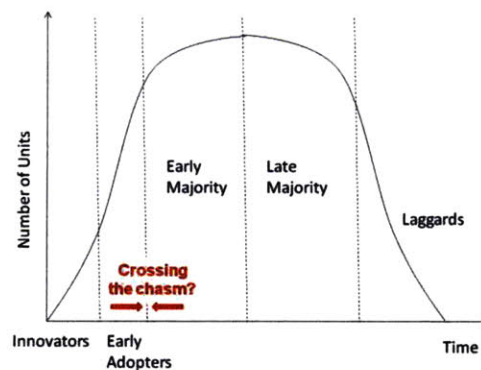


Figure 2-5: Moore’s Market Dynamics – Crossing the Chasm  
(Adapted from Davis, 2008).

Successful execution of both components of value creation, understanding technical and stakeholder evolution, depend on the type of organizational structure and organizational processes followed by industries and firms. Davis defines organizational structures as those behavioral patterns that are constantly repeated and resist change, enabling efficient and predictable coordination. For example, organizational structure may involve the level of hierarchy, unit networks, alliance networks, as well as the roles and rules existing within an organization. Davis defines a fundamental relationship (Figure 2-6) between performance and level of structure, showing a tension between organization flexibility and efficiency. In contrast, organizational processes are those behavioral patterns that are subject to adjustment according to time and place. Such “best practices” are harder to copy than organizational structures and could be a greater source of competitive advantage (Davis, 2008).

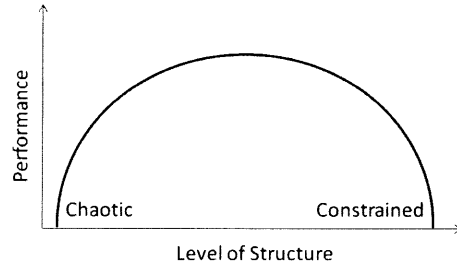


Figure 2-6: Organizational Performance according to Level of Structure  
(Adapted from Davis, 2008).

### 2.2.2 Value Capture

Batt describes value capture as the means through which the value added (created) of an investment is captured or recovered (Batt, 2001). Germany and Muralidharan identified three phases of value capture. The first phase is proving the feasibility and value of the innovation. The second phase consists of reducing uncertainty by defining the rules of the game. This is often done through standardization or by aligning mutual stakeholder interests through alliances. The third phase is to maximize the value derived from the innovation via targeted business and policy mechanisms, which frequently change over the life-cycle (Germany and Muralidharan, 2001).

Revisiting the last section, value creation does not automatically translate into value capture. Technology diffusion could be challenged if unbalances exist in the cost/benefit ratio and if realization of benefits depends on adoption by a large base of stakeholders (Shapiro and Hal, 1999), as in the case of civil aviation. Marais and Weigel have created a framework to explain that technology transition in air transport is challenged if the positive value created cannot be delivered to individual stakeholders through a balanced distribution of individual costs and benefits. Barriers to diffusion arise if some stakeholders reap a larger share of the benefits while others bear a larger portion of the costs (Marais and Weigel, 2006). Within their model, value analysis is defined as the net sum of benefits minus costs accrued during the life-cycle of an adopted technology. Their proposed value analysis includes those costs and benefits that are direct or indirect as well as those which are quantifiable or not so easily quantifiable, such as public trust and fulfillment of agency missions (Marais and Weigel, 2006). Figure 2-7 depicts a way

to represent the value distribution of costs and benefits across stakeholders under this framework.

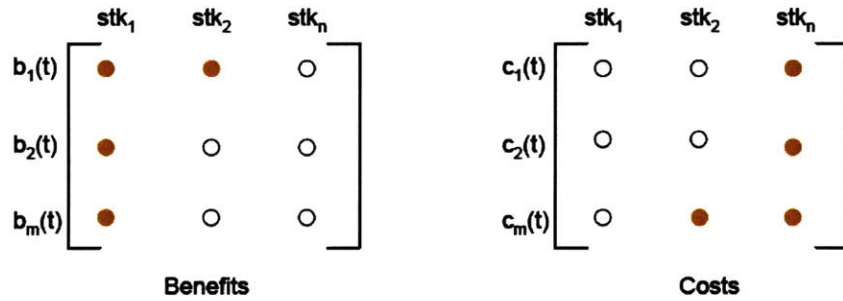


Figure 2-7: Example of Value Distribution of Costs and Benefits across Stakeholders  
(Taken from Marais and Weigel, 2006).

According to Marais and Weigel, merely identifying the distribution of costs and benefits across stakeholders is not sufficient unless a time dimension is considered. The authors propose conducting a phase value analysis to examine value distribution through the different stages of project implementation. Stakeholders are more likely to invest in a new technology if they can make a positive business case throughout the project life-cycle (Marais and Weigel, 2006). Figure 2-8 depicts a way to represent the value distribution of costs and benefits over time under this framework.

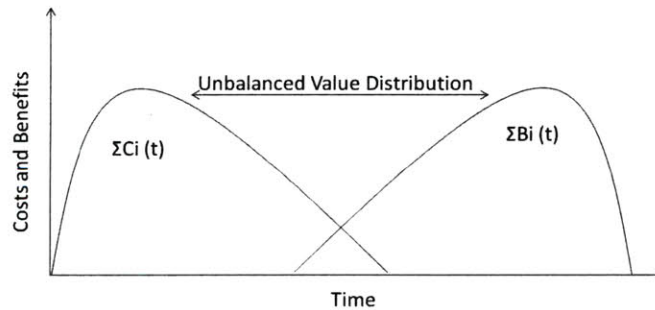


Figure 2-8: Example of Value Distribution of Costs and Benefits over Time  
(Adapted from Marais and Weigel, 2006).

The third and final dimension of the value analysis framework proposed by Marais and Weigel is uncertainty in costs and benefits. Uncertainty in the probability of increasing

costs and decreasing benefits could negatively affect value capture and ultimately deter investment in a new technology (Marais and Weigel, 2006). Successful value capture requires identifying and minimizing uncertainty to the extent possible. Figure 2-9 depicts a way to represent uncertainty in the phase value analysis.

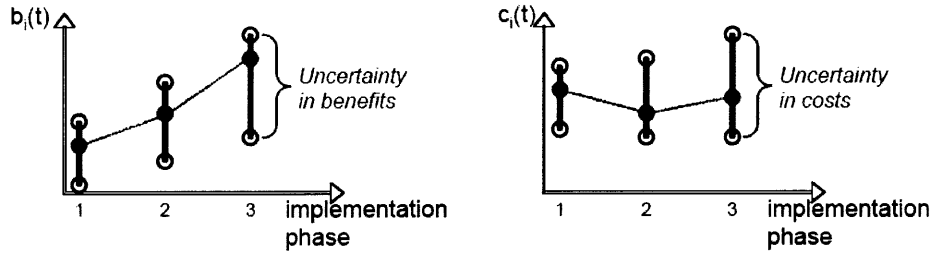


Figure 2-9: Uncertainty in Costs and Benefits under Phase Value Analysis  
(Adapted from Marais and Weigel, 2006).

Henderson notes that the mechanisms used to capture value from innovation are based on uniqueness or intellectual property, strategic position within the value chain and complementary assets, such as existing competencies and resources (Henderson, forthcoming). Most of the value captured from technologies in the field of air transport comes from complementary assets, either in the form of competencies and services offered or distribution channels and customer relationships (Davis, 2008). Sabatier argues that the effect of complementary assets is directly measured through price of services, milestones, royalties, time and cost savings, and as potential basis for new applications (Sabatier, 2008).

According to Arthur, the effect of increasing returns observed in high-tech industries can be used to facilitate technology transition. Arthur defines increasing returns as mechanisms of positive feedback that facilitate lock-in and advance a technology that is ahead even further ahead. Factors contributing to increasing returns and lock-in include high investment costs, facilitation of maintenance and updates after initial costs and training, and network effects (Arthur, 1986).

Davis identifies two types of network effects. Direct network effects depend on the size of the network, increasing value with number of users. In contrast, with indirect network effects, value increases with complementary products and services offered (Davis, 2008).

Network effects are illustrated in Figure 2-10. In this context, the setting of standards, or specifications that enable interoperability, is important in helping to create network effects, facilitate market tipping toward a preferred choice, and assure lock-in (Davis, 2008). Although not all markets tip and multiple standards can sometimes co-exist, the relationship between network effects and market tipping is illustrated in Figure 2-11. Along those lines, Shapiro and Hal argue that securing an installed base of users can help in blocking the setting of a different standard and, therefore, facilitate the value capture process (Shapiro and Hal, 1999).

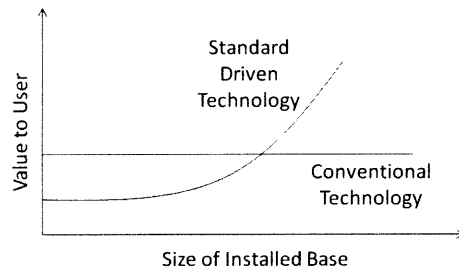


Figure 2-10: Network Effects and Standards (Adapted from Davis, 2008).

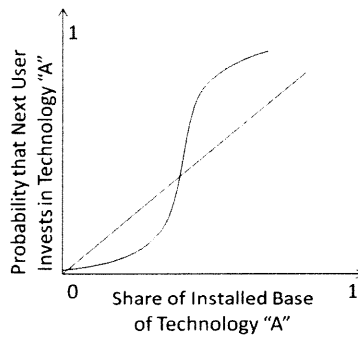


Figure 2-11: Relationship between Market Tipping and Network Effects (Adapted from Davis, 2008).

Laird, Nellthorp and Mackie argue that network effects arise as a consequence of one or more of the following network properties: sunk costs, economies of density and scope, congestibility and positive consumption externalities. Economies of density are seen on the supply side due to the reduction in unit costs resulting from the ability to increase capacity. Also on the supply side, economies of scope emerge from the ability to offer

multiple new services through a single new connection. Conversely, positive network effects are particularly noticeable on the demand size with increasing number of users (Lair, Nellthrop, and Mackie, 2005). Due to their potential to become congested, transport networks have a limit on the positive externalities achievable with a larger number of nodes and links. The analysis of these network characteristics is essential for maximizing the value captured through investment in a new technology. Transport networks are also affected by time and institutional dimensions. The time dimension refers to the commitment and stakeholder coordination beyond initial investment necessary to keep the network functional and prevent it from deteriorating. The institutional dimension regulates the intensity of the network effects (Carcamo-Dias and Goddard, 2007).

### 2.2.3 Value Delivery

To guarantee successful delivery of the technology value that has been created and captured, policy and operational strategies are necessary to minimize the impact of uncertainty and unbalances in the value distribution of costs and benefits across stakeholders and over time (Figure 2-12). Stakeholder reluctance to adopt a new technology in civil aviation can be overcome when realization of benefits is rapid, last through the life-cycle of a project and does not allow free-riders. Marais and Weigel propose four approaches (Figure 2-13) to foster technology transition in air transportation: 1) development of infrastructure, standards, processes, and certification, 2) inherent value derived from technology, 3) positive incentives, and punitive measures (Marais and Weigel, 2006).

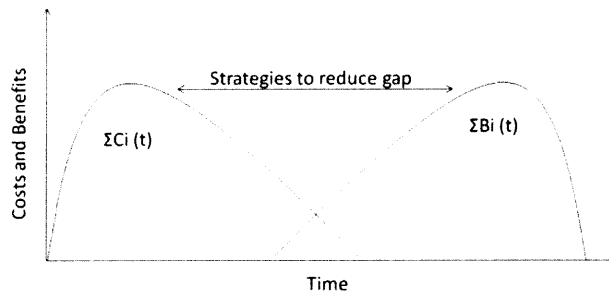


Figure 2-12: Strategies Necessary to Reduce Unbalance in Costs and Benefits  
(Adapted from Marais and Weigel, 2006).

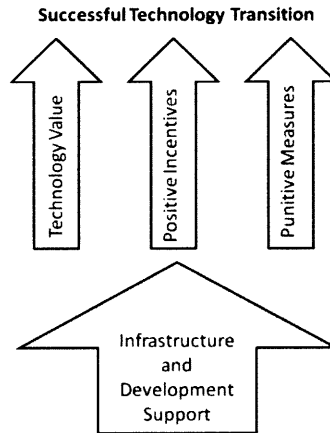


Figure 2-13: Approach to Encourage Technology Transition  
 (Adapted from Marais and Weigel, 2006).

The first approach, infrastructure development, is necessary to reassure stakeholders that realization of benefits is possible. The second approach, inherent technology, value can be achieved in three forms: 1) by continuing an existing service, 2) by improving an existing service, or 3) by enabling a new service. Of these forms, using the technology to merely continue a service without noticeable operational difference to adopters offers the lowest level of incentive to support transition. In this case, positive external incentives may be necessary to increase perceived value from adoption (Marais and Weigel, 2006). Finally, regulatory measures, such a mandate, may be used to maximize the positive externalities brought by network effects.

Carcamo-Dias and Goddard argue that in multinational infrastructure projects, countries need to reach an agreement on their expectations of a project, measures of success, effective alignment of incentives, and understanding of their financial, institutional, and human constraints. These foundations are necessary in order to achieve effective coordination in infrastructure projects. Network effects are also important on the supply side. Therefore, unilateral investment decisions introduce strategic uncertainty in the multinational infrastructure system. When a country decides not to invest, uncertainty reduces the benefits that partner countries perceive they could capture through their investment. Coordination failure is less likely to occur when domestic benefits from investment are large. Additionally, extensive interaction and feedback are necessary during the design, assessment, and evaluation phases of a project to ensure coordination success (Carcamo-Dias and Goddard, 2007).



## **2.2.4 Synthesis of Technology Transition Framework**

The following synthesis of the frameworks described previously will be used to analyze the case for data link over the North Atlantic airspace in terms of the concepts of value creation, capture, and delivery.

### Value Creation

The goal of creating value is to design competitive value propositions through an understanding of technical change and evolution of stakeholder needs. The main concepts of value creation are:

- Technology evolution and life-cycle
- Managing discontinuities through value creation
- Technology diffusion
- Roger's market segmentation dynamics: innovators, early adopter, early majority, late majority, and laggards
- Moore's market dynamics – crossing the chasm
- Sources of uncertainty in technology transition
- Organizational structure and organizational processes

### Value Capture

The goal of capturing value is to recover the value added (or created) of an investment. The main concepts of value capture are:

- Phases of value capture
- Value distribution of costs and benefits across stakeholders and over time

- Elements of value capture – complementary assets
- Increasing returns and network effects (direct and indirect)
- Network properties
- Market tipping and standards
- Risk and uncertainty as barriers for value capture

### Value Delivery

The goal of delivering value is to develop policy and operational strategies to minimize impact of uncertainty and unbalances in value distribution of costs and benefits across stakeholders and over time. The main concepts of value delivery are:

- Strategies to foster technology transition and reduce gap between costs and benefits
  - Development of infrastructure
  - Standards, processes and certification
  - Inherent value derived from technology
  - Positive incentives
  - Punitive measures
- Strategies to encourage successful coordination in multinational infrastructure projects.

## **2.3 Chapter Summary**

This chapter introduced key concepts of value creation, capture, and delivery to shape the framework of technology transition under which the case for data link in the North Atlantic airspace will be analyzed. Creating value through a new technology refers to designing competitive value propositions to stakeholders. Capturing value means recovering an investment in a technology through the value it creates. Delivering value refers to developing policies and business strategies to enable value capture. The realization of these three concepts is necessary to guarantee technology transition in air transportation.

## **Chapter 3**

# **Research and Data Collection Method**

This chapter describes the research and data collection method. Section 3.1 details the approach used to interview the two major stakeholder groups in the North Atlantic, commercial airlines and Air Navigation Service Providers (ANSPs). Section 3.2 outlines a profile of survey participants and shows those carriers and service providers which participated in the study. Section 3.3 summarizes the major findings of the stakeholder survey and section 3.4 synthesizes the key elements of this chapter.

### **3.1 Stakeholder Analysis Method**

The approach used to address the objectives described in the introduction is via a survey of the two major stakeholder groups in the NAT: commercial users (airlines) and Air Navigation Service Providers (ANSPs). The stakeholder survey explored five major research areas: 1) Perceived operational and coordination inefficiencies; 2) Opportunities to improve service; 3) Current and projected data link equipage and infrastructure in the NAT; 4) Value distribution of data link costs and benefits; and 5) Potential policy strategies to encourage data link adoption.

The survey was conducted as a structured interview in which participants were presented with a fixed set of open-ended questions in all five research areas. The majority of participants responded to questions via phone interviews while some others were interviewed in person or via e-mail. The survey instruments for airlines and ANSPs can be found in Appendices B and C, respectively.

### 3.2 Survey Participants

The subjects of the study were experts in the areas of data link and North Atlantic operations from the two stakeholder groups of interest. Senior level airline captains and air traffic controllers offered input on the technical component of the survey while managers in the areas of operations, planning, communications, and air traffic answered the business component. In the operators survey, 27 airlines from around the world were interviewed (Figure 3-1, Table 3-1), representing approximately 70% of NAT traffic (Figure 3-2).

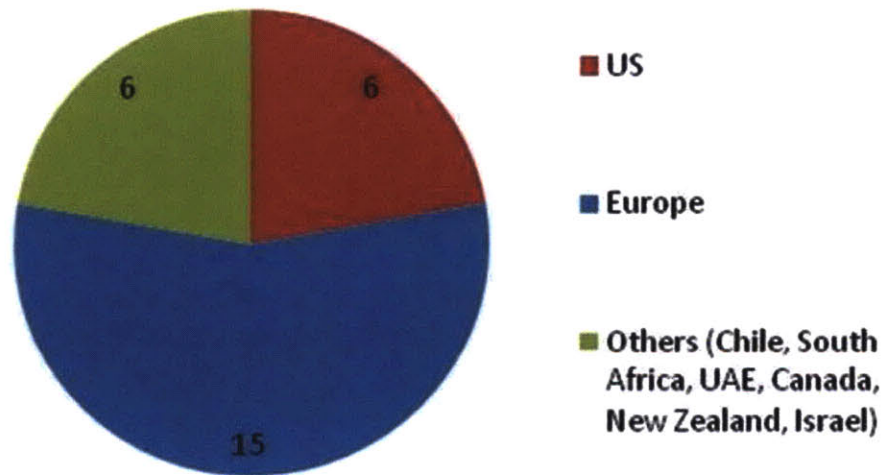
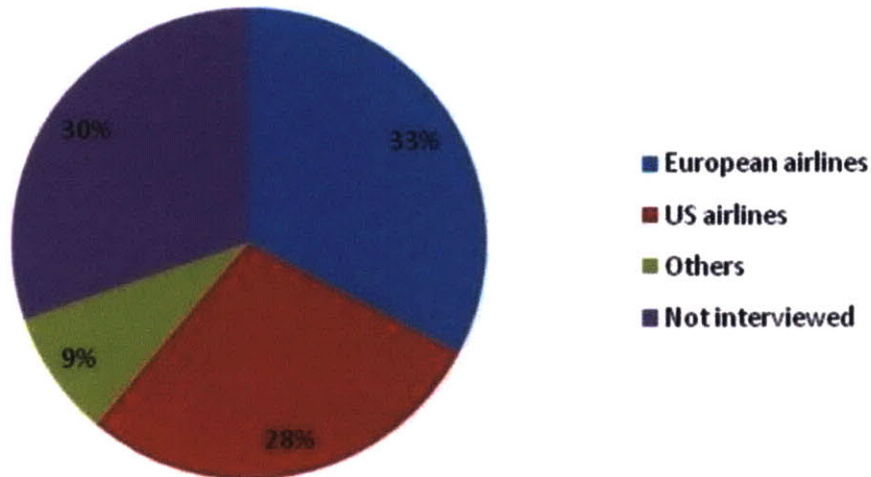


Figure 3-1: Geographic Distribution – Operators Survey

Table 3-1: Airline Interviews Conducted

<b>Airline</b>	<b>Country</b>
Air Canada	Canada
Air Europa	Spain
Air France	France
Air New Zealand	New Zealand
Austrian Airlines	Austria
British Airways	U.K.
Brussels Airlines	Brussels
Continental Airlines	U.S.
Czech Airlines	Czech Rep.
Delta Airlines	U.S.
El Al Israeli Airlines	Israel
Emirates Airlines	U.A.E.
FedEx	U.S.
Flyglobespan	U.K.
Iberia	Spain
Icelandair	Iceland
KLM	Netherlands
LAN	Chile
LTU	Germany
Lufthansa	Germany
Northwest Airlines	U.S.
Scandinavian Airlines System	Sweden
South African Airways	South Africa
Swiss International Airlines	Switzerland
United Airlines	U.S.
United Parcel Service	U.S.
Virgin Atlantic Airways	U.K.



**Based on BTS T100 Segment Data  
(Departures across NAT from Jan 01 to Dec 31, 2006)**

Figure 3-2: Representation of NAT traffic – Operators Survey

On the ANSP side, all of the oceanic service providers in the NAT participated in the survey. Table 3-2 summarizes the interviews conducted.

Table 3-2: NAT ANSPs Interviews Conducted.

<b>NAT ANSP</b>	<b>Country</b>
Bodo	Norway
Gander	Canada
New York	U.S.
Reykjavik	Iceland
Santa Maria	Portugal
Shanwick	U.K.
Shanwick Radio	Ireland
Sondrestrom	Denmark

Some participants indicated during the airline interviews that they were receiving significant operational and economic benefits from data link in the South Pacific (SoPAC) region, while the benefits they were receiving in the NAT were predominantly operational. Some of the carriers even mentioned that the main incentive they had to equip with data link was to gain access to more efficient operations in the SoPAC. The

NAT and the SoPAC differ greatly in the traffic volume handled, traffic growth rate, number of ANSPs, major traffic flows, either very long (e.g. Vancouver to Sydney) or very short (e.g. Truk to Majuro) flights in the SoPAC, and other special characteristics such as the Organized Track System (OTS) in the NAT. Acknowledging such differences, a direct comparison between the NAT and the SoPAC would not have been appropriate and was never intended. However, given the insight provided by some of the airlines, ANSPs in the SoPAC were interviewed to see what lessons could be learned from their data link implementation program. Table 3-3 shows the SoPAC ANSPs taking part in the survey.

Table 3-3: SoPAC ANSPs Interviews Conducted.

<b>SoPAC ANSP</b>	<b>Country</b>
Auckland	New Zealand
Brisbane	Australia
Nadi	Fiji
Oakland	U.S.
Tahiti	French Polynesia

### **3.3 Summary of Survey Data**

A survey of the two major stakeholder groups in the NAT, commercial operators and ANSPs, showed an agreement between stakeholders in their perception of operational and coordination inefficiencies, technologies and applications that could improve efficiency of operations, and the current value distribution of data link costs and benefits. In contrast, some differences in opinions were found in their current level of ground and airborne technical capabilities, services offered by ANSPs, planned initiatives, and in the efficacy and feasibility of strategies to encourage data link adoption.

