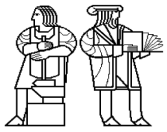

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IDENTIFYING THE DYNAMICS OF TECHNOLOGY TRANSITION: ADS-B ADOPTION IN THE NATIONAL AIRSPACE SYSTEM

Final Report – ESD.10, Introduction to Technology and Policy

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Massachusetts Institute of Technology
Technology and Policy Program

January 2007

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Identifying the Dynamics of Technology Transition:
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EXECUTIVE SUMMARY

Congestion is a growing problem in the National Airspace System (NAS). Predictions indicate that the NAS, as a whole, will be operating at 75% of capacity by 2010 [2] and that the demand in capacity in air transportation will double within a span of 10 to 35 years [3]. In order for the U.S. to maintain leadership in air transportation and meet the challenges of demand and efficiency of the 21st century, the NAS infrastructure, technology, and procedural strategies need to be modernized [4]. To this end, the FAA plans to implement a cooperative surveillance system called Automatic Dependent Surveillance – Broadcast, or ADS-B. The surveillance technology and its applications are expected to provide important operational improvements by addressing some of the limitations of the current surveillance system.

One of the key determinants for the success of a NAS-wide cooperative surveillance system will be the adoption of new technologies by multiple stakeholders. Successful transition in a complex system such as the NAS will be dependent on factors such as competing stakeholder objectives, safety considerations, technical maturity, equipage critical mass, resource limitations, and a balanced value distribution of costs and benefits over time among participants, both individually and as a group [5]. This study aimed to identify the dynamics of technology transition in a complex system so that they may be applied to the particular case of ADS-B adoption in the NAS. To that end, five cases of ADS-B adoption were examined to gain insights from their varied successes and stumbling blocks. They are Australia, the Gulf of Mexico, Capstone in Alaska, the United Parcel Service (UPS) tests in Louisville, and different ADS-B efforts around Europe.

The cases were systematically compared in order to identify transition dynamics. The comparison revealed two implementation scenarios that merit distinct policy treatments. Where adoption was precipitated by a specific, time-critical factor, implementation proceeded more rapidly and with less resistance; analogous to "a spark igniting a field of dry grass". Conversely, other cases, despite significant need, showed that in the absence of a time-critical, compelling catalyst, implementation proved more complicated and progressed slower; this scenario of progressive need leading to adoption can be likened to "a straw breaking the camel's back."

Key observation #1: There are two implementation scenarios that merit distinct policy treatments, *sparks* and *straws.*

Key observation #2: *Spark* dynamics weaken barriers.

It was also noted that when the impetus for change is championed by a party other than the system administrator, there seems to be an increased sense of legitimacy to the need. Other stakeholders seem more willing to buy-in to a project that was instigated by "one of their own."

Key observation #3: If a party other than the system administrator fills the role of facilitator, fewer external incentives are needed.

In all cases that are sufficiently mature to measure success, the incremental successes were cast as incentives for future equipage. When program goals are stated in such a way, that it is easy to recognize when they have been met, program enthusiasm has a way of snowballing.

Key Observation #4: If programs are rolled out in phases, and goals are measurable, attained success can be cast as an incentive in future stages.