The study indicated that participants perceive fuel penalties associated with the inability to fly preferred routes and levels as the main operational inefficiency in the NAT. Data link is seen as the enabler of improved efficiency of operations and the most valuable near term application of this technology is reducing separation standards. So far, data



link operational benefits have been significant but have not yet translated into economic benefits in the NAT given that such applications have not been implemented yet. The unbalance in the distribution of initial costs of investment and perceived benefits coupled with the uncertainty in the establishment and harmonization of procedures and technologies are the major barriers for successful data link transition in the NAT. A combination of operational, financial, and regulatory strategies may be necessary in order to leverage costs and benefits and encourage operators to equip.

### **3.4 Chapter Summary**

This chapter introduced the methodology followed to interview the two major stakeholder groups in the NAT, commercial operators and ANSPs. The survey covered five major research areas: 1) Perceived operational and coordination inefficiencies; 2) Opportunities to improve service; 3) Current and projected data link equipage and infrastructure in the NAT; 4) Value distribution of data link costs and benefits; and 5) Potential policy strategies to encourage data link adoption. Survey participants included 27 international airlines, seven ANPS in the NAT, and five ANSPs in the SoPAC. Findings indicate that fuel efficiency is the area where data link is perceived to have the most value, although changes to current operational procedures in the NAT are required in order to fully realize benefits. A portfolio of different policies may be required to encourage airborne equipage and ground support of new services.

## Chapter 4

# Value Creation Strategies Applied to the Case of Data Link

The goal of this chapter is to introduce value propositions enabled by data link through an understanding of the evolution of technology and stakeholder needs. The baseline of this chapter is to use the technology transition framework introduced in chapter 2 to understand value creation applied to the case for data link in the NAT. Section 4.1 will explore how value is created through data link technologies and applications. This section will introduce the data link evolution cycle, initiators of discontinuities, and ways in which data link could be used to manage such discontinuities. Section 4.2 will look at value creation through an understanding of data link diffusion by looking at trends, characterization of adopters, and potential challenges to cross the data link adoption chasm and encourage transition. Lastly, section 4.3 will discuss value creation through an overview of relevant organizational structures and processes.

### 4.1 Value Creation through Data Link Technologies and Applications

The core of value creation rests in the technology and the services or functions it enables. This section will look at how data link value propositions have evolved and bridged through discontinuities. Also, stakeholder perspectives on what they consider the most valuable data link technologies and applications will be analyzed.

### 4.1.1 Data Link Evolution Cycle

The first component of value creation is understanding technical change. In 1983, a committee charged by ICAO began the development of the concept of operations of the future Air Traffic Management (ATM) system based on improvements to the existing Communication, Navigation, and Surveillance (CNS) capabilities. From this effort, the development of the technical standards of the Future Air Navigation System (FANS) emerged in 1988. This is comparable to an era of ferment or discontinuity in the technology life cycle (Figure 4-1). In the early 1990s, Boeing introduced the ADS-C and CPDLC applications in its own version of FANS (known as FANS-1), supporting the B747 and later the B767, B717, B757, B777 and the MD-90, MD-10, and MD-11 families (Kerr, 2000). Similarly, Airbus developed a version of FANS (known as FANS-A) supporting the A340 and A320, and A330 aircraft (Kerr, 2000). The emergence of the “dominant design” of FANS-1/A is the second stage in the technology evolution life cycle. Since its origins, the FANS technology has seen a number of incremental improvements leading to new versions of the system, such as FANS-1/A+. Also, the technology has been introduced beyond its region of original application to other oceanic and remote areas, such as the North Atlantic. This marks the third phase in the technology life cycle. The fourth stage in the cycle, technology maturity, has enabled the development of new applications to improve operations and ATM, such as 30/30 NM reduced separation in the South Pacific.

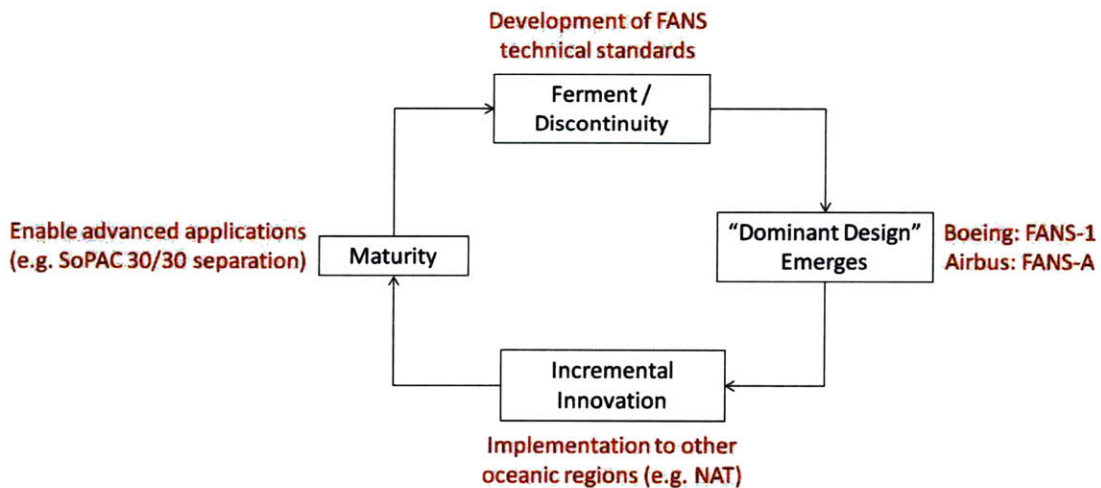


Figure 4-1: Technology Life Cycle (Adapted from Davis, 2008).

### 4.1.2 Initiators of Discontinuities

Under the framework of technology evolution described in Chapter 2, data link could be considered as a disruptive technology to HF voice. Recall that a disruptive technology is one which completely redefines performance trajectories (Christensen, 1997) and frequently enables the possibility of completely new applications (Henderson and Kim, 1990). An S-curve framework can be used to describe the path followed by data link development, showing the relationship between level of effort and improvement in performance (Utterback, 1994). Different performance metrics could be used to compare HF voice and data link, particularly through the FANS package. For example, looking at the communications dimension, Figure 4-2 shows that the mean delay of FANS messages is 0.26 min., while Figure 4-3 shows HF messages with a mean delay of 3.7 min. According to a study conducted by UK NATS, 89.6% of FANS reports arrive faster than HF messages (Coulsson, 2000). Similarly, Figure 4-4 shows a mean of 2.9 minutes as the difference between arrival times and corresponding HF reports (Coulsson, 2000).

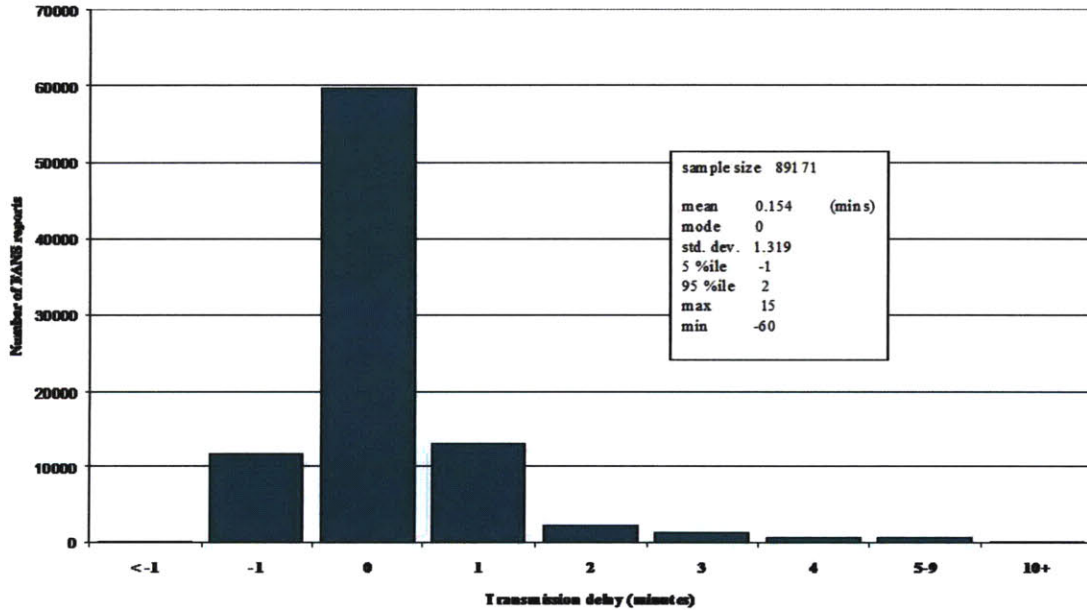


Figure 4-2: FANS Transmission Delays (Coulson, 2000).

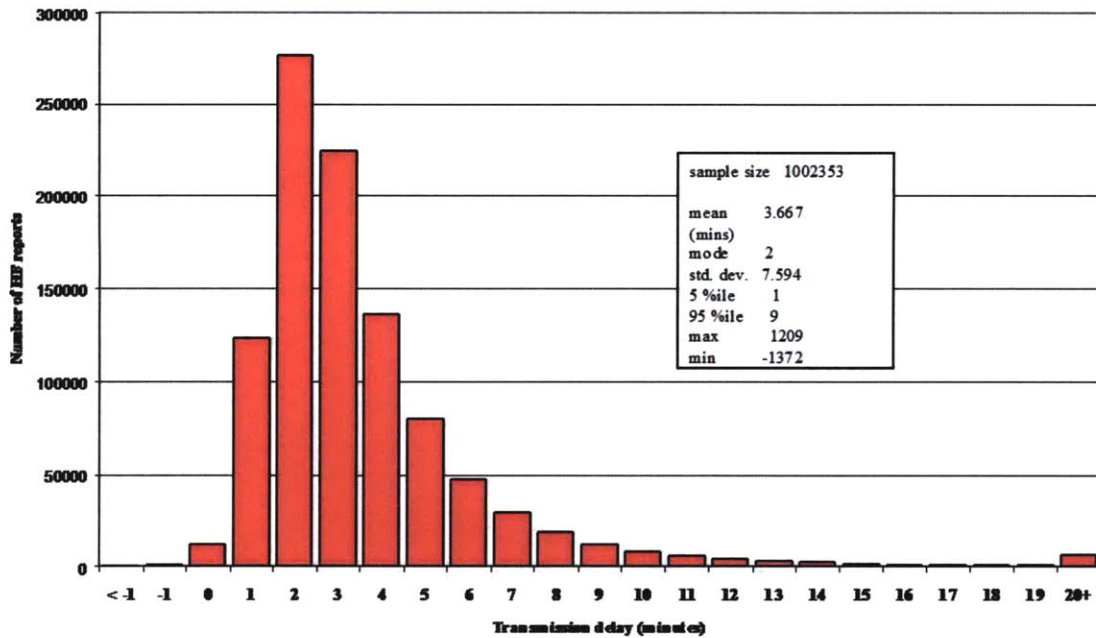


Figure 4-3: HF Voice Transmission Delays (Coulson, 2000).

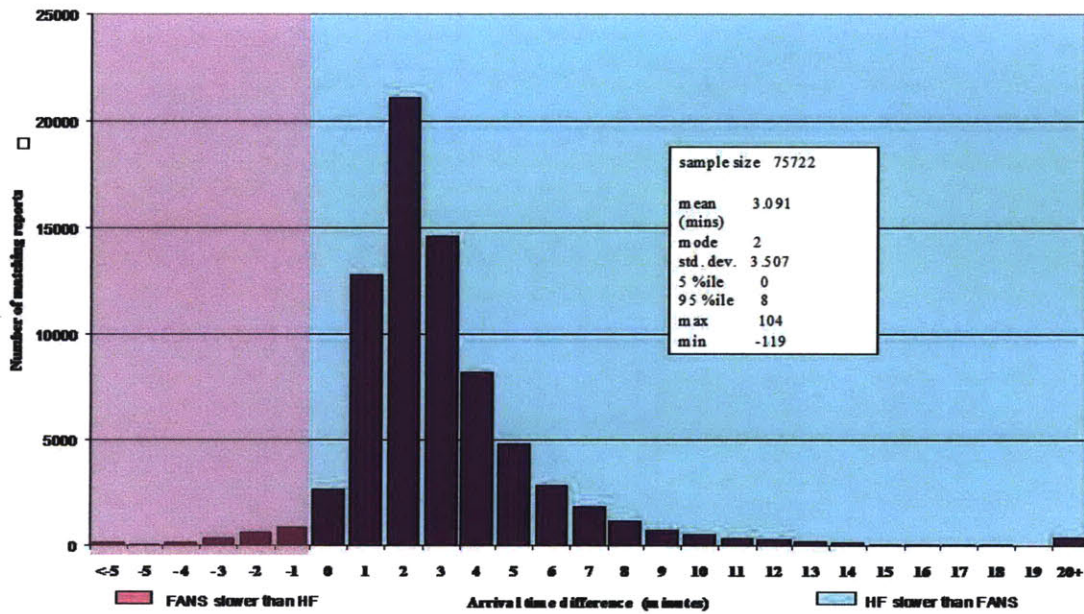


Figure 4-4: Difference in Arrival Times Between FANS and Corresponding HF Reports (Coulson, 2000).

The first curve in the diagram below (Figure 4-5) shows a hypothetical evolution of HF. During periods of take-off, ferment, and maturity, HF has enabled communication in

oceanic and remote areas where radar and VHF coverage is not possible, such as the NAT. However, with the level of projected traffic growth in the NAT, the Aeronautical Communications Group (NAT ACG) predicts that the HF network infrastructure will experience congestion problems as early as 2009 (NAT EFG, April 2008). Frequency saturation translates into more delays, triggering an effect of diminishing returns and creating a discontinuity in the S-curve. In contrast, the second curve in the diagram shows the hypothetical evolution of FANS. In the early stages of take-off and ferment, the FANS package was a more costly and less efficient solution than HF voice because it required additional avionics and infrastructure investment as well as the development of standards and procedures for its use. However, as seen in the data above, FANS has outperformed HF voice in different communication metrics, such as message delay and time of arrival. In the surveillance dimension, FANS has also outperformed HF, enabling position reports as frequent as every 5-15 minutes compared to once per hour using HF.

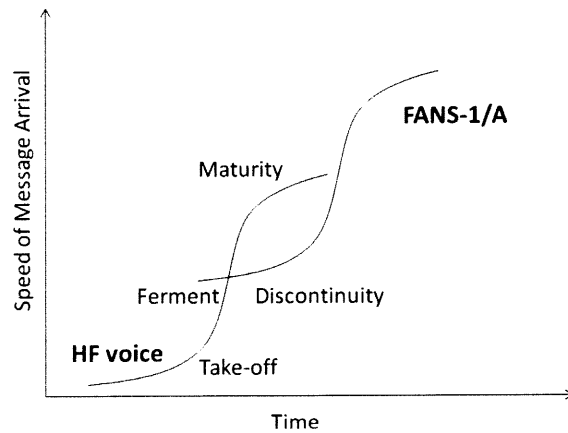


Figure 4-5: Technology Life Cycle as an S-Curve – HF and FANS-1/A  
(Adapted from Davis, 2008).

#### 4.1.2.1 North Atlantic Operational Inefficiencies

The first research area in the stakeholder survey, “Operational and Coordination Inefficiencies,” tries to identify some of the potential initiators of technical discontinuities in the NAT. The major inefficiency identified by the stakeholders is the fuel penalty associated with flying suboptimal flight levels and routes (Figure 4-6). In order to avoid

potential immediate or projected violations in separation standards, aircraft requests to change altitude or speed are sometimes denied, depending on traffic density (Figure 4-7). For example, as identified by Kerczewski et al., shifting a most fuel efficient route by 100 NM carries a time penalty of 27 minutes and over 1,000 gallons of fuel (Table 4-1). This could put airlines at an economic disadvantage when considering current fuel prices and the number of oceanic operations carriers conduct (Kerczewski, Greenfeld, and Welch, 2005).

Operational Inefficiencies	NAT ANSPs	SoPAC ANSPs	NAT Operators
Fuel penalties - large separation and suboptimal FLs and routes	●	●	●
HF voice: unreliability, congestion, 3 <sup>rd</sup> party relay	●	○	●
Delay in communicating with ATC and late issue clearances	●		●
Controller workload on least developed FIRs	●	○	
Predictability of meteorological information	●		
Lack of automation and conflict detection/resolution systems	●		
Potential constraints in infrastructure and capacity	○		

- > 2/3 participants
- > 1/3 and < 2/3 participants
- emphasized by less than 1/3 participants

Figure 4-6: Summary Main Operational Inefficiencies (Survey Results).

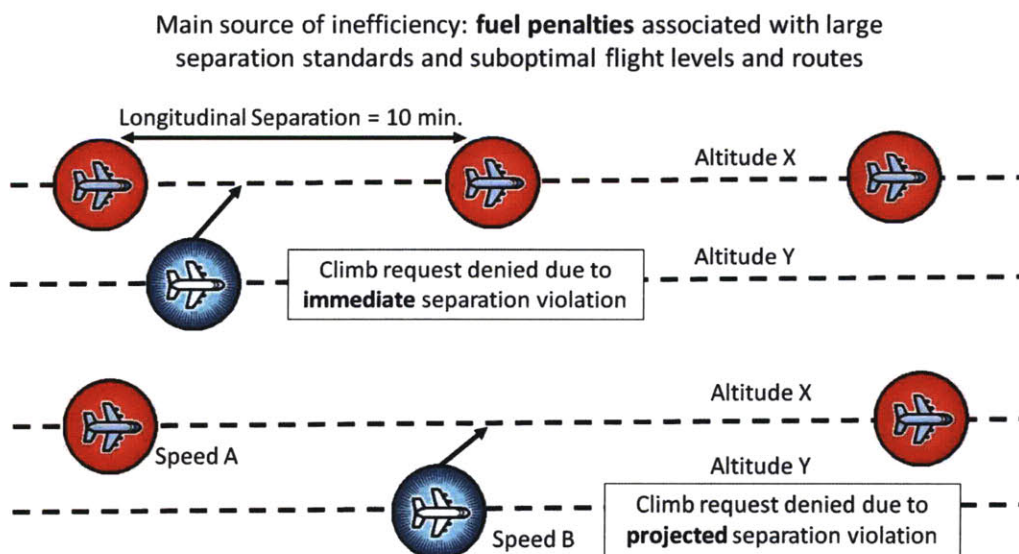


Figure 4-7: Fuel Penalties in Organized Track System (Adapted from Williams, 2005).

Table 4-1: Example of Economic Penalties Due to Inefficient Oceanic Routes  
(Kerczewsky, R., Greenfield, I., and Welch, B., 2005).

	<b>Most Fuel Efficient Route (*)</b>	<b>Fuel Efficient Route Shifted 100 NM</b>	<b>Difference</b>
<b>Distance</b>	5,770.7 NM	5,778.5 NM	7.8 NM
<b>Average Headwinds</b>	52 knots	66 knots	14 knots
<b>Time</b>	772 minutes	779 minutes	27 minutes
<b>Pounds of Fuel</b>	330,146 lbs	338,071 lbs	7,925 lbs
<b>Gallons of Fuel (1 gal = 6.78 lbs)</b>	48,694 gals	49,863 gals	1,169 gals
<b>Fuel cost @ \$3.1/gal (IATA September 2008)</b>	\$152,412	\$156,071	<b>\$3659</b>
* Using forecast winds and temps, fuel efficient tracks are built between city pairs			

Communication inefficiencies such as unreliability, misunderstandings, congestion, and third party relay associated with HF voice were particularly emphasized by the operators. Delays in communicating with ATC and late issue of oceanic clearances were also mentioned by the majority of operators and service providers. For example, some of the operators indicated that sometimes the time between request and action could take anything from 10 to 30 minutes when frequencies are busy. If process takes too long, clearance may no longer be applicable when received, as it happens under turbulence conditions.

Other operational inefficiencies were only identified by more than one third but less than two thirds of the ANSPs. These include: controller workload issues on the least developed Flight Information Regions (FIRs), unreliable meteorological information 12 hrs into the future, and lack of automation systems to transfer data between ground facilities. Figure 4-6 shows a summary of the survey findings in this area. Less than one third of the providers also mentioned concerns about potential capacity constraints in the least developed FIRs (mainly due to aging equipment) and lack of flexibility to transfer oceanic flights into domestic airspace, particularly in eastbound flights.



#### **4.1.2.2 North Atlantic Coordination Inefficiencies**

An important source of uncertainty and negative disruption to value creation is coordination. Stakeholders agreed that they would like to see more coordination in the establishment and harmonization of procedures. Participants differentiated between two fundamental problems, one across the NAT FIRs and one at a global scale, particularly between the U.S. and Europe. In the case of the NAT FIRs, stakeholders indicated that not all the providers offer the same level of service and technical development, which leads to slight differences in procedures for entrance, exit, communication message sets, and clearances. If ground infrastructure is not in place, aircraft need to transition to less efficient profiles when moving between advanced and less advanced FIRs. Additionally, not all ANSPs coordinate in the same way with each other; for example, some use data link automation systems while others communicate via telephone or fax. This translates into increased workload for controllers and delays in the response and approval of request for airlines.

In the case of global harmonization, carriers need common aircraft with common avionics, as many of them use their international fleet to do around the world flights (e.g. MEM to CDG to SFG to NRT to MEM). Equipping aircraft for just a few destinations and keeping them on those routes is very expensive; therefore, none of the carriers interviewed had an isolated fleet for NAT operations only. One of the examples raised was the incompatibility of equipment and message sets between the Future Air Navigation System (FANS) and the Aeronautical Telecommunications Network (ATN). Operators mentioned they would like FANS to be available in an ATN environment (as it happens now in Maastricht FIR), have dual-stack avionics for FANS and ATN (currently only offered in B787), and the standardization of a long term system. According to the NAT Data Link Steering Group (DLSG), ATN still has several shortcomings compared to FANS. For example, ATN aircraft do not support certain CPDLC elements that are essential in the NAT, do not include ADS-C reporting capability, and do not support satellite link, using VDL Mode 2 for transmission (NAT DLSG, September 2005). Therefore, FANS is perceived to continue as the leading oceanic technology in the near term.

Finally, some interviewees indicated that coordination is more challenging because there are more control areas than technically necessary. A summary of coordination inefficiencies is seen in Figure 4-8.

Coordination Inefficiencies	NAT ANSPs	SoPAC ANSPs	NAT Operators
Establishment & harmonization of technologies and procedures	●	●	●
Incompatibility of technologies – oceanic & continental airspace	●	◉	◉
Coordination between FIRs: data transfer and ATM	●	◉	◉
Necessary infrastructure not in place. Technology development not uniform. Long time to implement changes	◉	◉	◉
More control areas than technically necessary	◉	○	
Interface between oceanic and domestic airspace	◉		

● > 2/3 participants  
 ◉ > 1/3 and <2/3 participants  
 ○ emphasized by less than 1/3 participants

Figure 4-8: Summary of Main Coordination Inefficiencies (Survey Results).

### 4.1.3 Managing Discontinuities

The second component of value creation is understanding the evolution of the technical needs of stakeholders. The objective of the second research area in the stakeholder survey is to outline “opportunities for improvement” through technologies and applications in order to address the discontinuities or inefficiencies just described.

#### 4.1.3.1 Opportunities for Improvement: Technologies

More than two thirds of the respondents said that the FANS-1/A package was the near term technology that could help improve efficiency in the NAT. The communications and surveillance components of FANS are perceived as enablers of the safety case for potential reduction in separation minima. The communication element, known as Controller-Pilot Data Link Communication (CPDLC) allows direct exchange of requests, clearances, and negotiations. The surveillance component, Automatic Dependent Surveillance Contract (ADS-C), enables automatic reporting of position, velocity, intent, and meteorological data (Lelievre and Souchu, 2005 and FAA, September 2006).

Operators said they would like to see Satvoice as an alternative ATS communication mechanism, but they do not think this technology is practical as a primary method. Airlines do not like the additional cost associated with Satvoice nor having only one pilot in the communication loop.

More than two thirds of the ANSPs identified the ATS Inter-facility Data Communications (AIDC), conflict probe, and air traffic automation technologies as valuable for ground operations. These technologies allow the reduction of bottlenecks by streamlining the coordination between service providers, automatically sharing data with each other, and detecting conflicts in a time horizon.

Regarding long term technologies, ADS-B is perceived to have potential to enable applications such as in-trail climbs and descends. Although some ANSPs are already trying to monitor the number of aircraft squittering, stakeholders believe it would be a long time before ADS-B can become operational for oceanic applications. Survey results in this area are seen in Figure 4-9.

Technologies	NAT ANSPs	SoPAC ANSPs	NAT Operators
FANS package (ADS-C and CPDLC)	●	●	●
AIDC	●	●	
Oceanic automation & conflict monitoring	●	●	
RNP-4	○	○	○
Satvoice	○		○
GPS	○		○
RCP	○		
Radar	○		
ADS-B	○	○	○
Meteorological information	○		○
Dual stack for FANS-1/A and ATN	○		

● > 2/3 participants

○ > 1/3 and <2/3 participants

○ emphasized by less than 1/3 participants

■ Current technology

■ Future technology

Figure 4-9: Technologies Summary (Survey Results).

### 4.1.3.2 Opportunities for Improvement: Applications

More than two thirds of the participants mentioned that the application they value the most in the near term is improving fuel efficiency by reducing separation standards and gaining access to optimal flight levels and routes. Some operators mentioned as an example the route L888 (Figure 4-10) linking Asia and Europe via China and only available to FANS equipped aircraft (Warfield, Quantas). Stakeholders would also like to continue seeing improvements in communications and capacity. In the long term, in-trail procedures are one of the most valued data link applications. In-trail procedures are defined as those operations conducted to enable climbs and descents through otherwise blocked flight levels (ASSTAR, 2007). Other ways in which some ANSPs perceive potential for improving efficiency is by streamlining services offered and leveraging on strategic partnerships among providers. More details of such applications are seen in Figure 4-11.

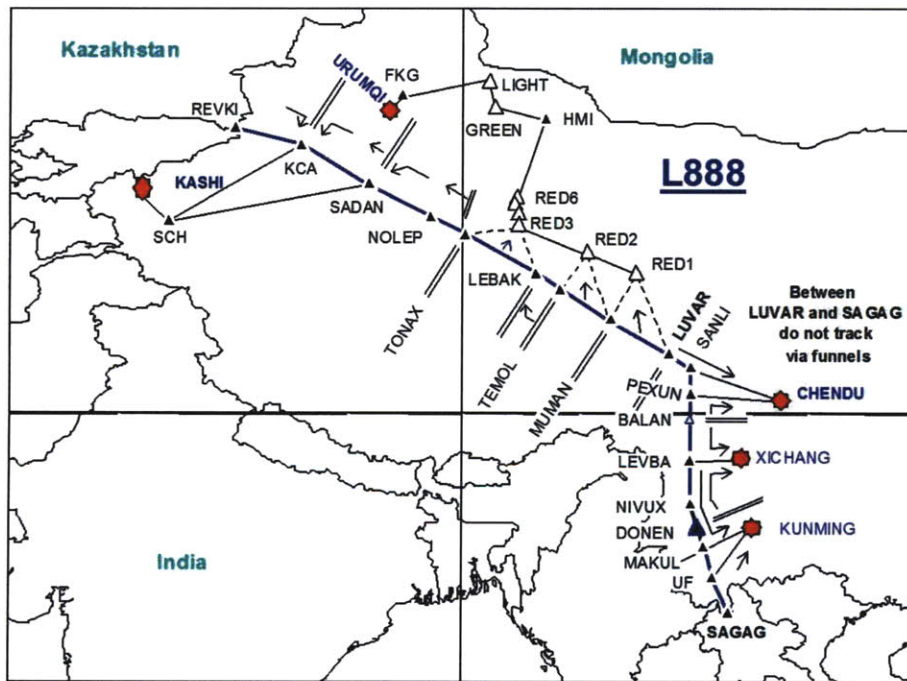


Figure 4-10: Route L888 (Warfield, Quantas).

Applications and Initiatives	NAT ANSPs	SoPAC ANSPs	NAT Operators
Reduce fuel burn: reduced separation, access to better routes & FLs	●	●	●
Reduce HF reports, congestion; eliminate operator relay; comm. reliability	●	●	●
Increase airspace capacity	●	●	○
Reduction in flight times and delays	●		○
Weather deviations and wind adjustments	●		○
Reduce controller workload	●		
In-trail procedures	○	○	○
Free flight operations		○	●
Dynamic Aircraft Route Planning (DARP)		●	○
Streamline services offered	○	○	
Strategic partnerships	●		

● > 2/3 participants

● > 1/3 and <2/3 participants

○ emphasized by less than 1/3 participants

■ Near term initiative

■ Long term initiative

■ Other initiatives

Figure 4-11: Applications Summary (Survey Results).

## 4.2 Value Creation through Data Link Diffusion

Recalling from Chapter 2, technical performance or superiority of a new technology may not guarantee diffusion in itself (Loch and Huberman, 1999). A disruptive technology may be received with inertia because it creates uncertainty for stakeholders, it calls for the adoption of new procedures and methods, and may be characterized by conflicting interest around it. Other factors adding to the inertia include: a large base of user population of current technology, small network externality benefits, large performance advantage of current technology, and uncertainty in the benefits provided by the new technology (Loch and Huberman, 1999). Data link adoption shows all of these characteristics. Throughout the remainder of this thesis, these sources of uncertainty will be analyzed in greater detail.

#### 4.2.1 Data Link Technologies Diffusion Trends

Current trends of data link diffusion are shown before moving on to discuss sources of uncertainty. Figure 4-12 shows traffic count in the NAT during the month of August between 1982 and 2006. The NAT is the busiest oceanic airspace in the world, with more than 1,000 operations per day and a steady projection in traffic growth levels. Figure 4-13 shows the percentage of ADS-C equipped flights going through Gander Oceanic between 2001 and 2005. Similarly, Figure 4-14 and Figure 4-15 show the percentage of ADS-C and CPDLC flights, respectively, going through Shanwick Oceanic between 2003 and 2006. As seen in these figures, the diffusion of ADS-C and CPDLC in the NAT is approximately 40%, and the equipage rate has remained fairly stable in recent years despite traffic growth. Further, the NAT Systems Planning Group indicates that the number of HF reports has actually increased, contrary to original expectations after data link was first implemented in the NAT (NAT SPG, May 2007).



Figure 4-12: NAT Traffic Count (Rome, 2006).

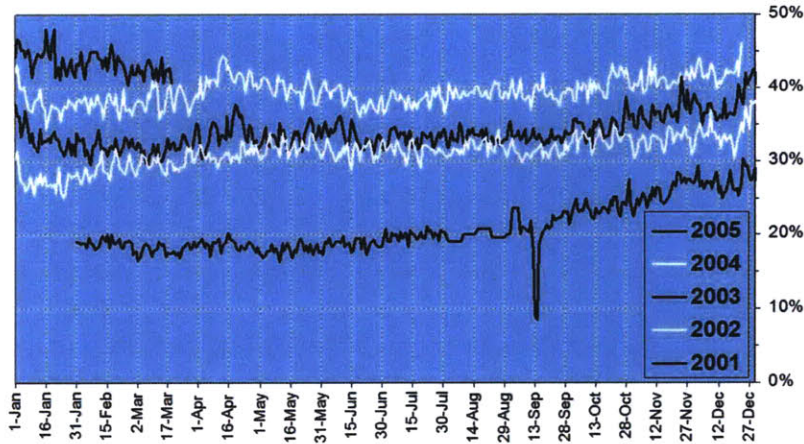


Figure 4-13: ADS% of Gander Flights (Dimock, 2005).

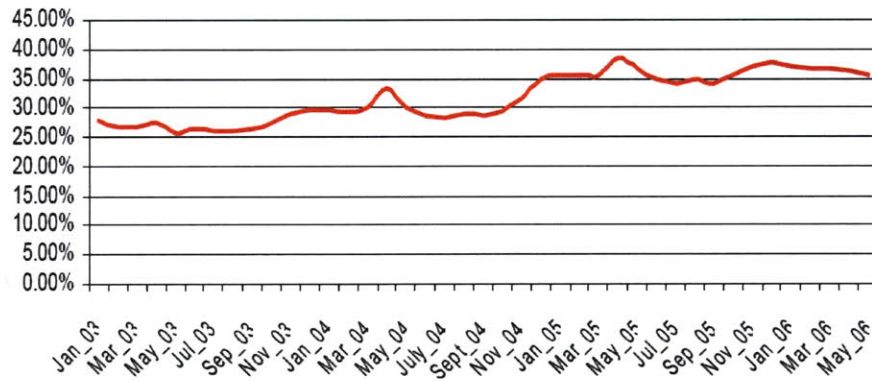


Figure 4-14: ADS% of Shanwick Flights (Davies, 2006).

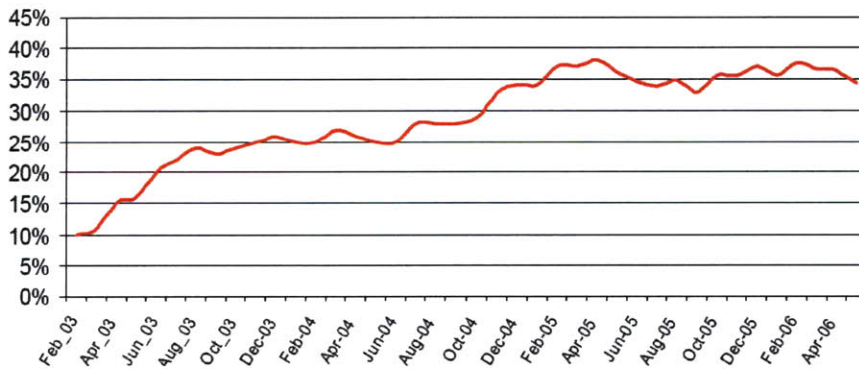


Figure 4-15: CPDLC% of Shanwick Flights (Davies, 2006).

Based on the current 40% FANS equipage level in the NAT, the Data Link Steering Group has made a projection of equipage growth based on three hypothetical scenarios (Figure 4-16). The most optimistic scenario predicts that 87% of the NAT traffic will be

FANS equipped by 2020. The most conservative scenario predicts a more moderate growth in aircraft equipped, reaching 56% by 2020. The future path of data link diffusion will depend, among other things, on the successful implementation of effective value capture and delivery strategies.

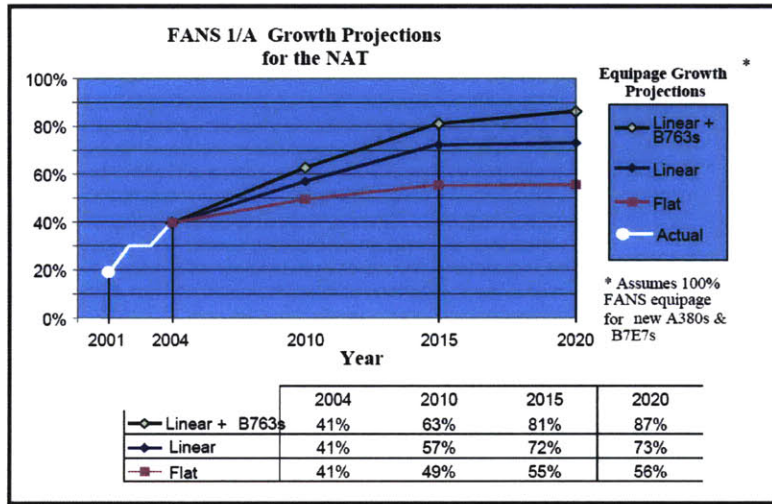


Figure 4-16: FANS-1/A Growth Projection Capabilities for the NAT (NAT DLSG, September 2005).

#### 4.2.2 Characterization of Adopters

This thesis is concerned with the adoption of data link by commercial airlines, on the airborne side, and by ANSPs, and on the ground side. The operators could be considered as a quasi-homogeneous group. As a business entity, their interest is to reduce costs and to maximize revenue in order to increase profits. Their investment decisions follow these principles.

Therefore, within Roger’s framework of market segmentation (Figure 4-17), very few of the operators would fit into the categories of innovators. A limited number of airlines, such as Qantas in the South Pacific, could be considered as early adopters who decide to invest in a new technology even at the early stages of deployment. The rationale behind this investment will often be to seek first-mover competitive advantage, such as Qantas access to the route L888 in China, reserved for FANS equipped aircraft. Most of



the major carriers in the NAT would fall into the categories of early and late majority adopters. Before committing to invest, airlines in these groups need a strong baseline of proven benefits and the infrastructure to support the technology. The last segment under the bell curve, technology laggards, is represented by those operators which cannot easily close a business case for data link even after infrastructure and benefits are in place. This could happen, for example, if fleet is too old to justify investment or if they are unable to explode the full potential of the technology due to nature or frequency of operations.

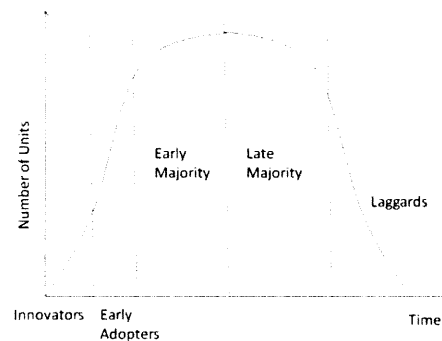


Figure 4-17: Rogers' Market Dynamics – Basic Segmentation  
(Adapted from Davis, 2008).

On the ground side, the NAT ANSPs are a more heterogeneous group than the operators. They differ in their regulatory and economic frameworks, the traffic volume they handle, and in their level of stake in the NAT. Figure 4-18 shows an approximate timeline for FANS implementation in the NAT. Roger's market segmentation model could also be applied to ANSPs. Those ANSPs with the most resources and interests at stake could be seen as innovators or early adopters (e.g. Gander, Shanwick, NY). They are the initiators of change. On the other hand, those with the least resources and relatively less direct benefit from data link adoption lay at the other end of the bell curve spectrum (e.g. Bodo). The rest of the ANSPs have followed a rationale for transition that would locate them within the mid-portion of the market segmentation model.

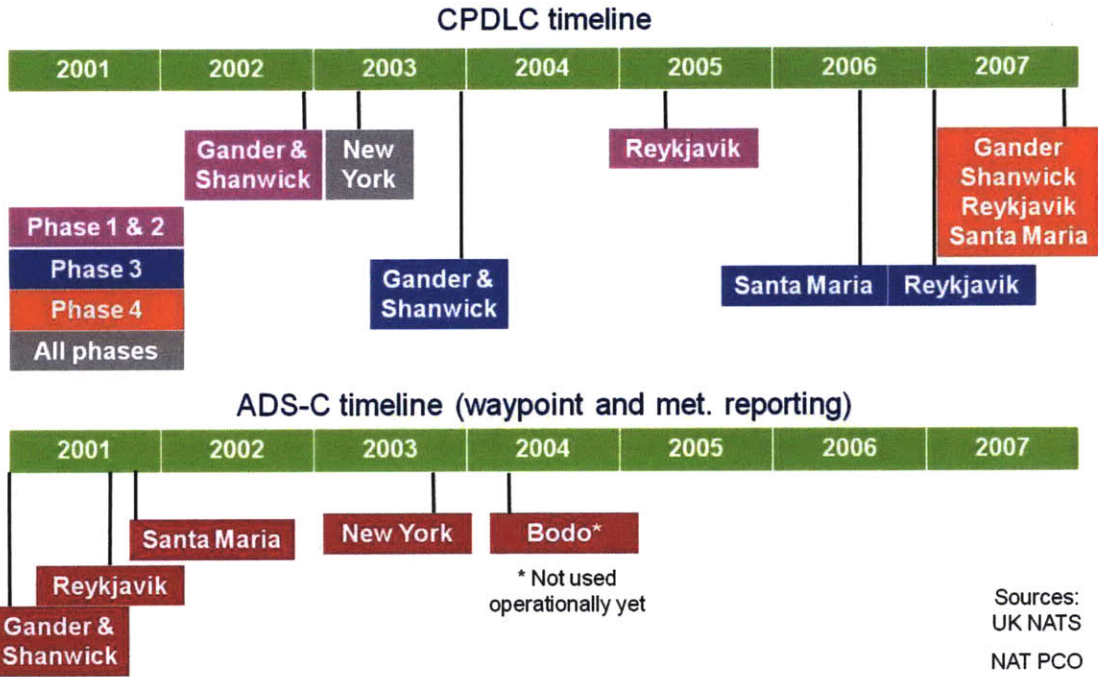


Figure 4-18: Approximate Timeline for FANS-1/A Implementation in the NAT.

#### 4.2.2.1 Current and Projected Data Link Equipage

The purpose of the third research area in the stakeholder survey “Current and Projected Data Link Equipage and Infrastructure” was to gain more insights into the dynamics of data link diffusion than what the aggregate trends and projections showed thus far. Given that FANS-1/A was selected as the current enabling technology that has the potential to improve efficiency of operations, data was gathered to determine the level of FANS equipped aircraft over the NAT. Although the responses varied greatly, the majority of the operators had their fleet at least partially equipped (Figure 4-19).

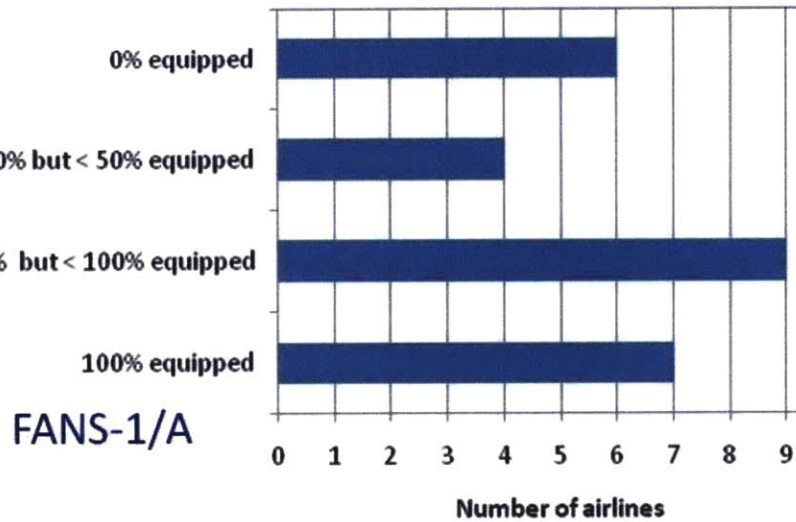


Figure 4-19: Percentage of NAT fleet equipped with FANS-1/A (Survey Results).

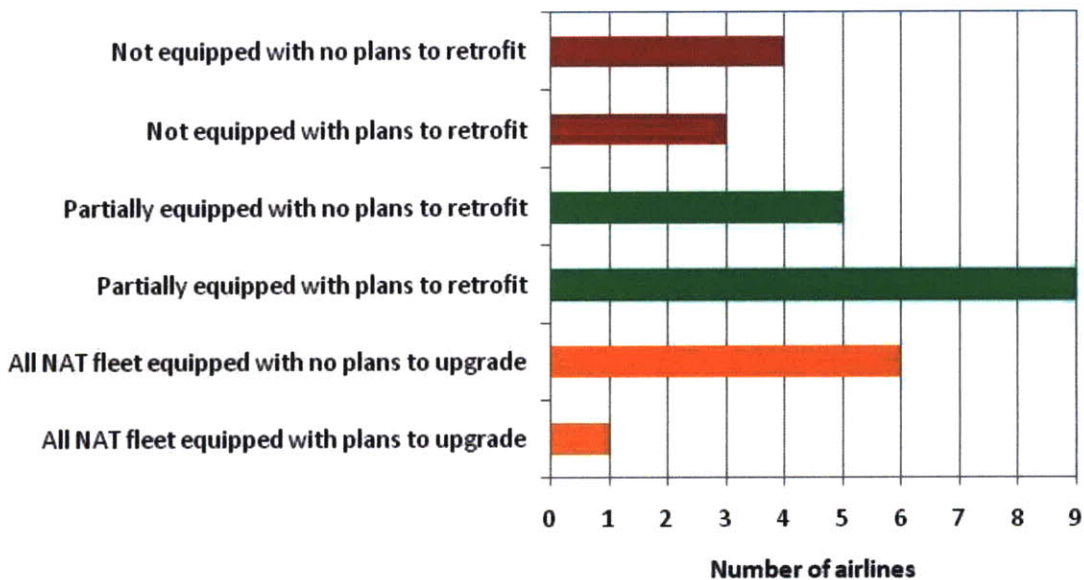


Figure 4-20: FANS-1/A Equipage Plans (Survey Results).

Based on their current equipage level, the next task was to assess retrofit plans (Figure 4-20). The majority of the airlines that were not equipped did not have any plans to retrofit or forward fit. Out of those airlines that were partially equipped, the opinions were very mixed between those that had plans to retrofit and those that did not. Finally, the great majority of the airlines that were 100% equipped with FANS had no plans to upgrade their systems.

#### 4.2.2.2 Current and Projected Data Link Infrastructure

On the ANSP side, the main data link technologies supported seemed homogeneous at first glance, but this is not always the case in reality. For example, even though most ANSPs support the FANS system (Figure 4-21), they do not necessarily support the same CPDLC message sets nor the same ADS-C contracts. Further, not all of the providers implemented the FANS components simultaneously; the transition lasted approximately between 2001 and 2007, as was shown in Figure 4-18.

Similarly, some providers use AIDC to coordinate with certain ANSPs while communicating through voice with others. Although most of the ANSPs interviewed support some form of automation system, these are not necessarily compatible with each other, which could be an issue for some ANSPs if changes to the current separation standards were to be implemented.

	Bodo	Gander	NY	Reykjavik	Shanwick	Santa Maria
CPDLC	○	●	●	●	●	●
ADS-C	○	●	●	●	●	●
AIDC	○	●	●	●	●	●
Automation	○	●	●	●	●	●
ADS-B	○	●	○	●	○	○
Radar	○	○	○	●	○	○
FMC-WPR	●	●	○	●	●	●
OCD	○	●	○	○	●	●
Backup system(s)	Assign diff. altitudes, paper strips, no backup	?	HF voice, flight strips	Fall back to previous automation system	Backup system and internal procedures	System recovery tool, manually augmented

● Available  
○ Not available

Figure 4-21: ANSP Infrastructure and Services Supported (Survey Results).