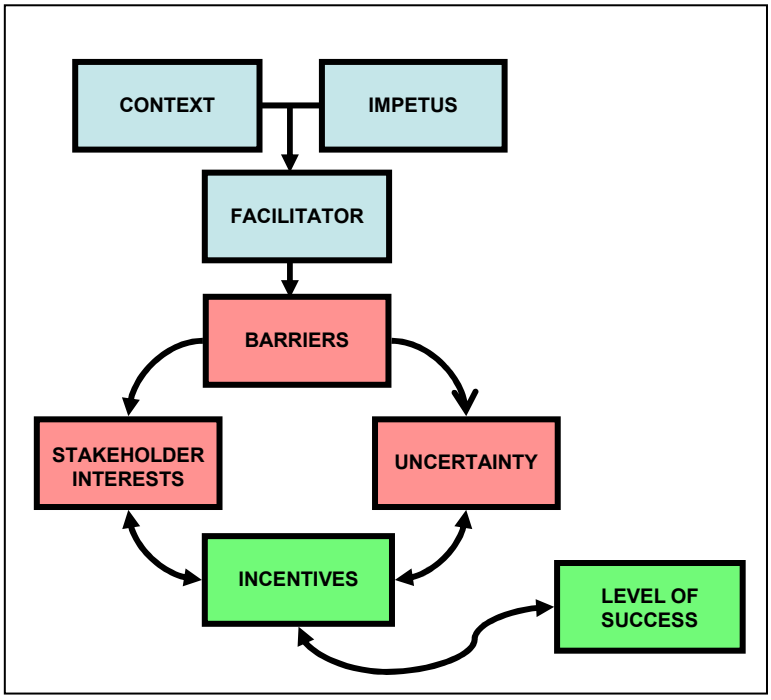

Figure 1 - Transition Dynamics Model

The comparison of case studies led to the development of the transition dynamics model shown in Figure 1. In this model, the context captures relevant aspects of the state of the system prior to transition. The impetus is that element of the context that instigates transition; it can either be a *spark* or a *straw*. This impetus leads one or several stakeholder(s) to take on the role of facilitator and initiate the process of adoption. If the facilitator is not the system administrator, transition tends to proceed more smoothly. Both uncertainty and conflicting stakeholder interests create barriers to transition. Incentives can be shaped to break down identified barriers. Lastly, past successes can be translated into incentives for further technology adoption.

This transition model was then used to assess the FAA strategies for ADS-B adoption in the National Airspace System (NAS). Based on the *spark/straw* classification discussed above, the NAS congestion issue is characterized by "straw piling up on the camel's back." Further, the FAA is both the facilitator and the system administrator in the NAS. This makes the lack of *spark* scenario even more challenging. To identify barriers faced by ADS-B adoption in the NAS a stakeholder analysis and mapping was performed. The one overwhelming trend that is apparent when stakeholder issues were mapped, according to whether they have system or individual impacts, is that individual impacts elicit a much stronger response than system level ones.

Key observation #5: Individual impacts elicit a much stronger response than system level ones.

To examine when issues identified by stakeholders would start to impact the airspace they were mapped according to equipage phases. The mapping showed that although safety is the most widely emphasized of the performance issues, safety enhancements require the most advanced level of ADS-B adoption before the full safety benefits will be realized.

Key Observation #6: Safety is a powerful lever.

While all stakeholders express a positive sentiment towards ADS-B adoption, many remain only guardedly optimistic. The delay of benefits inherently associated with a staged transition is the source of much of this hesitation.

Key Observation #7: The delay between investment and rewards is very important to the stakeholders.

The assessment of ADS-B adoption in the National Airspace System has revealed that the FAA is doing well in many areas. In particular, they are taking advantage of regional sparks by allowing segment one to be solely comprised of regional trials. In this manner, it will be able to use measured successes from these trials to incentivize ADS-B adoption later on. However, it appears that the FAA intends to complete the current set of trials and then implement ADS-B on a nation-wide scale. This seems unwise. While regulations must eventually be nation-wide, it makes sense to structure the implementation plan according to idiosyncrasies of the system.

Recommendation #1: The FAA should leverage regional *sparks* and allow the implementation plan to follow the National Airspace System's natural structure.

Further, regional implementation *sparks* will ignite a nation-wide fire through the commercial airlines. Since they frequent multiple airspaces, they will receive benefits from one pocket of critical mass and spread them to others. This will have the effect of normalizing the benefit delays. Moreover, achieving critical mass in regional pockets will serve to prove the benefits, which to this point, remain theoretical.

Recommendation #2: The FAA should use regionally demonstrated benefits to mitigate the uncertainty associated with future rewards.

The stakeholder issues analysis revealed that individual impacts elicit a much stronger response than system level ones. Yet many of the ADS-B benefits espoused by the FAA will be experienced at the system level. This is simply a matter of understanding your audience and framing the information so that it will be best received.

Recommendation #3: The FAA should frame benefits in such a way that individual stakeholders can relate to them.

Clarity and commitment to goals is the concern most emphasized by the stakeholders despite the fact that the FAA has remained transparent about their plans and goals by presenting their implementation timelines and goals at Industry Days and other venues. The uncertainty associated with FAA commitment is fundamentally a question of perception. This uncertainty can be mitigated by the FAA continuing to issue long-term plans, keeping to the adoption schedule and developing procedures for certification.

Recommendation #4: The FAA needs allocate effort to convincing the stakeholders that they are committed to ADS-B adoption.

By paying special attention to these four areas, the FAA may see less resistance from key stakeholders in the future.

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1 Introduction

Congestion is a growing problem in the National Airspace System (NAS). According to the US Department of Transportation, air traffic has been increasing at a rate six times faster than ground transportation and four times faster than the Gross Domestic Product (GDP) since 1960 [2]. Predictions indicate that the NAS, as a whole, will be operating at 75% of capacity by 2010 [2] and that the demand in capacity in air transportation will double within a span of 10 to 35 years [3]. Matters are worse in some regions, the northeast corridor is extremely congested and as of 2003, five of the busiest 35 airports in the U.S. were already in need of increased capacity [6]. Saturation of the NAS will negatively impact delays, cancellations, airfares, airport congestion, operator workload, and more.

In order for the U.S. to maintain leadership in air transportation and meet the challenges of demand and efficiency of the 21st century, the NAS infrastructure, technology, and procedural strategies need to be modernized [4]. To this end, the FAA plans to increase the number of runways, expand the capacity of existing runways, and introduce innovations in technologies and procedures [2, 7, 8]. One part of the technical approach is the introduction of a cooperative surveillance system that would increase the situational awareness of decision-makers [9]. This system will augment the current on-board see-and-avoid technology with a sense-and-avoid counterpart that will facilitate cooperation and coordination regarding safety (aircraft separation) and efficiency (traffic flow), thereby increasing the overall capacity of the system [10].

The leading cooperative surveillance system currently under consideration is Automatic Dependent Surveillance – Broadcast, or ADS-B. ADS-B and its applications are expected to provide important operational improvements by addressing some of the limitations of the current surveillance system, optimize the controller/flight crew workload and provide benefits in the areas of safety, capacity, efficiency and environmental impact, thus contributing to the overall air traffic control objectives. In the words of Marion Blakey, FAA administrator, "What this [ADS-B adoption] is going to mean for NGATS can be summed up in three words — safety, efficiency, and capacity" [11]. The FAA is not the only strong proponent of ADS-B; implementation efforts are currently underway on four continents. Regardless, a transformation of this magnitude will not be easy. There are many conflicting interests and views.

One of the key determinants for the success of a NAS-wide cooperative surveillance system will be the adoption of new technologies by multiple stakeholders. Successful transition in a complex system, such as the NAS, will be dependent on factors such as competing stakeholder objectives, safety considerations, technical maturity, equipage critical mass, resource limitations, and a balanced value distribution of costs and benefits over time among participants, both individually and as a group [5]. Moreover, the transition will not be immediate and simultaneous for all participants in the civil air transportation industry.

This study aims to identify the dynamics of technology transition in a complex system so that they may be applied to the particular case of ADS-B adoption in the NAS. In order to accomplish this, select mature cases of ADS-B implementation from around the world will be reviewed, compared and lessons generalized. These lessons will then structure an analysis of the NAS, leading to a NAS stakeholder analysis. A stakeholder mapping will then be performed followed by a discussion of uncertainty. Key observations will be generalized to the broader topic of technology transition in a complex system. Finally, an assessment of the FAA implementation strategy will be made with recommendations given.

The main contribution of this study to the field of air transportation is the development of a model to identify the dynamics of technology transition in a complex system such as the NAS. The selection of ADS-B adoption in the NAS as a case study aligns with the leading strategies currently considered for the modernization of the air transportation system (i.e. NGATS). Additionally, as shown by the transition model, a stakeholder mapping of interests is fundamental to the understanding of the type of incentives that will need to be created in order to achieve a successful transition. On that note, the key observations and recommendations addressed to the FAA are intended to provide insight into relevant aspects of consideration in the development of leverage strategies to encourage and expedite stakeholder participation in the modernization process.

2 ADS-B System Background

This section presents the technical ADS-B background that forms a basis for future discussions. It provides a brief description of the current surveillance system, explains how the ADS-B avionics work, and details the technical impact ADS-B will have on the NAS.

Automatic Dependent Surveillance - Broadcast is recognized as a key enabler for the modernization of the Air Traffic Control System. The system consists of a transmitter in an aircraft that generates ADS-B messages, the data link broadcast medium, and a receiver that processes and displays messages in another aircraft, vehicle, or ground system as shown in Figure 2.

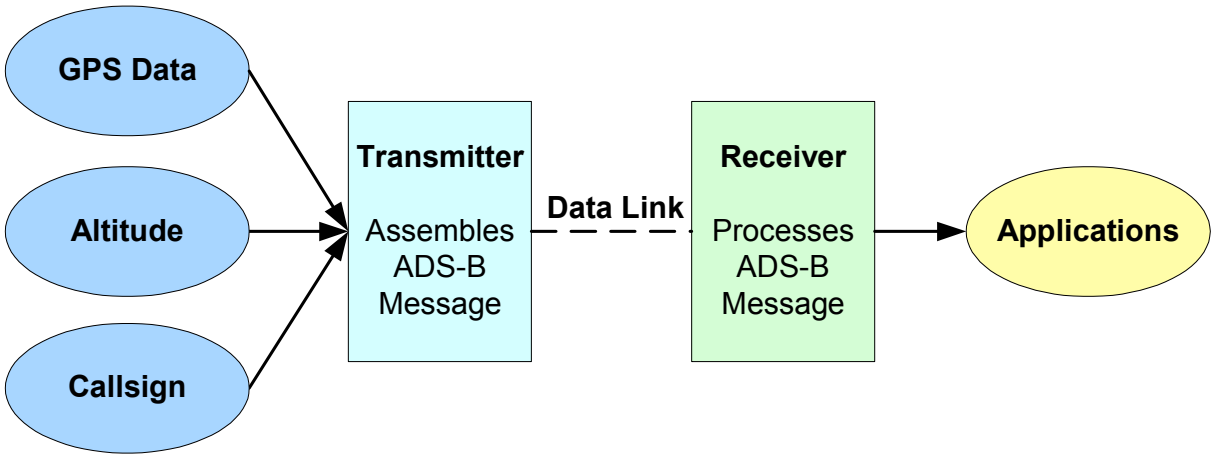

Figure 2 - Depiction of ADS-B message flow from aircraft to ground station or other aircraft[1]