In terms of plans that ANSPs have regarding infrastructure and services, the great majority indicated an on-going process of baseline system improvements as well as plans to participate in different regional initiatives (Figure 4-22). Although ANSPs tend to

collaborate with each other in such initiatives, some of these efforts are not completely harmonized across the NAT.

One of the most important developments, according to the value perceived by stakeholders, is the proposal to introduce limited lateral separation minima by 2009 with full implementation by 2012. This effort is part of the NAT Service Development Roadmap (NAT IMG, June 2008). Other initiatives include the AIRE program, under development as part of NexGen and SESAR efforts in the U.S. and Europe, respectively. The objective of AIRE is to develop procedures to reduce the environmental footprint in the NAT. Other programs are looking at possible ways to optimize oceanic flights, such as the recent preliminary trials of ADS-B in-trail climbs carried by Airbus, Reykjavik, and Shanwick (Hughes, 2008).

Projected Infrastructure and Services	NAT ANSPs	SoPAC ANSPs
Continuous process of baseline system improvements	●	●
New initiatives	●	●
No plans to upgrade	○	

● > 2/3 participants  
 ● > 1/3 and <2/3 participants  
 ○ emphasized by less than 1/3 participants

Figure 4-22: Projected ANSP Infrastructure and Services (Survey Results).

#### 4.2.2.3 Crossing the Chasm

In the operators case, strategies need to be implemented in order to cross the chasm and stimulate the momentum necessary to encourage further data link adoption. The inertia in this group comes primarily from their inability to close their business case for investment and uncertainty about the commitment on the ground side to support the infrastructure and develop the policies and procedures necessary to derive tangible benefits from data link.

The data link case for the ANSPs is fundamentally different to that of the airlines. For starters, the service providers have already put forward most of the initial investment to

support data link, at least with regards to the FANS package. The chasm they need to cross is primarily one of coordination and resolution of other issues that currently prevent maximizing the value that could be captured from the technology. The perspectives of both of these groups will be discussed in greater detail in the next chapters.

### **4.3 Value Creation through Organizational Structure and Processes**

This section explores the organizational structure of the two main stakeholder groups in the NAT. Understanding their structure will facilitate creating suitable strategies based on their flexibility (or inertia) to data link transition and improve coordination.

#### **4.3.1 Commercial Operators**

The major carriers serving the NAT follow different business models, mission statements, and operating practices. However, for the purposes of this thesis, this group is seen as a single entity facing the same challenges and constraints of the current industry environment. Airlines try to seek a balance in looking for ways to gain competitive advantage (for example, by investing in new technology) while managing with caution the level of risk they undertake.

The overall organization and structure of an airline is divided into different units, including: marketing, finance, customer service, flight operations, in-flight services, maintenance and engineering, industrial relations, scheduling, fleet planning, and forecasting (Hanahan, 2008). Interviews conducted as part of the NAT Operators survey revealed that strategic and tactical investment decisions take into consideration the impact to these different areas. For example, airlines want financial investments in new technology to allow them to have versatility to adjust their fleet planning and scheduling according to their demand forecast. Therefore, harmonization of technologies and procedures is fundamental to allow them to offer global solutions. Survey data also revealed that an airline frequently has a much shorter planning horizon than civil aviation authorities. The different organization units within an airline must retrofit each

other before committing to adopt a new technology. In spite of the superiority of a new technology, value creation and technology diffusion are affected if a positive business case cannot be made within the planning horizon.

### 4.3.2 Air Navigation Service Providers

ANSPs provide Air Traffic Management Services to ensure the safe and efficient operation of air traffic. However, as mentioned earlier, NAT ANSPs are a more heterogeneous group than the airspace users. Each ANSP has individual characteristics that make their investment decisions unique. They vary in the size of the airspace controlled, the volume of oceanic traffic handled, and, in some cases, the scope of services offered. Furthermore, they follow significantly different business models and regulatory frameworks, varying in their ownerships (e.g. government owned, private corporations), economic and safety regulations (e.g. internal, separate agencies), revenue (e.g. taxes, user fees) and financing sources (e.g. private & public loans, profits, equity capital, government funds), and access to capital markets (MBS Ottawa, 2006). These characteristics bring special challenges to the coordination of harmonized regional initiatives to support new infrastructure and services. Table 4-2 and Table 4-3 summarize some of the major structural highlights.

Table 4-2: ANSPs Size and Scope.

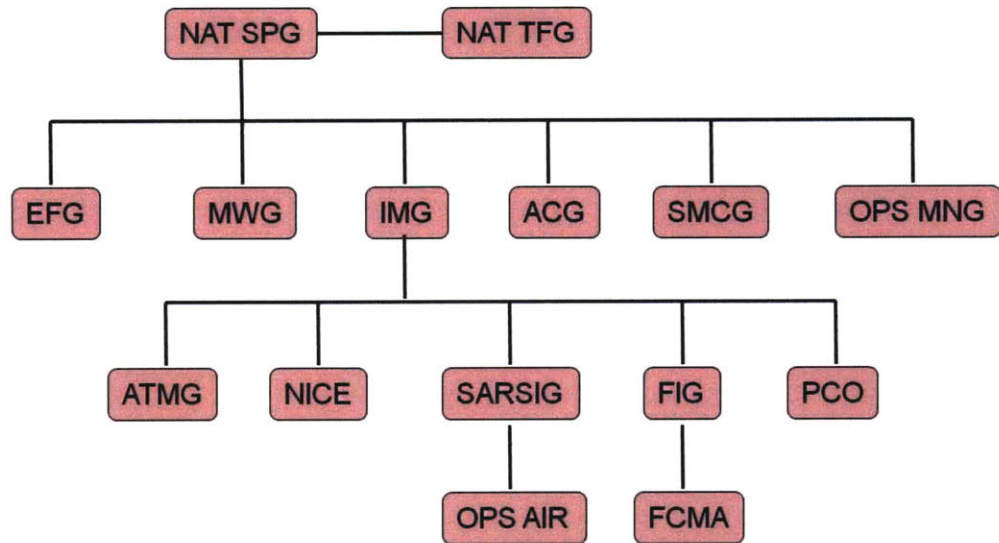
ANSP	Oceanic FIR	Size controlled airspace ('000 km <sup>2</sup> )	Volume oceanic traffic day	HF services
Avinor	Bodo	719 (D) & 1,310 (O)	10-70	Collocated ATCC
FAA ATO	NY / Oakland	8,516 (D) & 56,980 (O)	520/610	NYCradio - ARINC
IAA Ireland	Shanwick	453 (D & O)	N/A	Shanwick Radio
NATS UK	Shanwick	878 (D) & 2,230 (O)		Shanwick Radio
Nav Canada	Gander	15,062 (D) & 3,070 (O)	1200	Collocated OACC
BGSF APP	Sondrestrom	87.3 (65K ft-FL195 controlled airspace)	1-10	Providing VHF comm.
Nav Portugal	Santa Maria	666 (D) & 5,190 (O)	330	Collocated OACC

Table 4-3: ANSPs Structure and Business Models.

ANSP	Ownership	Economic Regulation	Safety Regulation	Revenue Sources	Finance (Budget)	Capital Market
Avinor	Joint-stock, government owned	Ministry Transport and Comm.	CAA	User fees	Profits, private & public loans	No
FAA ATO	Government department	NA – taxed based	Internal but separate	Taxes and fees	General fund	No
IAA Ireland	Joint-stock, government owned	Regulatory commission	Internal but separate	User fees	Profits, domestic government funds	Yes
Nav Canada	Non-for profit Private corporation	Self-regulatory pursuant to statutory charging principles	Separate MOT	User fees	Profits	Yes
NATS UK	Joint-stock Public-private partnership	UK CAA ERG formula linked to RPI	UK CAA SRG	User fees	Private loans, equity capital, profits	Yes
BGSF APP	State enterprise	CAA - SLV	CAA - SLV	User fees	Profits, dom. Gov.	No
Nav Portugal	Government owned enterprise	National Inst. Civil Aviation (INAC)	INAC	User fees	Equity capital / private & public loans	No

NAT ANSPs coordinate with each other through 12 ICAO NAT regional groups, which respond to the NAT Systems Planning Group (SPG). Figure 4-23 shows such organization. NAT regional groups assess the value created by a new technology and the impact it would have on safety and efficiency at the system and stakeholder levels before fostering transition. In spite of coordination efforts, the individual differences among ANSPs afore mentioned make coordination challenging. Each entity must consider its own service needs as well as its economic and institutional frameworks within their decision making process before deciding to invest in new infrastructure or services.





NAT SPG – North Atlantic Systems Planning Group	ATMG – Air Traffic Management Group
NAT TFG – North Atlantic Traffic Forecasting Group	NICE – NAT IMG Cost Effectiveness Program
EGF – Economic and Financial Group	SARSIG – Safety Analysis and Reduced Separation Implementation Group
MWG – Mathematician’s Working Group	FIG – FANS Implementation Group
IMG – Implementation Management Group	PCO – Program Coordination Office
ACG – Aeronautical Communications Group	OPS AIR – Operations and Airworthiness Subgroup
SMCG – System Management Coordination Group	FMCA – FANS Central Monitoring Agency
OPS MNG – Operations Manager’s Meeting	

Figure 4-23: ICAO North Atlantic Region Groups (NAT PCO, March 2007)

## 4.4 Chapter Summary

This chapter introduced value propositions enabled by data link through an understanding of the evolution of technology and stakeholder needs. Section 4.1 showed how data link has created value through a cycle of continuous evolution and in response to technical discontinuities. This section also showed the perspective of operators and service providers on what they think the major sources of operational discontinuities are and what they consider the most valuable data link technologies and applications. Findings indicate that fuel penalties associated with flying suboptimal flight levels and routes is the biggest inefficiency in the NAT. Data link, particularly through the FANS system in the near term, is seen as the enabling technology to improve efficiency of operations and manage discontinuities in the system. Reducing separation standards is the near term data link application that is most valued by stakeholders. However, coordination and harmonization issues threaten to limit the value created.

Section 4.2 looked at current and projected data link diffusion trends in the form of airborne equipment as well as infrastructure and services supported. Although the previous section outlined the potential of data link, this section showed that technical performance does not always guarantee diffusion. The model presented in this section helped understand why most of the operators need a proven base of benefits and ground commitment before they can make a decision to invest in data link. The framework facilitated seeing how the susceptibility of stakeholders to uncertainty varies according to what group of adopters they belong to. This characterization of adopters under different segments will be useful in identifying strategies to create momentum and cross the chasm of technology transition.

Section 4.3 highlighted some of the organizational characteristics of both stakeholder groups in the NAT. Understanding this aspect is important because successful value creation is bounded by the limitations and unique needs that are at the core of each group. Organizational structure could be used to promote synergies and strengthen cooperation where applicable. Strategies for value capture and delivery discussed in future chapters should also observe to these boundaries.

## Chapter 5

# Value Capture Strategies Applied to the Case of Data Link

This chapter will introduce relevant issues to consider when developing strategies to capture the value created by data link. Section 5.1 will discuss the current status of value distribution of data link costs and benefits in the North Atlantic as viewed from the stakeholders' perspective. Section 5.2 will give an overview of the major challenges to be resolved before the value derived from data link could be fully captured and delivered to stakeholders. Finally, Section 5.3 will explain the complexities that risk and uncertainty add to these issues.

### 5.1 Data Link Value Capture in the North Atlantic

Capturing value and realizing the full potential of data link depends on the successful balance between costs and benefits across stakeholders and over time, as suggested in the framework proposed by Marais and Weigel (2006). The value created through data link, as discussed in chapter 4, cannot be captured unless uncertainty in the net sum of total benefits minus costs is mitigated for individual stakeholders.

### 5.1.1 Value Distribution of Costs

The objective of the fourth research area of the stakeholder survey, “Data Link Value Distribution of Costs and Benefits,” was to investigate what are the most significant benefits received from data link to date and how these compare to the initial and recurring costs associated with the adoption of the technology. This sub-section will first look at the cost component. From strictly an economic perspective, stakeholders agree that initial costs for equipment and ground infrastructure are the expenditures that would most negatively influence their decision to adopt data link. Figure 5-1 summarizes survey responses on data link costs.

Data Link Costs	NAT ANSPs	SoPAC ANSPs	NAT Operators
Initial costs greater barrier to adopting data link than recurring costs	●	●	●
Initial investment in equipment and infrastructure	●	●	●
Loss of revenue due to airplane downtime			◐
Recurring costs and upgrades not a big issue once primary infrastructure and equipment established	◐	◐	●
Training of pilots and controllers	◐	◐	○

● > 2/3 participants

◐ > 1/3 and <2/3 participants

○ emphasized by less than 1/3 participants

■ Initial costs

■ Recurring costs

Figure 5-1: Data Link Costs Summary (Survey Results).

For the airlines, initial equipment and installation cost is the major barrier to equipage. In contrast, the majority of the service providers have already incurred most of the expenses associated with data link and automation infrastructure in the NAT. Nonetheless, some of the major challenges that ANSPs face in order to deliver value from data link relate to the implementation and coordination of policies and procedures.

Recurring costs such as communication charges, personnel training, and system maintenance play a lesser role in the business case of the stakeholders once the primary equipment is installed. For example, in the case of the ANSPs, it may take a couple of

years to implement a new application if base systems are already existent, but it could take up to 10 years or more if they have to install an automation system from scratch. Figure 5-2 and Figure 5-3 synthesize these perspectives under the model of value distribution among stakeholders and over time introduced by Marais and Weigel (2006).

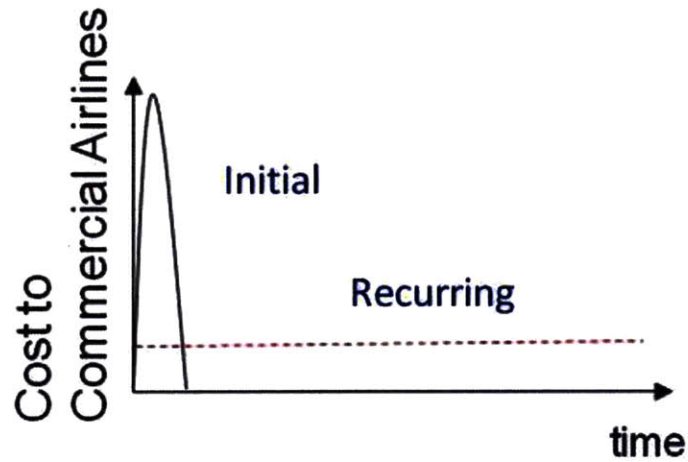


Figure 5-2: Time-Value Distribution of Data Link Costs: Operators  
(Adapted from Marais and Weigel, 2006).

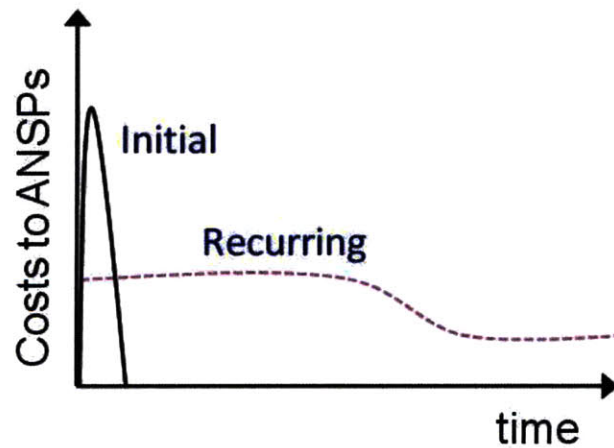


Figure 5-3: Time-Value Distribution of Data Link Costs: ANSPs  
(Adapted from Marais and Weigel, 2006).

### 5.1.2 Value Distribution of Benefits

This sub-section will look at the second component of value distribution, stakeholder benefits. All of the interviewees reported currently receiving significant operational benefits from data link. One of the most valued benefits is the improvement in clarity and availability of communications compared to HF voice. Even though demand for HF services has reportedly increased due to higher traffic volumes (NAT SPG, May 2007), data link has been effective in mitigating the impact of HF congestion. Also, stakeholders like the direct interface between pilots and controllers, bypassing radio operator relays used with HF.

Other operational benefits that were highlighted in the survey include more flexibility to grant and request clearances, reduction in pilot and controller workload, reduction in Gross Navigation Errors (GNE) by eliminating manual position reports, flexibility to request and avoid weather, improvements in AOC communications, in-flight monitoring and pre-flight operations, and greater access to emergency medical communications. Figure 5-4 shows a summary of current data link benefits.

Current Data Link Benefits	NAT ANSPs	SoPAC ANSPs	NAT Operators
Significant operational benefits	●	●	●
Communications: reliability, less HF congestion, speed, direct ATC link	●	●	●
Clearance flexibility; more access to efficient routes and FLs	●	●	●
Reduction in pilot/controller workload by using automatic position reports	○	●	●
Reduction in GNE by eliminating manual position reports	●		○
Flexibility to request and avoid weather			●
Airline communication, in-flight aircraft monitoring, pre-flight operations			●
Time savings in total block and turn around time			○
Diversion negotiation and access to emergency medical services			○
Significant economic benefit for users (reduced separation standards)		●	
Significant economic benefits for ANSPs			
Reduction in communication charges			○

● > 2/3 participants

● > 1/3 and <2/3 participants

○ emphasized by less than 1/3 participants

■ Operational benefits

■ Economic benefits

Figure 5-4: Data Link Benefits Summary (Survey Results)

Under the current system, each flight has to maintain the track, altitude, and Mach number assigned by the controller. A staggering 90% of all NAT flights file single altitude in their flight plan when crossing the OTS. A study conducted at the New York Oceanic FIR demonstrated that data link equipped aircraft are more likely to request level changes and improve operational efficiency than non-equipped aircraft. In the period between May 2004 and March 2005, 69% of all altitude changes came from data link flights, whereas only 58% were made by HF-only aircraft. The time to grant clearances also improved, taking only 4.2 minutes for requests made via data link compared to 8.9 minutes for requests via HF (Williams, 2005).

According to the NAT Data Link Steering Group, the initial rationale behind data link implementation in the NAT was based on a “no benefit” approach, given that some airlines were already equipped with the technology (NAT DLSG, September 2005). Currently, the need for more efficient and economic technical solutions is greater in order to be able to respond to a more challenging operational environment and growing traffic demand. Both operators and providers agreed that the data link technology currently available on aircraft has not been fully utilized and that users have not been able to capitalize on economic benefits, such as improving fuel efficiency. This is primarily because new procedures enabled by data link, such as reducing separation minima, have not been implemented in the NAT yet. It is worth mentioning that airlines did report getting substantial economic benefits in terms of fuel savings in the South Pacific, where 30/30 nautical miles (NM) reduced separation has been introduced. The only current economic return that airlines reported in the NAT is a reduction in communication charges offered by NavCanada.

According to the NAT Data Link Steering Group, the major economic benefit that data link could bring to the NAT ANSPs is through the possibility of phasing out HF voice as primary method of communications and reducing the current number of HF radio stations from six to two (NAT DLSG, September 2005). Since this has not happened yet, the ANSPs interviewed said they do not directly receive economic benefits from the data link services they offer. Therefore, a time lag exists between accrual of data link operational and economic benefits for operators and service providers. Figure 5-5 and

Figure 5-6 synthesize these perspectives under the framework proposed by Marais and Weigel (2006).

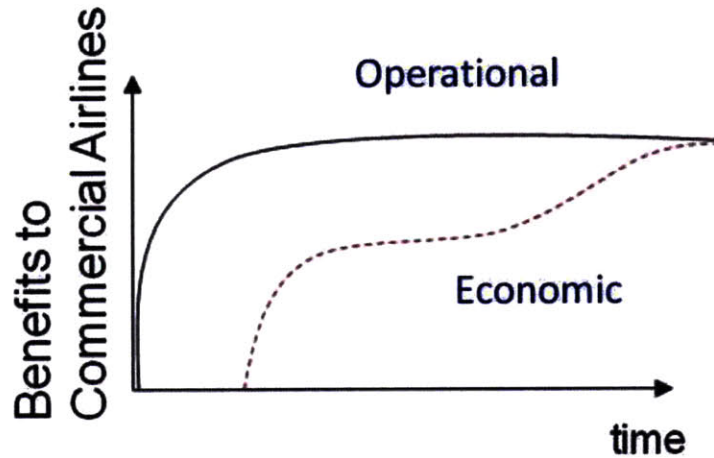


Figure 5-5: Time-Value Distribution of Data Link Costs: Operators  
(Adapted from Marais and Weigel, 2006).

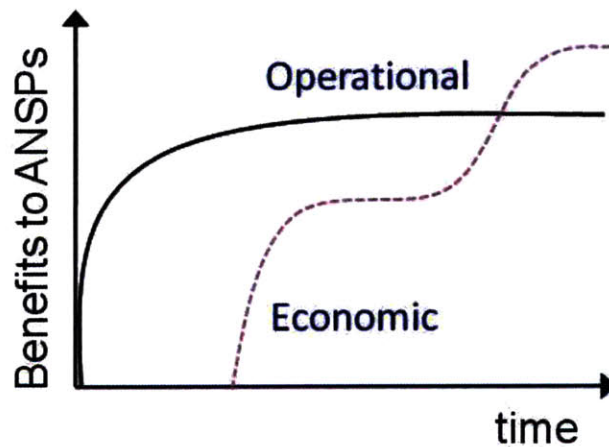


Figure 5-6: Time-Value Distribution of Data Link Costs: ANSPs  
(Adapted from Marais and Weigel, 2006).

## 5.2 Value Capture Elements

As mentioned in chapter 2, most of the value captured from data link is through complementary assets, such as services offered and new applications enabled (Davis,



2008). Some of the metrics used to measure the value captured include services, milestones, royalties, as well as time and cost savings (Sabatier, 2008). As seen from the stakeholder survey, there is a time gap between initial investment costs and accrualment of economic benefits for both airlines and service providers (Figure 5-7 and Figure 5-8). The full potential of data link in the NAT has not been captured yet, as no new applications that could justify a business case for investment have been implemented.

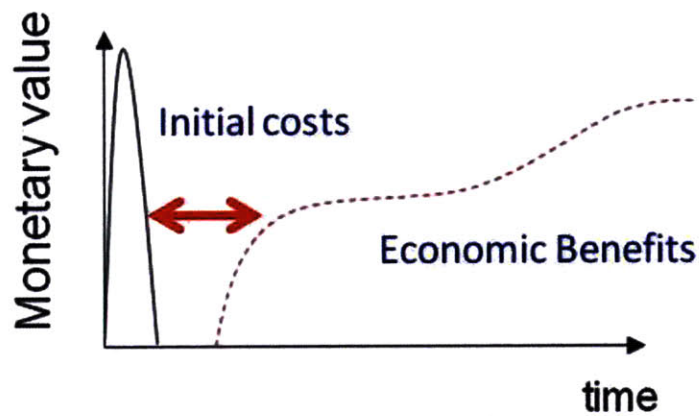


Figure 5-7: Summary of Time-Value Distribution of Data Link Costs and Benefits: Operators (Adapted from Marais and Weigel, 2006).

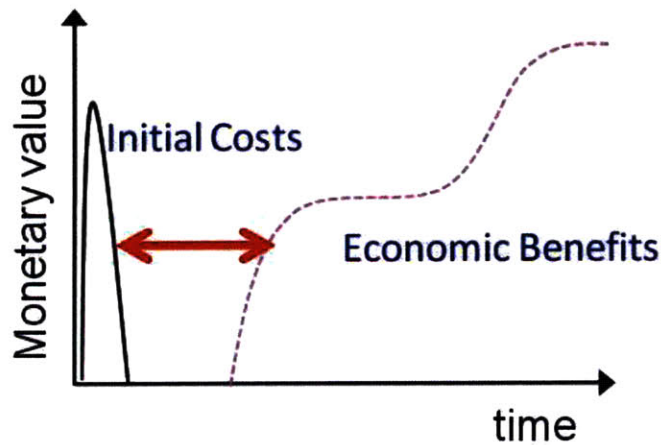


Figure 5-8: Summary of Time-Value Distribution of Data Link Costs and Benefits: ANSPs (Adapted from Marais and Weigel, 2006).

The stakeholder assessment identified fuel penalties associated with flying less than optimal flight routes and levels as the major operational inefficiency in the NAT. Wind streams and schedule preferences make certain tracks within the NAT OTS more demanded than others. This leads to periods of high traffic density throughout the day on the most preferred tracks. Clearance requests are sometimes denied due to traffic volume, forcing operators to fly below optimal conditions of fuel efficiency. Limitations in frequency of position reports to maintain surveillance and HF voice communications contribute to this effect (Williams et al, 2005). Data link, particularly through the FANS system, is perceived as the enabler to improve efficiency of operations, and the most valuable application identified is reducing separation minima.

Reduced separation has already been introduced successfully in the South Pacific. Auckland Oceanic, Oakland Oceanic, Nadi, Honiara, and Nauru FIRs have implemented data-link-based 30 NM longitudinal and 30 NM lateral separations (Pina, 2007). Nonetheless, reducing separation minima in the NAT represents a new set of challenges. A number of issues need to be resolved before value from data link can be delivered to all stakeholders. Some of these concerns include (Figure 5-9): safety, policies and procedures, technical and coordination issues, user equipage and network effects, and a business case for operators and service providers. A brief overview of each follows.

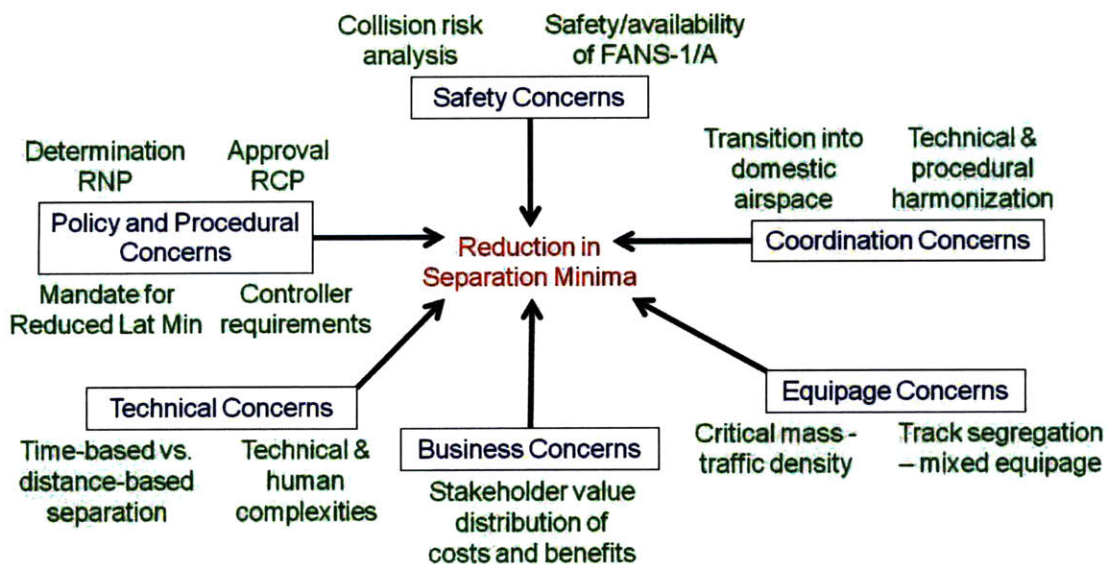


Figure 5-9: Elements in the Case for Reduced Separation Minima over the NAT.

### 5.2.1 Technical Issues

The current operational environment in the NAT is based on strategic separation, with controllers intervening only when necessary. Moving the current distance/time based separation standards in the OTS (60 NM or 1 degree lateral and 10 min longitudinal) to an entirely distance-based tactical environment (e.g. 30/30 NM separation) will call for significant changes to Gander and Shanwick automation systems. Further, a tactical environment will require controllers having direct responsibility for separation and intervening more frequently, as flights will be able to operate under scenarios of potential conflict. Justifying a business case under this environment may be difficult due to increases in development and staffing costs (NavCanada, January 2007).

According to the NAT Service Development Roadmap, significant benefits could still be achieved while maintaining a distance/time based environment for lateral/longitudinal separation, respectively (NAT SPG, June 2007). The main technical requirement for reducing separation minima is increasing position reporting rate through ADS-C and CPDLC equipage. For example, Williams et al report that a 30/30 NM (lateral/longitudinal) separation requires approximately 6 minutes of communication and controller intervention time with ADS-C position updates every 14 minutes at a latency of no more than 1 minute. Going to 20/20 NM separation would require approximately the same communication specifications with position report updates every minute at no more than 15 seconds of latency (Williams et al., 2005).

Reducing lateral separation by half a degree (to approx. 22.5 NM) will require determining a navigation performance standard, although preliminary indications suggests that RNP-2 may meet these criteria. To meet the RNP-2 standard, an aircraft would have to be able to navigate with a cross-track and along-track Total System Error (TSE) less than  $\pm 2$  NM during 95% of total flight time (ICAO Secretariat, 1999). Additionally, the specification of a Required Communications Performance (RCP) may be needed in order to meet the safety case (NavCanada, January 2007). RCP specifies standards for communication delay time, continuity, availability, coverage, accuracy, and integrity (Kraft, 2007 and Hollinger et al., 2005).

On the ground side, implementing 30/30 NM separation in the South Pacific required ANSPs to have automation systems, such as FAA's ATOP, with available tools for

separation assurance, conflict prediction and reporting, graphic dynamic situation display, automatic coordination, flight data management, communications, and interfacility coordination (FAA, October 2005).

One technical challenge to overcome in the future is preventing congestion of the HF network infrastructure, which is expected to take place as early as 2009 if traffic and voice messages continue to grow at projected rates. Contrary to expectations, the number of HF messages in the NAT has not been reduced since FANS-1/A was introduced. The requirement or preference to use HF voice in addition to data link coupled with the growth in traffic demand have negatively impacted HF regression efforts. Reportedly, an aircraft fully observing data link procedures in Shanwick Oceanic will only make one less HF contact than an aircraft observing HF procedures only (NAT SPG, June 2007). One alternative that could facilitate HF regression could be to investigate the possibility of defining an RCP standard that includes SATCOM voice as a back-up medium for data link operations in the event of FANS system failure (NAT SPG, November 2007).

Additionally, according to the NAT Systems Planning Group, there are still some technical issues impacting FANS-1/A operations. For example, Oakland Center reportedly experienced 38 outages in communication that affected either data, voice, or both between September 2006 and August 2007. Up to 81% of those outages lasted 10 minutes or longer. Other unsolved issues include problems related to ADS-C lateral deviation contracts and improvements necessary to data link training of pilots and controllers (NAT SPG, November 2007).

### **5.2.2 Safety Issues**

At the moment, the FANS-1/A system (ADS-C and CPDLC) is the only technology that could meet the safety case for reducing separation in the NAT (NAT DLSPG, September 2005). A safety case needs development in order to demonstrate that the risk of collision remains acceptably low and that the reliability and availability of the FANS system is sufficient. A safety assessment will also be necessary to reduce time-based longitudinal separation and to determine the required navigation performance needed to change lateral separation from one to half a degree (NAT SPG, June 2007).

The probability of collision risk is a function of navigation, route configuration, traffic density, and surveillance, communication, and ATC capabilities (Figure 5-10). Each of these factors requires attention before introducing any changes to the current NAT concept of operations (ICAO Secretariat, 1999).

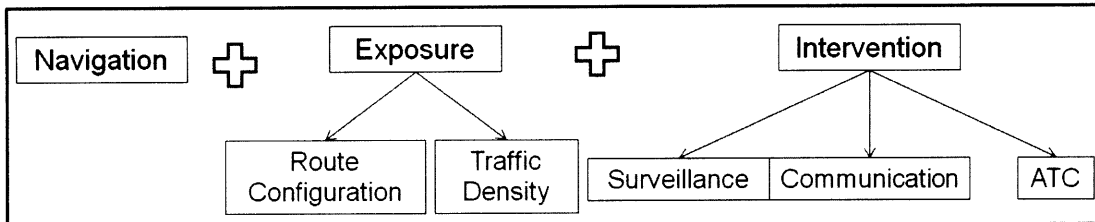


Figure 5-10: Safety Characteristics that Affect Separation Standards  
(Adapted from ICAO Secretariat, 1999).

Currently, risk in the NAT is very close to the Target Level of Safety (TLS) and measures are necessary to prevent and mitigate such risk. Data link has brought safety improvements to the NAT system by eliminating the manual insertion of data into the Flight Management System (FMS) and, therefore, reducing the possibility of GNEs. By communicating via CPDLC, the risk of misinterpreting a clearance or request is reduced as well (NAT DLSG, September 2005).

Despite improvements, certain data link issues related to safety require solution. For example, several instances have been reported of misunderstandings of CPDLC message terminology and clearances. Some of these have resulted in Large Height Deviations (LHD). A great number of errors in lateral and longitudinal navigational performance result from the re-issue of CPDLC clearances. At the moment, there is no CPDLC message convention that could be used to cancel a previous clearance. Other reports point to occurrences of non-compliance with restrictions or clearances, particularly in the Santa Maria Oceanic Center. Additionally, improving navigational practices of aircrew is needed to help detect and prevent GNEs (NAT SPG, June 2007).

In order to reduce separation in the NAT, the controller needs to be able to use the primary method of communication to intervene in the resolution of a potential conflict within four minutes. The back-up method of communication shall allow intervention within 10.5 minutes in case of primary system failure (NAT DLSG, September 2005).

Regarding a backup communication capability, there is some concern about the use of SATCOM voice and the possibility of a single point of failure (NAT SPG, June 2007). On the surveillance side, an ADS-C position report needs to be received within three minutes. Otherwise, action must be taken to get the report either via ADS-C or CPDLC. If report is still overdue after six minutes and there is the possibility of conflict, controller must be able to intervene and resolve issue within 7.5 minutes (NAT DLSG, September 2005).

### **5.2.3 Policy and Procedural Issues**

In order to reduce separation minima, new policies and procedures will have to be developed. These include RNP-based certification and operational procedures for lateral spacing and time-based procedures for longitudinal separation. Policy measures such as track segregation and a data link mandate may have to be considered to try to maximize efficiencies and reduce penalties.

Additionally, stakeholder responsibilities should be clearly outlined in the following areas (EUROCONTROL, May 2006):

- ANSPs: deployment and integration of necessary data link systems, provision of data link services according to quality agreed, coordination and service level agreements with other ANSPs, training guidelines for controllers and maintenance staff, safety and conformity assessment, publication and revision of data link documentation for operators.
- Operators: Aircraft equipage and integration of necessary data link systems, pilot training, and conformity assessment of airborne provisions.

### **5.2.4 Coordination Issues**

The interface between oceanic and domestic airspace needs to be carefully considered when implementing any changes to the current operational environment. Efficiencies gained by reducing separation standards in the oceanic sector could be lost if domestic airspace becomes overloaded with traffic, particularly when approaching European

airspace on eastbound flights (NavCanada, January 2007). Coordination between ANSPs and users is necessary to ensure end to end operational solutions in the NAT.

Further, as seen in the survey data, stakeholders do not want to see multiple technologies and procedures for pilots and controllers in different regions. Care must be taken to work toward developing an environment that allows carriers to operate globally and seamlessly (NAT SPG, June 2007).

### **5.2.5 Equipage Issues**

Achieving significant benefits from reduced separation depends on a high percentage of traffic meeting equipage requirements. The SoPAC has already introduced reduced separation (30/30 NM), user preferred routes, re-routing capabilities, and weather deviations. In this region, 80% of the fleet uses FANS-1/A (Kraft, 2007). In contrast, the NAT Systems Planning Group (SPG) estimates that approximately 40% of flights are currently transmitting ADS-C reports (NAT SPG, June 2007). In this kind of mixed equipage environment, initial realization of benefits will probably imply airspace segregation or implementation of preferred routes (Figure 5-11). An important policy question is how to maximize value delivery and leverage on equipage network effects while minimizing penalties to those aircraft unable to equip.

According to interviewees, reducing longitudinal separation in the OTS does not depend on achieving a critical mass of equipped aircraft. Separation could be reduced longitudinally between two consecutive ADS-C equipped flights using the Mach number technique without having to alter standard separation between the second ADS-C flight and a following third non-equipped aircraft. In contrast, reducing lateral separation minima between OTS tracks from one to half a degree will require all aircraft on these tracks to meet equipage requirements. Reducing lateral separation will enable the introduction of more tracks, therefore increasing capacity and placement of more tracks in favorable wind streams.

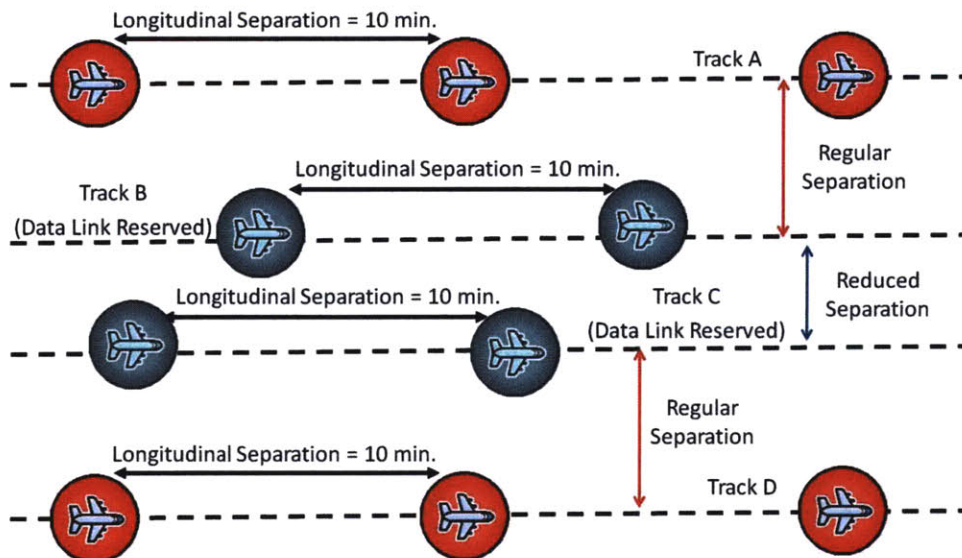


Figure 5-11: Reduction of Lateral Separation and Track Segregation  
(Adapted from Williams, 2005).

Williams, A. R. prepared a study for CSSI and the NASA Glenn Research Center on the potential benefits of reducing separation minima in the NAT OTS. The study shows flight efficiency benefits for commercial operators according to three equipage scenarios. Their findings indicate that benefits are sensitive to equipage levels, projected traffic demand, and segregation policies implemented. On average, equipped and non-equipped aircraft benefit from reduced separation, although equipped flights have 2-5 times more opportunity to accrue benefits while getting penalized 30-70% less frequently. The study also found that benefits depend on the spatial and temporal distribution of aircraft clusters (Williams, 2005).

Williams argues that depending on traffic density, equipage rates, and the procedural strategy implemented, there could be a trade-off in benefits between equipped and unequipped aircraft. Under the first scenario, current lateral separation is maintained and a track (or a couple of tracks) is designated for equipped aircraft only. If the equipage rate is low, flights in the reserved tracks will get the most benefits while penalizing unequipped flights at the same time. The second scenario is just like the first one, but with a high equipage rate. In this case, equipped aircraft will tend to move to the preferred track, increasing density in this track and reducing benefits. At the same time, unequipped flights in regular tracks will benefit from reduced congestion. A third



scenario is considered under conditions of high equipage rates. In order to deliver value to operators under these conditions, additional tracks are needed. Doing so requires reducing separation between tracks reserved for equipped aircraft while maintaining original separation between tracks with mixed or unequipped flights (Figure 5-11). Since equipped flights will prefer to operate along reserved tracks, unequipped flights are still able to benefit from reduced congestion under this scenario (Williams, 2005).

In addition to flight efficiency, human factors need to be addressed when considering reducing separation standards in the NAT. Operational and procedural complexity has a direct effect on controller's tendency to performance degradation. During the first stages of transition, a mixed equipage environment increases complexity. The likelihood of controller error increases with low to medium levels of equipage because of incorrect system abstractions. According to Pina's study, segregating the airspace to separate equipped and non-equipped is an alternative to help controllers reduce complexity and model two quasi-homogeneous groups, thereby, mitigating the likelihood of controller error. Pina also suggests considering dynamic segregation to balance the tradeoff between equipage mix and system throughput (Pina, 2007).

ADS-C In-Trail Procedures (ITPs) are another data link application which benefit potential is directly affected by equipage rates. ITPs enable reducing longitudinal separation between two aircraft when the first aircraft is in level flight and the second one climbs or descends through this altitude in order to reach another flight level. According to the Informal Pacific ATC Coordination Group (IPACG), ADS-C in-trail procedures (ITP) could enable fuel savings in the Oakland Pacific FIR of up to 20,000 lbs per day with 35% FANS equipage and up to 40,000 lbs per day with 100% equipage. For the New York FIR, 100% equipage could enable fuel savings of 2,900 lbs per day. However, an equipage rate as low as 15% did not show any significant benefits. Potential benefits in the NAT could be much higher if these procedures were to be introduced in other FIRS with higher traffic density. (IPACG, November 2007).

These perspectives on the importance of equipage rates on data link value capture can be studied under the framework of network effects introduced in the Technology Transition Framework (Chapter 2). Data link exhibits characteristics of both direct and indirect network effects. Direct network effects exist because average fuel benefits captured increase with the number of flights equipped. On the other hand, indirect network effects

exist because certain policies, such as airspace segregation, will only benefit equipped aircraft. Complementary services, such as a faster clearance response, are another example of indirect network effects.

With regards to the relationship between network effects and standards, recall from Chapter 2 that setting standards, or specifications that enable interoperability, is important in helping create network effects and assure lock-in (Davis, 2008). In the case of data link, setting technical (e.g. RCP, RNP) and procedural (e.g. access to airspace) requirements necessary to reduce separation in the NAT will help mitigate uncertainty and promote equipage.

Similarly, data link exhibits characteristics of the network properties described by Laird, Nellthorp, and Mackie: sunk costs, economies of density and scope, congestibility, and positive consumption externalities (Laird, Nellthorp, and Mackie, 2005). Some of the initial investment incurred by ANSPs to implement data link services and install automation systems can be considered as sunk costs. ANSPs see economies of density by increasing their revenue and reducing their unit costs if data link can enable capacity increases. Just like HF voice approaching congestion, data link also has the possibility of becoming saturated. Further, as seen in this section, not only the networks themselves can experience this problem; if a policy of reserving certain OTS tracks for equipped aircraft is introduced, care must be put to balance the number of reserved tracks according to equipage rates in order to prevent track saturation and potential diminishing returns from data link adoption.

### **5.2.6 Business Case**

As seen in previous sections, data link applications, such as reducing separation standards, have characteristics of positive network externalities. This means that the value captured from the technology increases with more aircraft equipping. However, the stakeholder analysis showed that operators lack a direct incentive to equip with data link due to unbalances in the distributions of costs and benefits. On the ground side, most of the upfront investment to offer data link services has already been incurred. However, a number of issues need resolution before data link value can be fully delivered to stakeholders. Both groups, operators and ANSPs, need to make projections into the

future on their investment and the amount of value they expect to capture from it. Data link transition may be delayed if stakeholders cannot close their business case, even if the technical and policy cases are clear.

#### **5.2.6.1 Business Case Objectives**

The objective of this section is to set up the major elements involved in assessing the financial viability of adopting data link. This includes outlining the methodology to conduct a Net Present Value Analysis (NPV) and balance the cash flows of revenues and expenditures during the lifecycle of a data link investment in the NAT. Each of the categories presented in the NPV analysis model can be expanded or tailored as necessary.

#### **5.2.6.2 Operators Business Case Considerations**

In order to make a positive business case to equip with data link, operators would only consider investing in a new technology if they can see a return on investment (ROI) within one to three years. Additionally, it is hard to justify the cost of retrofit if aircraft have less than ten years of expected service life. At less than five years, cost would be prohibitive. Apparently, cost is easier to justify when fleet is partially equipped and all new airplanes already have the latest technology. Initial costs depend highly on equipment initially installed on the airplane.

According to the level of retrofit necessary, installation process could take anything from one day to a month. Loss revenue caused by grounding airplanes to retrofit would be, in most cases, prohibitive. Airlines try to mitigate this cost by taking advantage of C-checks to retrofit. Most operators indicated that unless there is an urgent issue, such as a mandate, they would not ground an airplane just to install equipment. Due to retrofit costs, future data link applications may be more applicable to new aircraft already equipped from manufacturer.

Figure 5-12 shows the potential sources of costs and economic benefits directly informing the operators' business case for data link. Direct costs identified include avionics procurement and installation, personnel training, equipment maintenance, and

communication/ANSP charges. Meanwhile, airlines' potential to gain economic benefits from data link comes primarily from cost avoidance in the form of fuel and time savings by improving flight efficiency. One possible source of direct economic benefit is using fuel saved to carry additional cargo revenue. In fact, the benefit brought by additional cargo could be substantially greater than benefits brought by fuel savings. Williams reports that in 2001, fuel price was \$0.12/lb while average unit revenue of additional cargo was \$1.60/lb (Williams, 2005). Investment decisions depend on how well airlines can balance such cost and benefit components within their planning horizon.

As seen in the survey results, data link operational benefits have so far been more significant and prompt than economic benefits. The survey also showed that initial cost of investment is the major barrier to operators equipage. Airlines recognize there would be a business case to invest in data link if applications such as reduced separation are in place. Since this has not been the case yet, they cannot easily close the gap existing in their business case between initial costs and return on investment. Therefore, a major barrier to data link adoption is the uncertainty from the ground side in the establishment and harmonization of technologies and procedures.

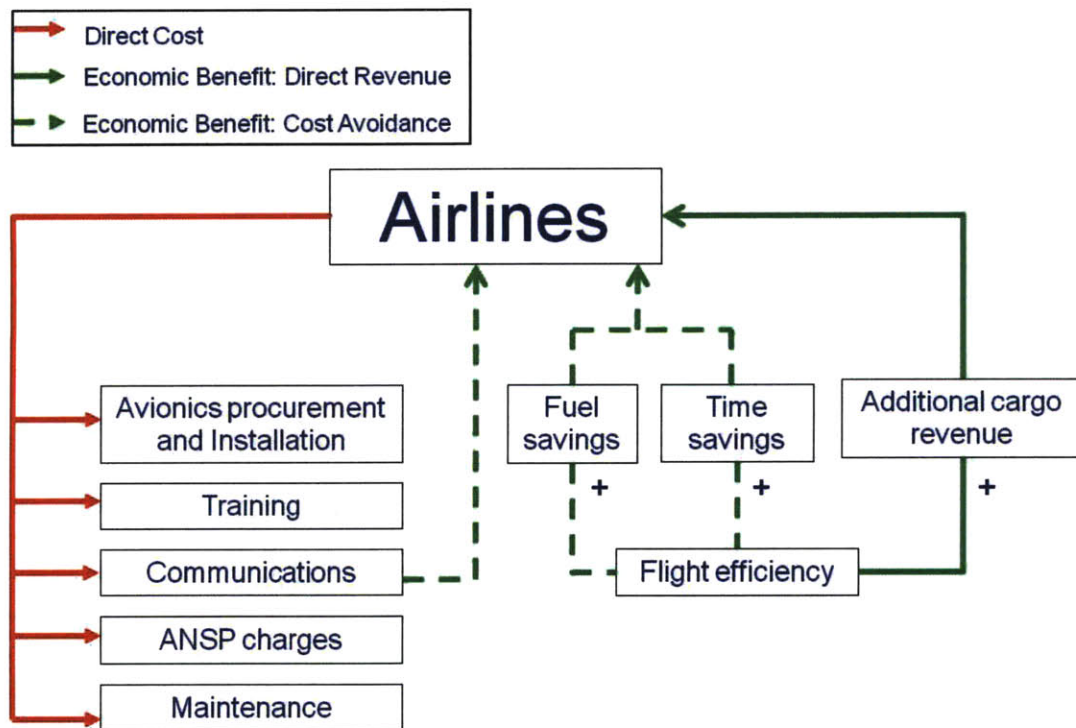


Figure 5-12: Data Link Business Case Elements: Airlines.

### 5.2.6.3 ANSPs Business Case Considerations

As mentioned in Chapter 4, the NAT ANSPs are a more heterogeneous group than the operators. Each ANSP has individual characteristics that make their investment decisions unique and they follow significantly different business models and regulatory frameworks, varying in their ownerships, economic and safety regulations, revenue and financing sources, and access to capital markets.

Figure 5-13 shows general flows of cost and revenue for an ANSP. How each of these elements affects their case for data link and what flexibility providers have to influence them will depend on the particular structure they follow. Direct costs identified include ground infrastructure and equipment, maintenance, training, personnel, and communications. According to their individual model, each ANSP's main source of direct revenue comes from user fees, which depend on the number of airplanes they serve and on the revenue per airplane they receive. Additionally, if the ANSP is responsible for the provision of HF services, data link could potentially be a source of cost avoidance on HF infrastructure if dependence on HF voice could be reduced.

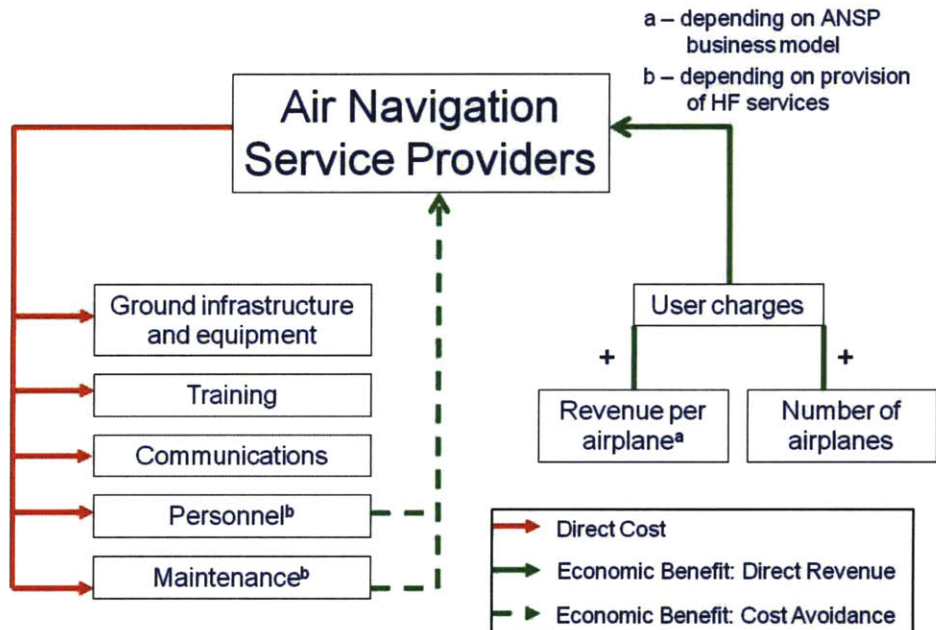


Figure 5-13: Data Link Business Case Elements: ANSPs.

Similar to the operators' case, a gap exists between initial investment costs and economic benefits for the service providers. However, contrary to the airlines, the majority of the ANSPs have already made the initial investments to support air traffic automation systems and data link technologies (such as ADS and CPDLC). Some of the major challenges on the ground side refer to addressing the rest of the concerns described above in order to deliver value to stakeholders and reduce uncertainty.

#### 5.2.6.4 Business Case Setup

The viability of a data link investment depends on a positive net present value (NPV) in which the total benefit recovered exceeds the total cost of investment throughout the life-cycle. Using the NPV method requires to account for yearly estimations of costs and benefits and discount them back to the starting year. This allows accounting for those costs that may only be present during the transition period. Figure 5-14 shows an overview of the net present value approach (ICAO Secretariat, 1995).

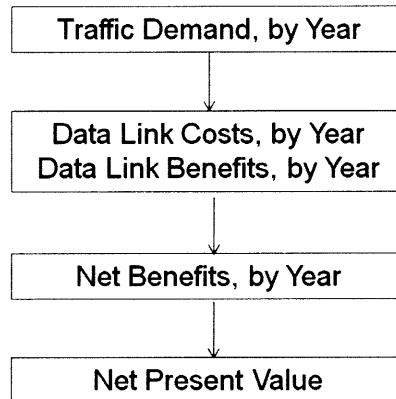


Figure 5-14: Overview of Net Present Value Approach  
(Adapted from ICAO Secretariat, 1995).

Estimations of future costs and benefits depend directly on traffic demand. A forecast of traffic volume throughout the planning cycle is essential for the analysis. The number of flight hours can be calculated as shown in equations 1 and 2. The forecast of flight hours and aircraft numbers can be recorded as shown in Table A - 1 (ICAO Secretariat, 1995):

$$\textit{Flight hours} = (\textit{aircraft movements} \times \textit{Average distance flown}) / \textit{average speed} \quad (\textit{eq. 1})$$

$$\text{Flight hours (year } t) = (\text{flight hours base year } b) \times (1+p)^t \times (1-f)^t \times (1-s)^t \quad (\text{eq. } 2)$$

where:

$p$  = average annual growth in passengers (in fraction)

$f$  = average annual growth in average load factor (in fraction)

$s$  = average annual growth in average aircraft size (in fraction)

The actual time period of analysis must be chosen based on the planning horizon that stakeholders deem most convenient for a positive return on investment (ROI). In the stakeholder interviews, operators mentioned they look for a positive ROI within one to three years maximum before deciding to invest in a new technology. In contrast, ANSPs have a longer planning horizon than the airlines, and it is not surprising for this group to plan their investment decisions 10 – 20 years into the future.

### Operators Expenditures

The objective of this subsection is to account for all the operator initial and recurring expenditures associated with equipping with FANS-1/A, the enabling technology to reduce separation standards in the NAT. The cost elements considered are described in the data link business case elements (Figure 5-12): avionics procurement and installation, training, maintenance, and communication charges. Yearly investment costs will depend primarily on the fleet equipage rate and avionics price.

Table A - 2 shows details of avionics investment costs based on fleet planning, avionics costs, and other costs associated with avionics installation, such as labor, certification, and airplane downtime. Table A - 3 shows expenditures related to communication costs paid to ANSPs or third party providers for both HF voice and data link services. Table A - 4 details costs related to maintaining present-technology during transition. Table A - 5 and Table A - 6 show avionics maintenance and training costs.

Given that the complete set of technical requirements and standards (e.g. RNP, RCP) necessary to reduce separation is still under development, the model here presented is only limited to costs associated with FANS-1/A. However, it is possible that achieving the benefits described in the next section, may require additional investment to upgrade current systems. Changes to the model presented should be made accordingly.

### Operators Benefits

The objective of this subsection is to account for operator's benefits, as described in the data link business case elements (Figure 5-12): fuel savings, time savings, and additional cargo revenue. Savings related to flight efficiency depend on specific aircraft operating costs and aircraft categories, so benefits for each should be computed separately. Total savings are computed by adding benefits per aircraft category. Table A - 7 and Table A - 8 show details of these benefits.

### Summary of Operators Costs and Benefits

Table A - 9 shows a summary of the net yearly balance of costs and benefits that operators could expect by implementing FANS-1/A.

### ANSPs Expenditures

A similar process can be followed to setup the business case for ANSPs. The objective of this subsection is to account for all the initial and recurring expenditures incurred by ANSPs related to data link. Recall that all of the NAT ANSPs, with the exception of Bodo, are already offering FANS-1/A services for CPDLC and ADS-C. Recall also that a number of non-economic issues represent the major challenge to be resolved before FANS applications, such as reducing separation, can be implemented. Therefore, whereas the business case setup for operators focused on a NPV analysis to equip with FANS, the one for ANSPs will be more generic. The ANSPs business case setup will cover costs of additional investments, if any, to existing systems. The costs elements considered are described in Figure 5-13, and include: ground infrastructure and equipment, training, communications, personnel, and maintenance.



Table A - 10 shows a forecast of new data link ground infrastructure, equipment and software investment, and other expenditures associated with initial installation, including labor and certification. Table A - 11 summarizes data link communication costs paid to third party providers. Table A - 12 and Table A - 13 detail forecast of investment costs necessary to maintain HF networks in the long run, with or without phase out possibility. Finally, Table A - 14 and Table A - 15 show details of maintenance and personnel training expenditures, respectively.

### ANSPs Benefits

The objective of this subsection is to account for ANSP benefits, as described in the data link business case elements (Figure 5-13). Arguably, the greatest economic benefit for ANSPs derived from the provision of data link services is through potential cuts in operational costs by phasing out the current HF infrastructure in the long run. However, the time when this could happen is uncertain, as expectations indicate that reliance in HF will continue in the foreseeable future. Both scenarios (Table A - 12 and Table A - 13) are accounted for in the NPV analysis.

The other potential source through which ANSPs could benefit is user fees. If airspace capacity increases, ANSPs could in theory serve more airplanes and, therefore, capture more revenue. This model does not account for increases in staffing and other costs associated with increasing capacity. If data is available, such costs should be considered in the calculation. Further, if the final NPV is negative, user fees could be adjusted to leverage costs accordingly during the ANSPs' planning horizon. Therefore, user fees are considered as another potential source of ANSP benefit; although it is recognized that due to their economic and regulatory frameworks, some aviation authorities may not allow for immediate increases to user fees as part of the cost recovery program. Table A - 16 shows details of benefits derived from user fees.

### Summary of ANSPs Costs and Benefits

Table A - 17 and Table A - 18 show a summary of the net yearly balance of costs and benefits from the ANSPs' cost benefit analysis.

### Net Present Value (NPV) Calculation

Yearly net benefits summarized in Table A - 9 for operators and Table A - 17 and Table A - 18 for ANSPs need to be discounted back to an equivalent present value in order to be useful in assessing the viability of a project. The algebraic sum of the discounted present values will give the NPV of the project. A positive NPV represents a viable investment. Individual NPV calculations should be made for both stakeholder groups. Equation 3 shows the general procedure for calculating the NPV using summary data from Table A - 9 for operators and Table A - 17 and Table A - 18 for ANSP's (ICAO Secretariat, 1995).

$$NPV = Z_1/(1 + r) + Z_2/(1 + r)^2 + Z_3/(1 + r)^3 + \dots \quad (eq. 3)$$

Where  $r = d/100$  and  $d =$  discount rate in percent per year.

## **5.3 Risk and Uncertainty as Barriers for Value Capture**

As described in the technology transition framework proposed by Marais and Weigel, uncertainty in the probability of increasing costs and decreasing benefits could negatively affect value capture and ultimately deter investment in a new technology (Marais and Weigel, 2006). The NPV methodology presented in section 5.2 is based on several assumptions on the values of the variables involved. Despite efforts to make the best estimates, several degrees of uncertainty affect these variables. The impact that uncertainty has on the viability of a project could be approximated by conducting a sensitivity analysis of the major assumptions made.

In the case of the operators, the main source of uncertainty impacting their business case to equip with FANS-1/A is the projection of economic benefits due to flight efficiency. As seen throughout this chapter, operators have not seen tangible benefits from the technology in the NAT so far. A number of issues related to technology, safety, policies and procedures, coordination, and equipment remain to be resolved before value can be captured by stakeholders. Each of these elements introduces a level of uncertainty that could dramatically change the benefits projected, and therefore the outcome, of an

airline’s business case. These elements affect each other and require to be addressed simultaneously.

As an example of the impact of uncertainty on the projection of flight efficiency benefits, revisit the study conducted by Williams for NASA and CSSI. Williams studied three different demand levels according to projections on traffic volumes for 2005, 2010, and 2015. For each demand level, she accounted for four degrees of fleet equipage in the NAT: 25%, 50%, 75%, and 100%. Finally, she investigated three scenarios of airspace segregation. Her first scenario was one with regular OTS tracks and a mixed of equipped and unequipped flights. Her second scenario was one that maintained the current OTS structure, but reserved some middle tracks for equipped flights only. Finally, her third scenario introduced additional tracks in the OTS by reducing separation among them and reserving tracks for equipped aircraft only. Her study showed that projected benefits were very dependent on all three variables: traffic density, equipage levels, and airspace segregation policies (Williams, 2005). Her findings are shown in Table 5-1.

Table 5-1: Overall Annual Benefits Summary: Maximum Possible Additional Cargo Revenue Assumed (from Williams, 2005).

	2005				2010				2015			
	25%	50%	75%	100%	25%	50%	75%	100%	25%	50%	75%	100%
<b>Regular Tracks</b>	\$ 36 M	\$ 78 M	\$ 113 M	\$ 133 M	\$ 106 M	\$ 162 M	\$ 251 M	\$ 277 M	\$ 213 M	\$ 334 M	\$ 440 M	\$ 512 M
<b>Segregated Tracks</b>	\$ 8 M	\$ 62 M	\$ 91 M		\$ 45 M	\$ 146 M	\$ 205 M		\$ 139 M	\$ 353 M	\$ 413 M	
<b>Additional Seg. Tracks</b>		\$ 71 M	\$ 105 M	\$ 151 M		\$ 160 M	\$ 233 M	\$ 300 M		\$ 354 M	\$ 459 M	\$ 569 M

Operators also feel uncertainty on the investments they need to make. Cost uncertainty emerges from 1) lack of coordination and global harmonization of technologies and procedures and 2) actual costs to meet the requirements to qualify for reduced separation or other advanced applications.

On the ANSPs side, there is significant uncertainty on how to implement data link applications and realize benefits. For example, initial projections to slowly reduce the demand for HF services after introduction of data link have already proven to be overly optimistic. Therefore, reductions in operating costs associated with HF regression may actually take longer to realize than originally thought. At the same time, benefits

brought by potential increases in capacity are also uncertain unless new policies and procedures are introduced in the NAT. The cost of doing so, in terms of investment and coordination efforts, may also be higher and may delay benefits longer than expected.

## **5.4 Chapter Summary**

This chapter introduced some of the relevant issues to consider when developing strategies to capture the value created by data link. Section 5.1 discussed the current status of value distribution of data link costs and benefits in the North Atlantic as viewed from the stakeholders' perspective. It was shown in this section that unbalances exist in the value distribution of data link costs and benefits over time. The unbalanced distribution creates a time gap between initial investment costs and the realization of benefits, which imposes a barrier for data link equipping and support of new services. The same observation was seen for both operators and service providers.

Section 5.2 gave an overview of the major challenges to be resolved before the value derived from data link could be fully captured and delivered to stakeholders. These include issues related to technology, safety, policies and procedures, coordination, network effects, and cost-benefit ratios. This section also presented a preliminary model to setup the main elements informing the business case for data link from the perspective of operators and ANSPs. The methodology used to develop the business case was a Net Present Value Analysis (NPV) of the total expenditures and benefits accrued during a project life-cycle.

Finally, Section 5.3 explained the complexities that risk and uncertainty add to these issues. Based on the variables studied throughout this chapter, the major area of uncertainty for stakeholders is the projection of potential benefits derived from the technology. Uncertainty elements retrofit each other and require simultaneous addressing.

## **Chapter 6**

# **Value Delivery Strategies Applied to the Case of Data Link**

Successful delivery to all stakeholders of the value created and captured from data link requires implementing dynamic strategies to minimize the impact of uncertainty and unbalances in the distribution of costs and benefits. Section 6.1 will discuss strategies that could be used to encourage operators to adopt data link. Section 6.2 will address mechanisms to improve coordination among ANSPs and facilitate delivery of harmonized data link solutions. Finally, section 6.3 will evaluate issues surrounding the feasibility and effectiveness of the different policy measures introduced. Section 6.3 will also determine how these delivery strategies relate to uncertainty elements of value creation and value capture.

### **6.1 Policy Strategies to Encourage Operators to Adopt Data Link**

The fifth and last research area of the stakeholder survey addressed potential strategies to promote data link adoption. Throughout the survey, airlines emphasized the importance of infrastructural development and procedural implementation as the foundation to enable benefits. Based on their current level of equipage, operators seem to

favor different strategies to incentivize equipage. Nonetheless, they all commonly favor the implementation of a data link mandate in the NAT as a way to demonstrate ground commitment and minimize uncertainty. Other strategies favored by operators include greater access to airspace, reduction in communication and navigation charges, and subsidies to cover initial costs. Figure 6-1 to Figure 6-3 show a summary of survey responses according to different levels of equipage.

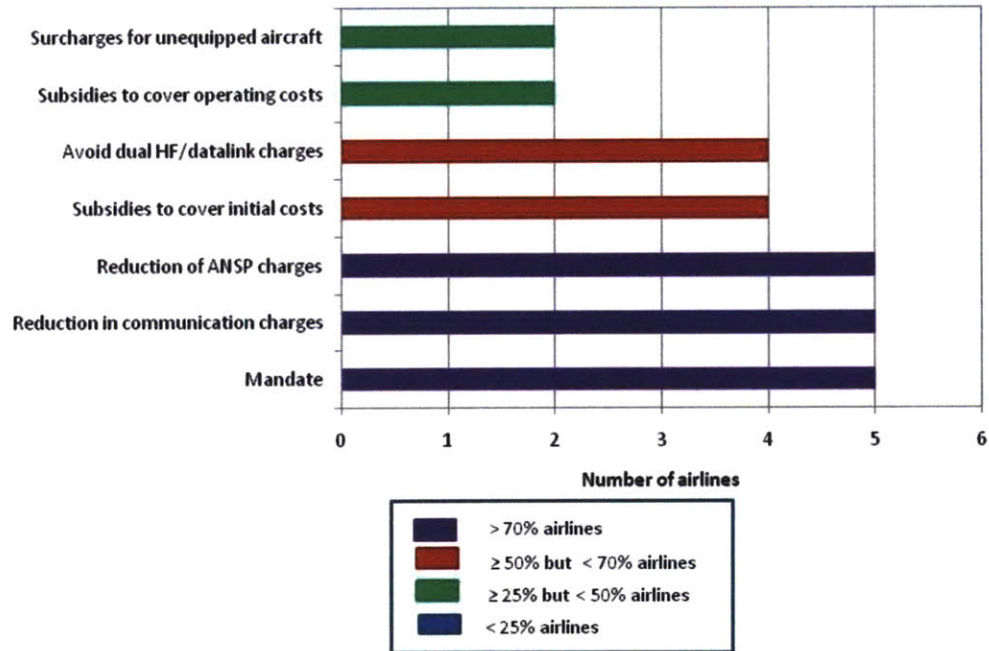


Figure 6-1: Strategies According to Airlines 100% Equipped with FANS-1/A – 7 Total - (Survey Results).

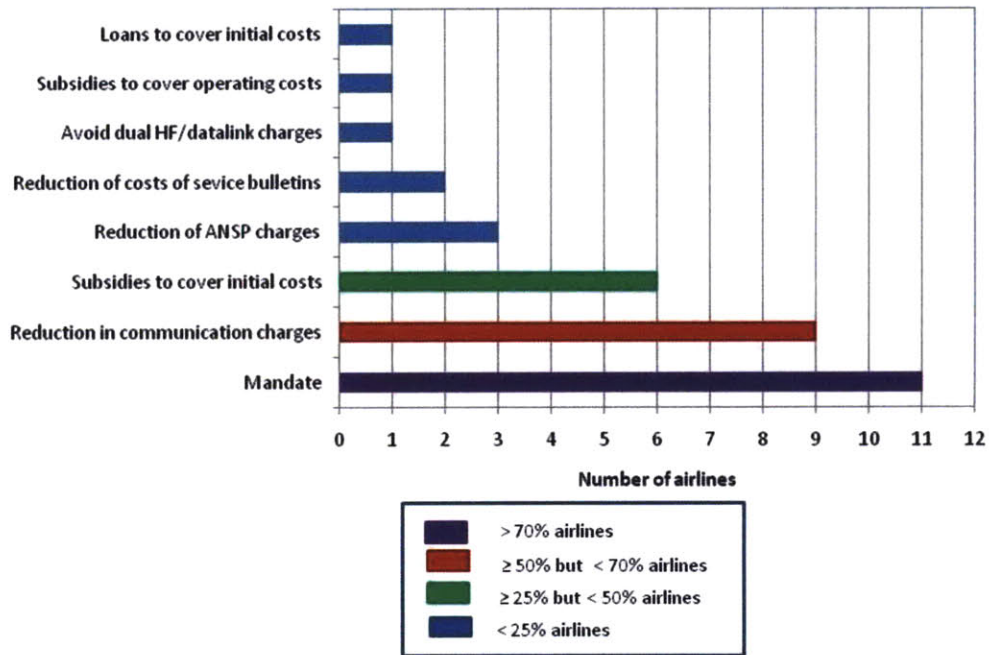


Figure 6-2: Strategies According to Airlines with NAT Fleet Partially Equipped with FANS-1/A – 14 Total – (Survey Results).

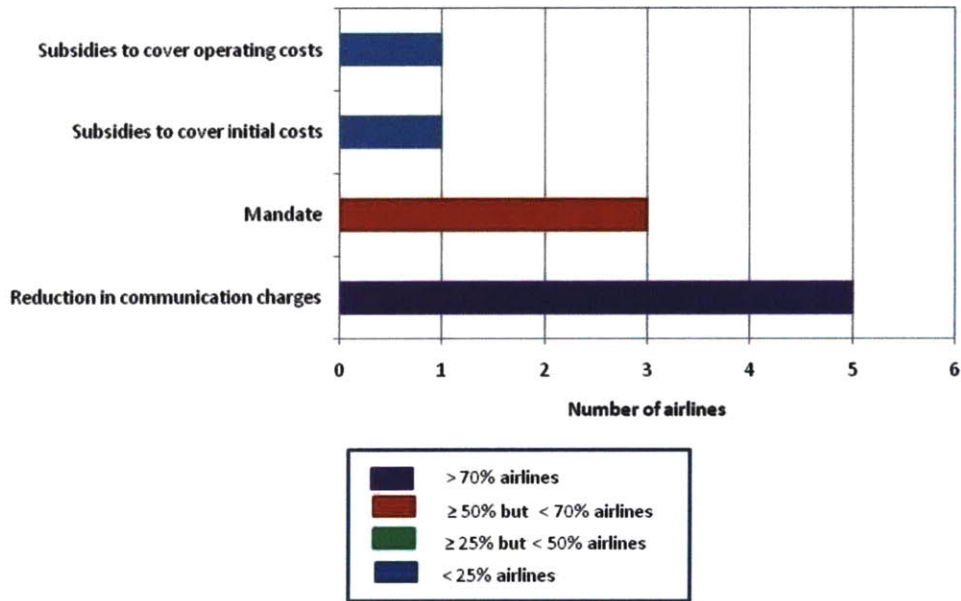


Figure 6-3: Strategies According to Airlines not Equipped with FANS-1/A – 6 Total – (Survey Results).

Operators' perspectives on strategies were aligned with the framework presented by Marais and Weigel to foster technology transition in air transportation: 1) development of infrastructure, standards, processes, and certification, 2) inherent value derived from technology, 3) positive incentives, and 4) regulatory measures (Marais and Weigel, 2006).

Several operators indicated that they would like to see a phase strategy similar to the one implemented by Eurocontrol in the Link 2000+ Program. The first phase would include technology demonstration and infrastructure deployment. The objective of this phase would be to develop an implementation roadmap and to demonstrate economic benefits for the users. The second phase would be based on positive incentives, such as reduction in communication charges and increased access to airspace, to encourage voluntary equipage first. Finally, the third phase would include regulatory measures, such as mandates, with the objective of achieving a critical mass that would allow the implementation of major data link applications. Carriers highlighted the importance of maintaining strong interactions with key industry and government stakeholders throughout the entire process. Figure 6-4 summarizes this phase strategy.

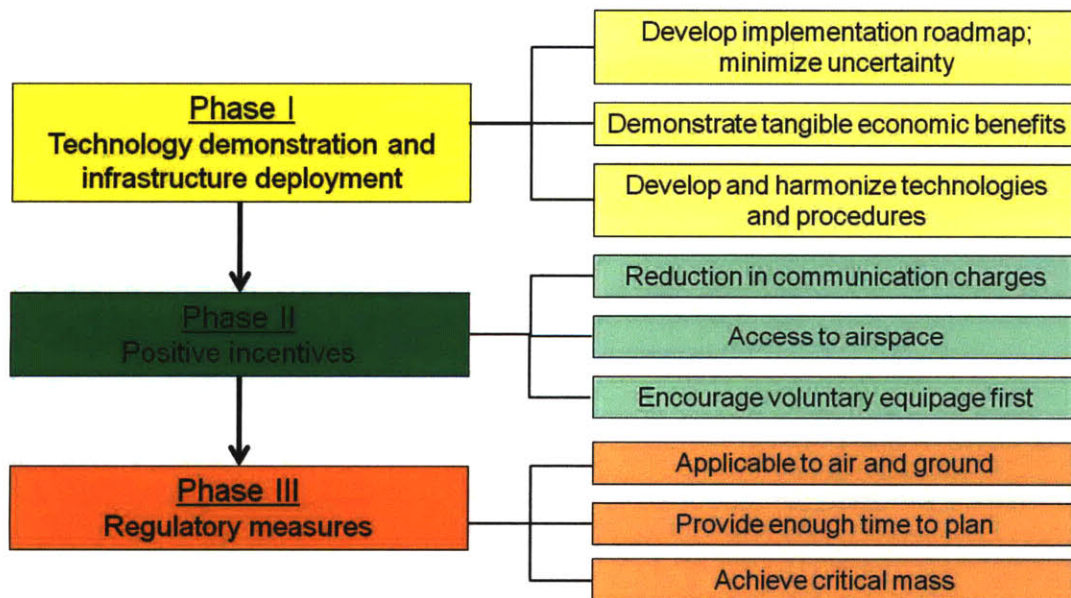


Figure 6-4: Phase Approach: Operator Strategies (Survey Results).

Regarding a potential reduction in communication charges, airlines said that although they cannot make a business case based on communication charges alone, a reduction



could play a substantial role in their decision to equip. In order for a reduction in charges to be effective, it would have to be significantly less (at least between 25 and 50%) than current costs. For some of the ANSPs, however, it may not be feasible to implement this policy because of the cost recovery structures they follow. ANSPs were concerned about potential penalties to those aircraft which may not be able to equip with FANS and mentioned that this measure would have to be directly supported and requested by airspace users.

One important difference between survey findings and Marais-Weigel's model is that, as long as a positive cost benefit analysis has been proven, airlines do not really perceive a data link mandate as a punitive measure. Instead, operators see a mandate as an effective way to reduce uncertainty, as it assures ground commitment and the feasibility of obtaining economic benefits from equipage investment. If a data link mandate is to be implemented in the NAT, airlines would like to have enough time for planning (no less than five years) within their business horizon. Airlines would like to actively take part in the coordination of such policy and agree, together with service providers, on the minimum airborne and ground capabilities necessary before a mandate is issued.

According to the Data Link Implementation Task Force (DLITF) created by the International Air Transport Association (IATA), a data link mandate could bring considerable benefits, including: 1) making implementation of ATM improvements more predictable, as planned equipage could be achieved according to tangible objectives; 2) helping avionics and airframe manufacturers plan forward fit options and equipment needs according to known demand; and 3) accelerating equipage by facilitating planning of a system of positive incentives for those equipping before mandate becomes effective. To the contrary, the disadvantages of not having a mandate could be serious and hard to decouple. For example, the lack of commitment from ground and airborne sides makes it difficult to set concrete milestones, which in turn causes delays in the realization of benefits. Unbalances in the value distribution of costs and benefits leads airlines to postpone equipage and wait for ground side to commit and vice versa, interrupting the process indefinitely or stalling it completely (Zerkowitz, unknown).

ANSPs perceive a potential mandate from a more conservative approach than the airlines. For example, service providers were concerned that this measure would be unpopular because of the high costs associated, inability to equip some aircraft, lack of

clearly demonstrated benefits, and potential conflicts with other data link initiatives around the globe. Nonetheless, they acknowledged that a mandate may be necessary in the long run if reduced lateral separation is introduced in the NAT.

Most operators seem to support a policy that will allow greater access to airspace to those aircraft that are data link equipped. Some of them gave as an example the route L888 in China, available only to FANS equipped aircraft. Although certain applications would inherently be available only to data link aircraft, stakeholders showed concern about potential penalties to those airplanes for which equipage cannot be economically justified. They would like to see initiatives in place to accommodate these aircraft outside airspace where mandate is in effect.

Direct subsidies to cover initial cost were another strategy favored by most airlines and considered to be more effective than communication subsidies. Some of the participants mentioned that they would like to see subsidies if ANSPs expect tangible costs reductions from their equipage. However, carriers also highlighted that they would not want to see unequipped aircraft penalized with surcharges. To the contrary, ANSPs did not consider financial subsidies as a feasible alternative to encourage data link adoption among users, as the great majority of the providers are not in the position to implement this policy due to restrictions in the business models and regulatory frameworks they follow.

According to the ICAO Airports Economics Panel (AEP) and the Air Navigation Services Economics Panel (ANSEP), incentive schemes for airspace users should be transparent, non-discriminatory, clearly stated, measurable, and limited in time, scope, and amount. Groups also state that costs incurred due to incentive mechanisms should be chargeable to airspace users over time and costs tailored accordingly. User charges, however, should also decrease proportionately to improvements in efficiency achieved due to equipage efforts (ICAO AEP and ANSEP, February 2008).

## **6.2 Policy Strategies to Encourage Service Providers to Adopt Data Link**

Three different kinds of strategies were identified to encourage ANSPs to further offer data link enabled services and promote harmonization of technologies and procedures. These are: airline consultation, regional working groups, and strategic partnerships among providers.

Through the survey, it was found that ANSPs highly value the opinions of airspace users and will frequently try to accommodate changes requested by airlines; providing such requests do not compromise the safety or the efficiency of operations. In fact, user request was the main driver that led to the implementation of FANS-1/A in the NAT. The most important communication channel between airlines and service providers is through IATA representation in working groups, although some ANSPs also have independent informal consultation forums with operators.

ANSPs also stressed the importance of NAT regional working groups, as they are the instruments for the coordination and implementation of technical, procedural, and policy changes. One limitation of such groups is that they do not have any real power to neither enforce nor accelerate change. Some of the providers argued that although there is extensive communication within such groups, the structured level of hierarchy they follow sometimes slows down decisions. Interviewees said they would like to see as much horizontal communication across the NAT sub-groups as there is vertically and reminded of the importance of working toward SESAR (Europe) and NextGen (U.S.) harmonized developments. In the SoPAC, survey respondents agreed the dynamics of the two informal FANS-1/A planning and implementation regional groups was very effective. These two SoPAC groups are not directly part of ICAO, although they operate under ICAO principles and have direct participation of all stakeholders in the region.

Finally, the stakeholder survey revealed that ANSPs often create strategic partnerships with each other as a way to facilitate moving forward with new initiatives. Despite the regulatory and operational differences among ANSPs, this strategy could be further used to improve and accelerate coordination. Examples of such partnerships include efforts between Shanwick and Gander Oceanic to reduce separation minima in the Organized

Track System as well as automation of flight data transfer between facilities in Reykjavik and Bodo Centers.

The Atlantic Interoperability Initiative to Reduce Emissions (AIRE), is a collaboration between government agencies, airlines, airports, and industry representatives with the objective of developing procedures to reduce operational footprint in civil aviation through pre-flight and in-flight dynamic optimization of flight profiles (4-D trajectory optimization). Two initial demonstrations will use FANS-1/A (ADS-C and CPDLC) as well as AIDC for coordination between Santa Maria and NY Oceanic Centers (FAA, October 2007).

The Joint Financing Agreements between Iceland and Denmark are another example of strategic partnerships. The agreements are administered by the ICAO Secretariat, with the ICAO Council providing general oversight and Iceland and Denmark providing air traffic, meteorological, and communication services. The two part agreement, one between Iceland and other states using services and another between these states and Denmark, have enabled service provision at a lower cost than in other facilities in the NAT and ensured availability of financial funds on a fair and equitable basis for users and contracting states. More than 90% of the revenue for provision of services comes from user fees, 5% comes from Iceland and Denmark contributions, and the remaining revenue from payments made by states who are parties to agreements (ICAO, 2003).

The joint venture for provision of HF services between Iceland Radio and Shanwick Radio is yet another partnership example. This effort enables a flexible frequency and boundary allocation between the two centers, helping distribute workload more evenly during peak traffic times while remaining seamless and transparent to airspace users and Control Centers in Shanwick and Reykjavik. Other operational benefits derived from the initiative include improving traffic distribution, alleviating HF congestion, optimizing service to customers, sharing training and acquisition of equipment, and reducing staff requirements over time. Safety and redundancy are also improved through joint effort given that, if poor HF conditions exist in one center, the other one may provide full service without sovereignty concerns (Jonasson, September 2004).

Such examples are in accordance with the characteristics of multinational infrastructure projects introduced in Chapter 2. As Carcamo-Dias and Goddard argue, infrastructure

projects show network effects on the supply side, risking coordination failure if investment decisions are made unilaterally (Carcamo-Dias and Goddard, 2007). Partnerships help mitigate uncertainty and promote cooperation, as they encourage countries to reach agreements on their expectations of a project, measures of success, alignment of incentives, and understanding of their financial, institutional, and human constraints.

### 6.3 Evaluation of Policy Strategies to Facilitate Value Delivery

On the operators' side, a data link mandate and improved access to airspace seemed to be both the most feasible and effective policy measures to foster data link equipage. On the ANSPs' side, airline consultation, regional working groups, and strategic partnerships were the preferred strategies to encourage ANSPs to support more data link services. Figure 6-5 shows a comparison of these initiatives in terms of their potential effectiveness and feasibility, as perceived by the stakeholders.

Strategy	Effectiveness in encouraging adoption			Feasibility to implement with success		
	NAT Operators	NAT ANSPs	SoPAC ANSPs	NAT Operators	NAT ANSPs	SoPAC ANSPs
Reduction in comm. charges	●	●	○	●	○	○
Data link mandate	●	●	○	●	●	○
Access to airspace	●	●	●	●	●	●
Direct subsidies	●	N/A	○	●	○	○
Airline consultation	N/A	●	●	N/A	●	●
Regional working groups	N/A	●	●	N/A	●	●
Strategic partnerships	N/A	●	●	N/A	●	●

● - high  
● - medium  
○ - low

■ - Airline strategies  
■ - ANSPs strategies

Figure 6-5: Stakeholder Summary on Strategies to Incentivize Data Link Adoption (Survey Results).

The policy strategies discussed in this chapter can be tailored to address specific elements of uncertainty in the delivery of value from data link to all stakeholders. In the case of operator strategies, the target of the majority of the policies considered is to help airlines close their business case for data link investment, either by promoting the early realization of benefits (e.g. reduction in communication charges and access to airspace) or by delaying or reducing costs (e.g. direct subsidies). These policy schemes also intent to resolve mixed equipage issues and foster benefits derived from network effects.

A data link mandate for air and ground is one of the most effective strategies due to the number of uncertainty issues it addresses in parallel. As indicated in section 6.1, a mandate would allow setting tangible milestones to develop new policies and procedures. Achieving these goals would require improvements in coordination among stakeholders in order to find solutions to the most prominent technical and safety elements that currently affect the case for data link in the NAT. In turn, realization of benefits would allow stakeholders to justify their decision to invest in data link based on a solid business case, therefore yielding higher rates of equipage in the NAT.

Regarding ANSPs strategies, the focus of all three mechanisms (airline consultation, regional working groups, and strategic partnerships) is to improve coordination among stakeholders. Effective coordination is the core foundation from which all the issues surrounding data link value creation, capture, and delivery in the NAT can be addressed.

## **6.4 Chapter Summary**

This chapter discussed different policy mechanisms that could be used to enable successful data link value delivery to all stakeholders. The primary objective of the policy schemes introduced is to minimize the impact of uncertainty in order to encourage operators to adopt data link and to facilitate coordination among ANSPs so they can work toward harmonized data link solutions.

## Chapter 7

# Conclusions

This thesis analyzed the problem of data link in the North Atlantic under a framework of technology transition by integrating strategies to create, capture, and deliver value from data link to all stakeholders. Section 7.1 will present a summary of the major findings of this thesis. Section 7.2 will describe the contributions of this work to the field of air transportation, and section 7.3 will indicate potential directions for future work.

### 7.1 Summary of Findings

Under the technology transition framework presented, creating value through a new technology, such as data link, refers to designing competitive value propositions to stakeholders. Capturing value means recovering an investment in a technology through the value it creates. Delivering value refers to developing policies and business strategies to enable value capture. The realization of these three concepts is necessary to guarantee technology transition.

A survey of the two major stakeholder groups in the NAT, commercial operators and ANSPs, was conducted in order to determine the best strategies for increasing efficiency of operations in the NAT and promoting the adoption of data link communications. The survey covered five major research areas: 1) Perceived operational and coordination

inefficiencies; 2) Opportunities to improve service; 3) Current and projected data link equipage and infrastructure in the NAT; 4) Value distribution of data link costs and benefits; and 5) Potential policy strategies to encourage data link adoption. Survey participants included 27 international airlines, seven ANPS in the NAT, and five ANSPs in the SoPAC.

The study showed an agreement between stakeholders in their perception of operational and coordination inefficiencies, technologies and applications that could improve operations, and the current value distribution of data link costs and benefits. In contrast, some differences in opinions were found in their current level of technical capabilities, services offered, planned initiatives and in the efficacy and feasibility of strategies to encourage data link adoption.

Data link creates value for stakeholders through an understanding of the evolution of technology and stakeholder needs and through a cycle of continuous evolution in response to technical discontinuities. Survey findings indicate that fuel penalties associated with flying suboptimal flight levels and routes is the biggest inefficiency in the NAT. Data link, particularly through the FANS system (ADS-C and CPDLC) in the near term, is seen as the enabling technology to improve efficiency of operations and to manage discontinuities in the system. Reducing separation standards is the near term data link application that is most valued by stakeholders. However, coordination and harmonization issues threaten to limit the value created by the technology.

Data link diffusion trends in the form of airborne equipage as well as infrastructure and services supported is not always guaranteed as a result of value created due to improvements in technical performance. Operators need a proven base of benefits and ground commitment before they can make a decision to invest in data link. The framework presented in this thesis facilitated seeing the variation in susceptibility to uncertainty of stakeholders according to the characterization of technology adopters they belong to. This characterization is useful in identifying tailored strategies to create momentum and cross the chasm of technology transition.

Understanding organizational characteristic of both stakeholder groups in the NAT is important because successful value creation is bounded by the limitations and unique needs that are at the core of each group. Organizational structure could be used to



promote synergies and strengthen cooperation where applicable. Strategies for value capture and delivery should also observe to these boundaries.

With regards to value capture, unbalances exist in the value distribution of data link costs and benefits over time. So far, data link operational benefits have been significant but have not yet translated into economic benefits in the NAT given that such applications have not been implemented. The unbalanced distribution creates a time gap between initial investment costs and the realization of benefits, which imposes a barrier for data link equipage and support of new services. The same observation was seen for both operators and service providers.

Delivering value from data link is more than balancing costs and benefits. Another barrier to data link adoption is the uncertainty in a number of issues which need resolution before the value created through data link could be fully captured and delivered to stakeholders. These include issues related to technology, safety, policies and procedures, coordination, network effects, and a positive business case for investment. A combination of operational, financial and regulatory schemes may be necessary to leverage costs and benefits and ensure successful data link value delivery to all stakeholders. The primary objective of the policy schemes introduced in this thesis is to minimize the impact of uncertainty in order to encourage operators to adopt data link and to facilitate coordination among service providers.

## **7.2 Contributions**

Previous work has been done in identifying some of the elements of value creation, capture, and delivery discussed in this thesis with application to the case of data link over the North Atlantic. So far, past research has focused on isolated components of the data link case. For example, studies have been conducted to identify potential new services and benefits derived from data link but have not addressed issues which need resolution before such benefits can be realized; including uncertainty, technical limits, coordination, or implementation strategies. The contribution of this thesis is to analyze the case of data link in the North Atlantic under a framework of technology transition by integrating strategies to create, capture and deliver value to all stakeholders. In doing so, this thesis identifies how uncertainty and risk affect the case for data link in the

NAT and argues how the different elements involved need to be addressed simultaneously while considering different stakeholder needs and characteristics.

### **7.3 Future Work**

Future work could be done to characterize some of the elements in the case for data link from a quantitative perspective under the framework of value creation, capture, and delivery introduced in this thesis. Particular emphasis could be placed in measuring systematically the impact of uncertainty. Another area that needs further development is gathering data to conduct a business case for data link under different planning scenarios by following the cost benefit analysis setup introduced in this thesis.

# Appendices

## Appendix A. Business Case Setup

General<sup>1</sup>

Table A - 1: Forecast of Flight-Hours and Aircraft Numbers.

<b>Aircraft Operators</b>	<b>Base Year Y1</b>	<b>Y2</b>	<b>Y3</b>	<b>Y4</b>	<b>.....</b>	<b>Y20</b>
Flight hours (thousands) [A]						
Aircraft utilization (hours per aircraft per year) [B]						
Aircraft numbers [C=1000*A/B]						

<sup>1</sup> All tables adapted from ICAO Secretariat, 1995.

Operators Expenditures

Table A - 2: Forecast of FANS-1/A Avionics Investment.

<b>Aircraft Operators</b>	<b>Base Year Y1</b>	<b>Y2</b>	<b>Y3</b>
Number of aircraft allocated to airspace [A=C in Table A - 1]			
Proportion of those aircraft to be equipped with FANS [B]			
Number of aircraft to equip [C=A*B]			
Increase in number of equipped aircraft [D=C <sub>t</sub> -C <sub>t-1</sub> ]			
Price of equipping each aircraft (thousands of dollars) [E]			
Investment in equipment (thousands of dollars) [F=D*E]			
Other expenditures associated with avionics installation (e.g. labor, certification, airplane downtime) [G]			
Total investment in FANS-1/A avionics [H=F+G]			

Table A - 3: Forecast of Communication Costs – Paid to ANSPs or Third Party Providers – Including HF and Data Link.

<b>Aircraft Operators</b>	<b>Base Year Y1</b>	<b>Y2</b>	<b>Y3</b>
Total flight hours (thousands) [A=A in Table A - 1]			
Proportion of aircraft which are FANS equipped [B=B in Table A - 2]			
Hours flown by FANS equipped aircraft [C=A*B]			
Proportion of hours when FANS is used [D]			
Quantity of data link messages per hour (Kbits) [E]			
Quantity of HF messages per hour [F]			
Quantity of data link messages per year (thousands of Kbits) [G=C*D*E]			
Quantity of HF messages per year [H=C*D*F]			
Data link transmission price (dollars per Kbit) [I]			
HF transmission price (dollars per message) [J]			
Total data link communication costs (thousands of dollars) [K=G*I]			
Total HF communication costs (thousands of dollars) [L=H*J]			
Total communication cost [M=K+L]			

Table A - 4: Forecast of Investment in Present-Technology Avionics during Transition.

<b>Aircraft Operators</b>	<b>Base Year Y1</b>	<b>Y2</b>	<b>Y3</b>
Number of aircraft allocated to airspace (A=A in Table A - 1)			
Proportion of Existing Avionics Suites to be Replaced (B)			
Number of Avionics Suites Replaced (C=A*B)			
Number of Extra-Avionics Suites Associated with Fleet Expansion (D=A <sub>t</sub> -A <sub>t-1</sub> )			
Number of new avionics suites necessary for all aircraft to retain present-technology (E=C+D)			
Price per avionics suite (thousands of dollars) (F)			
Investment (thousands of dollars) (G=EXF)			

Table A - 5: Forecast of FANS-1/A Maintenance Investment.

<b>Aircraft Operators</b>	<b>Base Year Y1</b>	<b>Y2</b>	<b>Y3</b>
Number of aircraft equipped (A=C in Table A - 2)			
Proportion of aircraft to require avionics maintenance (B)			
Number of aircraft to be maintained (C=A*B)			
Maintenance Costs (e.g. avionics, labor, ground time) (D)			
Maintenance Investment (E=C*D)			

Table A - 6: Forecast of Personnel Training Costs (FANS-1/A).

<b>Aircraft Operators</b>	<b>Base Year Y1</b>	<b>Y2</b>	<b>Y3</b>
Total number of pilots with FANS proficiency [A=A]			
Number of pilots requiring new training [B=A <sub>t</sub> -A <sub>t-1</sub> ]			
Cost of training per pilot [C]			
Total cost of pilot training [D=B*C]			

Operators Benefits

Table A - 7: Forecast of Aircraft Efficiency Benefits for a Particular Aircraft Category.

<b>Aircraft Operators</b>	<b>Base Year Y1</b>	<b>Y2</b>	<b>Y3</b>
Number of flight hours (thousands) [A=A in Table A - 1]			
Proportion of total hours flown by particular aircraft category [B]			
Proportion of same aircraft category equipped with FANS-1/A [C]			
Percentage reduction in flight hours enabled by FANS-1/A [D]			
Reduction in flight hours enabled by FANS-1/A (thousands) [E=A*B*C*D/100]			
Variable aircraft operating costs per hours for particular aircraft type [F]			
Operating costs savings (thousands of dollars) [G=E*F]			

Table A - 8: Forecast of Additional Cargo Revenue for a Particular Aircraft Category  
(FANS-1/A).

<b>Aircraft Operators</b>	<b>Base Year Y1</b>	<b>Y2</b>	<b>Y3</b>
Number of flight hours (thousands) [A=A in Table A - 1]			
Proportion of total hours flown by particular aircraft category [B]			
Proportion of same aircraft category equipped with FANS-1/A [C]			
Maximum additional cargo enabled by gains in flight efficiency (lb per aircraft) [D]			
Unit price of cargo revenue (dollars per lb) [E]			
Additional cargo revenue (dollars) [F = A*B*C*D*E]			



Summary of Operators Costs and Benefits

Table A - 9: Forecast of all Costs and Benefits Associated with FANS-1/A.

<b>Aircraft Operators</b>	<b>Base Y1</b>	<b>Y2</b>	<b>Y3</b>
<b>Costs (C)</b>			
Avionics investment (Table A - 2)			
Communication costs (Table A - 3)			
Avionics investment in present technology (Table A - 4)			
Maintenance investment ( Table A - 5)			
Personnel training costs (Table A - 6)			
<b>Benefits (B)</b>			
Aircraft efficiency benefits (Table A - 7)			
Additional cargo revenue (Table A - 8)			
<b>Yearly net benefit (Z) = <math>\Sigma(B) - \Sigma(C)</math></b>			

ANSPs Expenditures

Table A - 10: Forecast of New Data Link Infrastructure and Equipment Investment.

<b>ANSPs</b>	<b>Base Year Y1</b>	<b>Y2</b>	<b>Y3</b>	<b>.....</b>	<b>Y20</b>
Investment in new data link equipment and software (thousands of dollars) [A]					
Investment in new data link ground infrastructure (thousands of dollars) [B]					
Other expenditures associated with avionics installation (e.g. labor, certification, etc.) (thousands of dollars) [C]					
Total new data link investment [D=A+B+C]					

Table A - 11: Forecast of Data Link Communication Costs – Paid to Third Party Providers.

<b>ANSPs</b>	<b>Base Year Y1</b>	<b>Y2</b>	<b>Y3</b>	<b>.....</b>	<b>Y20</b>
Quantity of data link messages per year (thousands of Kbits) [A=G in 4-3]					
Data link transmission price to third party provider (dollars per Kbit) [B]					
Total data link communication costs (thousands of dollars) [C=A*B]					

Table A - 12: Forecast of Investment in Maintaining HF Network in the Long Run (No Phase Out Possibility).

<b>ANSPs</b>	<b>Base Year Y1</b>	<b>Y2</b>	<b>Y3</b>	<b>.....</b>	<b>Y20</b>
Infrastructure cost to maintain HF network (thousands of dollars) [A]					
System and software costs to maintain HF network (thousands of dollars) [B]					
Labor and personnel costs to maintain and operate HF network (thousands of dollars)[C]					
Total HF Maintenance Investment (thousands of dollars) [D=A+B+C]					

Table A - 13: Forecast of Investment in Maintaining HF Network during Transition (Phase Out Possibility).

<b>ANSPs</b>	<b>Base Year Y1</b>	<b>Y2</b>	<b>Y3</b>	<b>.....</b>	<b>Y20</b>
Infrastructure cost to maintain HF network (thousands of dollars) [A]					
System and software costs to maintain HF network (thousands of dollars) [B]					
Labor and personnel costs to maintain and operate HF network (thousands of dollars)[C]					
Total HF maintenance investment (thousands of dollars) [D=A+B+C]					

Table A - 14: Forecast of Investment in Maintaining Data Link Systems.

<b>ANSPs</b>	<b>Base Year Y1</b>	<b>Y2</b>	<b>Y3</b>	<b>.....</b>	<b>Y20</b>
Infrastructure cost to maintain data link systems (thousands of dollars) [A]					
System and software costs to maintain data link units (thousands of dollars) [B]					
Labor and personnel costs to maintain operate data link systems (thousands of dollars)[C]					
Total data link maintenance investment (thousands of dollars) [D=A+B+C]					

Table A - 15: Forecast of Personnel Training Costs Associated with Data Link Systems.

<b>ANSPs</b>	<b>Base Year Y1</b>	<b>Y2</b>	<b>Y3</b>	<b>.....</b>	<b>Y20</b>
Total number of controllers with data link proficiency [A=A]					
Number of controllers requiring new training [B=A <sub>t</sub> -A <sub>t-1</sub> ]					
Cost of training per controller [C]					
Total cost of controller training [D=B*C]					

ANSPs Benefits

Table A - 16: Forecast of Communication Costs – Paid to ANSPs – Including HF and Data Link.

ANSPs	Base Year Y1	Y2	Y3	.....	Y20
Total flight hours (thousands) [A=A in Table A - 1]					
Proportion of aircraft which are FANS equipped [B=B in Table A - 2]					
Hours flown by FANS equipped aircraft [C=A*B]					
Proportion of hours when FANS is used [D]					
Quantity of data link messages per hour (Kbits) [E]					
Quantity of HF messages per hour [F]					
Quantity of data link messages per year (thousands of Kbits) [G=C*D*E]					
Quantity of HF messages per year [H=C*D*F]					
Data link transmission price (dollars per Kbit) [I]					
HF transmission price (dollars per message) [J]					
Total data link communication costs (thousands of dollars) [K=G*I]					
Total HF communication costs (thousands of dollars) [L=H*J]					
Total communication cost [M=K+L]					

Summary of ANSPs Costs and Benefits

Table A - 17: Forecast of all Costs and Benefits Associated with ANSPs Data Link Support, without Possibility of Phasing out HF Infrastructure in the Long Run.

ANSPs	Base Year Y1	Y2	Y3	.....	Y20
<b>Costs (C)</b>					
New data link infrastructure and equipment (Table A - 10)					
ANSPs data link communication costs paid to third party providers (Table A - 11)					
Maintenance of HF network infrastructure (Table A - 12)					
Maintenance investment in data link systems (Table A - 14)					
Personnel training costs (Table A - 15)					
<b>Benefits (B)</b>					
Communication costs paid to ANSPs (Table A - 16)					
<b>Yearly net benefit (Z) = <math>\Sigma(B) - \Sigma(C)</math></b>					

Table A - 18: Forecast of all Costs and Benefits Associated with ANSPs Data Link Support, with Possibility of Phasing Out HF Infrastructure in the Long Run.

ANSPs	Base Year Y1	Y2	Y3	.....	Y20
<b>Costs (C)</b>					
New data link infrastructure and equipment (Table A - 10)					
ANSPs data link communication costs paid to third party providers (Table A - 11)					
Maintenance of HF network infrastructure (Table A - 13)					
Maintenance investment in data link systems (Table A - 14)					
Personnel training costs (Table A - 15)					
<b>Benefits (B)</b>					
Communication costs paid to ANSPs (Table A - 16)					
<b>Yearly net benefit (Z) = <math>\Sigma(B) - \Sigma(C)</math></b>					

# Appendix B. Interview Instrument – Operators Survey

Norma V. Campos, Prof. Annalisa Weigel, and Prof. John Hansman

MIT International Center for Air Transportation (ICAT)

**Carrier Name:** \_\_\_\_\_

**Interviewee:** \_\_\_\_\_ **Date:** \_\_\_\_\_

*Lack of continuous and reliable surveillance in the North Atlantic airspace results in large separation standards and limited oceanic clearances. Data link communication capabilities are one promising option to increase efficiencies. The goal of this survey is to identify: operational inefficiencies and opportunities for improvement in the North Atlantic, including approaches which would improve flexibility using data link communications; current and projected data link equipage levels and use; and benefits and costs associated with the adoption of data link.*



## **Part I: Background**

- 1.1 What is your role in your airline?
- 1.2 What is your experience with North Atlantic operations?

## **Part II: Operations in the North Atlantic (NAT)**

- 2.1 Do you think there are any operational inefficiencies in the North Atlantic?  
  
If yes, which?
- 2.2 In your opinion, what are the main sources of these inefficiencies?
- 2.3 Do these inefficiencies directly affect your airline operations? How?
- 2.4 Are any of these inefficiencies directly related to harmonization? What aspects of harmonization are more important to your airline (e.g. equipment, procedures, charging, etc.)?
- 2.5 Are any of these inefficiencies directly related to coordination between FIRs?
- 2.6 What capabilities or services would you like to have that you currently do not have in terms of:
  - a) Communication
  - b) Navigation
  - c) Surveillance
  - d) Meteorological Information
  - e) Air traffic management

2.7 Do you think that technology plays a role in allowing you to achieve the capabilities and/or services you listed above?

If yes, how?

2.8 Do you think that procedures and airspace management play a role in allowing you to achieve the capabilities and/or services you listed above?

If yes, how?

2.9 Will the U.S.-EU open skies agreements have an impact on your airline? How? Do you see a market growth resulting from them?

**Part III: Technology – NAT fleet data link equipage and use**

2.1 Do you have an isolated fleet for North Atlantic operations?

If yes, is the data link avionics equipage different from the rest of your fleet?

If so, how are they different?

2.1 What kind of equipment do you use in the NAT?

2.2 What kind of data link avionics do you currently have installed in your North Atlantic fleet?

2.3 What percentage of your fleet is data link equipped?

2.4 Has your airline participated in EUROCONTROL's Link 2000+ ATN program?

If so, how was this experience?

What impact does this have in your NAT operations?

If no, are there any plans to participate?

2.5 Do you currently have plans to increase the equipage of data link avionics in your NAT fleet?

If yes, what systems and when?

3.7 Would this data link equipment be primarily installed on new aircraft or retrofit on your existing fleet?

3.8 What data link enabled services do you currently use in your NAT operations? (e.g. position reporting, clearance requests)

3.9 How frequently do you use data link enabled services?

3.10 We recognize cost of services as sensitive information, but could you provide us with an order of magnitude comparison between ANSP and communication charges?

3.11 What are the factors that drive your decision to use data link? (e.g. communication charges)

#### **Part IV: Technology – Data Link Applications and Benefits**

4.1 Are you currently receiving any benefits from your data link equipage?

4.2 Are you receiving direct economic benefits from data link? Which? (See list at the end for examples)

4.3 Are you receiving direct operational benefits from data link? Which?

4.4 What do you see as the near, mid, and far term potential applications of data link communications and what data link alternatives do they depend on (ADS, CPDLC, ADS-B, Satvoice, FMC WPR, HFDL)? (See list at the end for application examples)

4.5 Which of these applications are more important for your organization?

- 4.6 What do you see as the main requirements to achieve these applications? (e.g. infrastructure, special equipment, new procedures, etc.)
- 4.7 What level of data link equipage in the NAT system do you think would be required before these applications could be implemented?
- 4.8 When do you anticipate obtaining these data link applications?
- 4.9 What do you see as the main obstacles at a system level in obtaining the data link applications you mentioned?

**Part V: Technology – Data Link Costs**

- 5.1 What do you see as the main barriers or concerns for your airline regarding the adoption of data link equipage?
- 5.2 What initial costs would most negatively affect your decision to equip with data link (e.g. avionics procurement, avionics installation, initial personnel training, etc.)?
- 5.3 What recurring costs would most negatively affect your decision to equip with data link? (e.g. communication charges, ANSP charges, etc.)
- 5.4 How would initial and recurring costs compare in the way they influence your decision to equip with data link? Could you provide us with orders of magnitude for comparison?
- 5.5 What applications, incentives, or mandates (financial, regulatory, etc.) would be most effective in encouraging your fleet to equip? (See list at the end for examples)
- 5.6 Would your airline consider equipping based on reduction in communication charges? What percentage of reduction in charges would have to be implemented in order to make it significant for your airline?

## **List of Applications and Benefits**

### Communication Applications

- Elimination of radio operator relay between pilots and controllers
- Improvement in reliability of communications
- Reduction of delay in communications
- Faster and more accurate emergency and non-routine communications
- Granting/requesting clearances and conducting negotiations
- Communication coverage in polar regions (HF DL)

### Communication and Surveillance Applications

- Reduction of crew workload
- Reduction in frequency congestion
- Weather deviations and wind adjustments
- Elimination of high frequency (HF) radio position reports
- Reduction in fuel consumption by operating at optimum FL
- Improvement in safety by increasing situational awareness, avoiding weather, and conducting more accurate and timely communications
- Reduction of flight times and delays by flying under more efficient routes and procedures

- Reduction of Gross Navigation Errors (GNE) by eliminating manual waypoint insertion errors
- 50 NM longitudinal separation
- 30 NM longitudinal / lateral separation
- Dynamic aircraft route planning (DARP)

### Surveillance Applications

- In-trail follow
- Free-Flight Operations (Self-separation and selection of route, speed, and altitude)
- Passing
- Improvement of surveillance accuracy and update rates

### **List of Incentives to Encourage Data Link Equipage**

#### Direct incentives

- Reduction in communication charges for equipped aircraft
- Reduction in ANSP charges for equipped aircraft
- Avoid dual HF/data link charge for equipped aircraft
- Surcharges for unequipped aircraft

#### Exemptions

- Subsidies for initial avionics cost (hardware, installation)

- Subsidies for avionics equipment operating costs
- Subsidies for personnel training costs
- Vouchers/tax incentives for initial costs
- Loans to cover initial costs

Others

- Future data link mandate(s) in the NAT
- Standardization of operating procedures

# Appendix C. Interview Instrument – Air Navigation Service Provider Survey

Norma V. Campos, Prof. Annalisa Weigel, and Prof. John Hansman

MIT International Center for Air Transportation (ICAT)

**ANSP:** \_\_\_\_\_

**Interviewee:** \_\_\_\_\_ **Date:** \_\_\_\_\_

*Lack of continuous and reliable surveillance in the North Atlantic airspace results in large separation standards and limited oceanic clearances. Data link communication capabilities are one promising option to increase efficiencies. The objective of this survey is to identify the following: 1) operational inefficiencies and opportunities for improvement in the North Atlantic, including approaches which would improve flexibility using data link communications; 2) infrastructure available and services offered by the different ANSPs in an effort to assess technical and coordination gaps which could negatively affect efficiency of operations; 3) barriers and enablers for data link implementation in terms of direct costs and benefits derived from such technologies; and 4) strategies to leverage costs and benefits, facilitate coordination, reduce uncertainty, and encourage data link equipage and services.*



**Part I: Background**

5.7 What is your role in your ANSP?

5.8 What is your experience with North Atlantic operations?

**Part II: Operations in the North Atlantic (NAT)**

2.1 Do you think there are any operational inefficiencies in the North Atlantic?

If yes, which?

2.2 In your opinion, what are the main sources of these inefficiencies?

2.3 Do these inefficiencies directly affect your ANSP operations? How?

2.4 Do you think these inefficiencies affect airline operations? How?

2.5 Are any of these inefficiencies directly related to harmonization? What aspects of harmonization are more important to your ANSP (e.g. equipment, procedures, charging, etc.)?

2.6 Are any of these inefficiencies directly related to coordination with other ANSPs?

2.7 What criteria does your ANSP use to grant or deny clearances?

Do data link equipped aircraft get any operational advantage in such decisions?

2.8 What separation standards are currently supported by your ANSP (time and distance based)?

2.9 Do you see any difference in terms of efficiency of operations between the NAT and the Pacific?

If so, what are the main sources of such differences?

- 2.10 Do you see any issues of harmonization of technologies between oceanic and continental airspace? (i.e. JPDO ADS-B plans in the U.S., ATN Link 2000+ in Europe, and FANS-1/A over the NAT)

### **Part III: Opportunities to Improve Service**

- 2.1 What are the technical and safety requirements necessary to reduce separation standards over the NAT?

What are the policy and procedural requirements?

- 2.1 What are the main challenges for your ANSP in order to reduce separation standards over the NAT (e.g. infrastructure, special equipment, establishment of policies and procedures, etc.)?

- 2.2 What do you see as the main challenges for users of the system in order to reduce separation standards?

- 2.3 What level of data link equipage in the NAT system do you think would be required before reduced separation could be implemented?

- 2.4 What technologies or capabilities could improve efficiency of operations over the NAT in the near, medium, and long terms?

- 2.5 What are the potential applications of such technologies? (Refer to list at the end for examples)

- 2.6 Would these applications bring any economic or operational benefits to your ANSP? If so, which?

- 2.7 Would these applications bring any economic or operational benefits to the users of the system?

If so, which?

- 2.8 What do you see as the main financial and policy challenges for service providers to achieve such applications?

What are the main financial and policy challenges for the users of the system?

**Part IV: Technology, Infrastructure, and Services Offered (Current and Projected)**

- 2.1 Does the ANSP currently support FANS CPDLC in the oceanic environment?

If yes:

What uplinks and downlinks are currently supported?

What phase of CPDLC implementation does your ANSP offer?

What services does your ANSP provide via CPDLC?

- 2.1 Does your ANSP currently support FANS ADS-C in the oceanic environment?

If yes:

What ADS contracts are currently supported?

What services does your ANSP provide via ADS-C?

- 4.3 Does your ANSP currently support other data link technologies in the oceanic environment (e.g. ATN CPDLC, ADS-B, etc.)?

- 4.4 Does your ANSP support any system for oceanic automation? If so, which?

- 4.5 Does your ANSP support ATS Interfacility Data Communications (AIDC) or other ground-to-ground coordination system?

- 4.6 How do you coordinate with other ANSPs in terms of technology, procedures, and charging schemes?

- 4.7 Does your ANSP have any plans to coordinate with other ANSPs in trying to improve efficiency of operations? If so, how? What are the major barriers associated?
- 4.8 What tools does your ANSP use for conformance monitoring and conflict detection and resolution?
- 4.9 What tools does your ANSP use for coordination and management of flight data?
- 4.10 What other relevant tools not mentioned above does your ANSP currently use for decision support, coordination, and air traffic management? (See list at the end for examples)
- 4.11 Does your ANSP have any plans to deploy infrastructure or conduct trials to upgrade any of the systems and tools described above? If so, which applications will be supported and when? What are the major challenges associated?
- 4.12 Does your ANSP have any plans to implement new procedures to improve efficiency of operations? What are the major barriers associated?
- 4.13 How long does it usually take for an ANSP to implement any new application, considering initial infrastructure deployment, implementation of procedures and trial periods?
- 4.14 What backup procedures does your ANSP use in the event of a system failure?
- 4.15 Have you seen a change in demand for HF services resulting from the implementation of data link? Why do you think this is the case?
- 4.16 Do you think data link technology currently available on aircraft is fully utilized with the services that your ANSP supports? How?

## **Part V: Value Distribution of Data Link Costs and Benefits**

- 5.1 Is your ANSP receiving any direct economic or operational benefit from data link? If so, which?
- 5.2 What are the factors that drive your ANSP's decision to offer data link services?
- 5.3 Do you see any disadvantages for your ANSP in the implementation and use of data link communications? If so, which?
- 5.4 Do you think that the users of the system have received any operational and economic benefits derived from data link? If so, which?
- 5.5 What initial costs would most negatively affect your decision to support new data link applications (e.g. infrastructure deployment, implementation of new procedures, initial personnel training, etc.)?
- 5.6 What recurring costs would most negatively affect your decision to support new data link applications? (e.g. infrastructure maintenance, continuing personnel training, etc.)
- 5.7 How would initial and recurring costs compare in the way they influence your decision to support new data link applications? Could you provide us with rough estimates on the order of magnitude of these costs?
- 5.8 What kind of fee structure does your ANSP follow for services offered?
- 5.9 What does your ANSP consider in making a business case to deploy infrastructure and implement new procedures to support new data link services? Does ANSP capitalize directly from such services?

## **Part VI: Strategies to Encourage Data Link Equipage and Services**

- 2.1 Would your ANSP consider giving a reduction in communication charges to encourage operators to equip with data link?

If yes, what percentage of reduction would your ANSP be willing to give?

What are the major challenges associated with this?

- 2.1 Would your ANSP consider giving preferential treatment for data link equipped aircraft to encourage more operators to equip?

If yes, what kind of preferential treatment would your ANSP be willing to give?

What are the major barriers associated with this?

- 6.3 How effective would your ANSP consider the implementation of a data link mandate for both air and ground?

- 6.4 What incentives or mandates (financial, regulatory, etc.) would be most effective in encouraging your ANSP to support more data link services?

## **Part VII. Open Skies**

- 7.1 Will the U.S.-EU open skies agreements have an impact on your ANSP? How?

- 7.2 Do you see a change in demand resulting from the agreements?

If so, does your ANSP have any plans to react to such changes?

## **Data Link Applications and Benefits**

### Communication Applications

- Elimination of radio operator relay between pilots and controllers
- Improvement in reliability of communications
- Reduction of delay in communications
- Faster and more accurate emergency and non-routine communications
- Granting/requesting clearances and conducting negotiations
- Communication coverage in polar regions (HF DL)

### Communication and Surveillance Applications

- Reduction of crew workload
- Reduction in frequency congestion
- Weather deviations and wind adjustments
- Elimination of high frequency (HF) radio position reports
- Reduction in fuel consumption by operating at optimum FL
- Improvement in safety by increasing situational awareness, avoiding weather, and conducting more accurate and timely communications
- Reduction of flight times and delays by flying under more efficient routes and procedures

- Reduction of Gross Navigation Errors (GNE) by eliminating manual waypoint insertion errors
- 50 NM longitudinal separation
- 30 NM longitudinal / lateral separation
- Dynamic aircraft route planning (DARP)

### Surveillance Applications

- In-trail follow
- Free-Flight Operations (Self-separation and selection of route, speed, and altitude)
- Passing
- Improvement of surveillance accuracy and update rates

### **Decision Support, Coordination, and Air Traffic Management Tools**

#### Automated

- Procedural conflict probe
- Aircraft situation display
- Electronic flight data display
- Route conformance monitoring
- 4-D conformance monitoring
- Automated coordination alerting



- Automated Interfacility Data Communications (AIDC)

### Manual

- Paper flight progress strips
- Plotting boards
- Manual speed-time-distance flight computer

### Flow Management

- Optimal/flexible track generation
- Flexible airspace boundaries
- Aircraft to track capacity balancing

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