ADS-B is "automatic" in that it sends out its information at regular intervals without any action by the pilots or ground controllers; "dependent" because it requires input from the GPS and aircraft instruments in order to work; "surveillance" refers to a method of determining the location of other aircraft or vehicles; and "broadcast" because the signal is sent out indiscriminately and can be received by anyone in range operating on the same frequency. Based on the level of equipage, some users will only be able to transmit messages over the data link, while others will be able to transmit and receive.

[1] Figure 2 and component description adapted from AN-Conf/11-WP/6,Appendix A, pg. A-11, ADS-B Concept of Use. The Eleventh Air Navigation Conference presented this paper at their 2003 meeting. This reference is the Appendix to the paper which contains a description of the ADS-B system and how it will be employed. It is the Concept of Use document presented to the conference.

2.1 Current Surveillance System

The current Air Traffic Control system is based on surveillance by radar stations. Air traffic controllers monitor which aircraft are in the sky from ground radar stations enabling them to direct the aircraft, keep them separated, and sequence them for takeoff or landing. Because ground controllers are limited to their radar images and position reports from the pilots, they use conservative spacing to keep aircraft separated. Pilots have no visibility of other aircraft sharing the airspace other than traffic reports from the ground controllers. They also have little visibility of weather in their flight path other than what is reported by ground based weather stations. This causes a huge dependence on radio communications which are vulnerable to frequency congestion, misunderstandings, and even weather effects. During periods of low visibility and high traffic, this can cause serious delays and safety hazards. These challenges will only increase as the airspace becomes more crowded in the coming years.

2.2 Equipage

Initially, most aircraft will use their existing transponders to transmit ADS-B data. This configuration, known as 'ASD-B Out', requires very little modification to current transponders, and hence, poses less expense and risk to early adopters. Once critical mass is achieved, users can benefit from the efficiencies gained by ATC from more accurate position reporting, but the system will not provide any additional cockpit information.

There is a second configuration known as ADS-B In. If aircraft are equipped with a CDTI (Cockpit Display of Traffic Information), they will receive ADS-B messages from other aircraft in the area as well as from ground stations. To utilize ADS-B In, aircraft cockpits and avionics will have to be significantly upgraded to accommodate the CDTI. While this involves more expense than ADS-B Out, the benefits are measurably greater, particularly for receiving information about traffic and weather.

In order for any aircraft to utilize the ADS-B system, the ground control stations must be in place prior to the aircraft equipage. They serve as the backbone of the system. They are much cheaper ($100,000-400,000) than radar control sites ($1-4 million) and are much easier to maintain [12]. The ADS-B ground stations will be able to transmit and receive data in two formats (Mode S, UAT) and will have controllers available to help manage all the information that the aircraft are sending and/or requesting. The ground control stations will also manage the services provided to pilots over the ADS-B system. These include both the flight applications for making flying more efficient and the information services reporting traffic and weather (TIS-B, FIS-B).

2.3 Implementation of ADS-B

Implementation of ADS-B will change every aspect of the current ATC system. Ground radar stations will be augmented and eventually replaced with Ground ADS-B stations for surveillance. Ground controllers will see aircraft on a map display based on the GPS coordinates that the aircraft send to the ground station. The accuracy will no longer suffer based on the proximity to the radar; the positions should be accurate whenever the aircraft is receiving good data from the GNSS Satellites. It will extend the surveillance coverage for low altitudes (below existing radar coverage) and areas where no radar coverage currently exists, leading to more efficient use of airspace.

The use of GPS based positions greatly increases the accuracy of the displayed positions and will give the controllers more flexibility to reduce spacing between aircraft. Air Traffic Controllers will be able to reduce the time between regular takeoffs and landings at airports to handle the increasing future demand. It will also increase airport safety and capacity, especially under low visibility conditions, by providing airport surface surveillance and, at the same time, protecting against runway incursions. ADS-B will enable the identification and monitoring of relevant airport vehicles as well as aircraft [13].

ADS-B will also create numerous efficiencies in the cockpit. Navigation will be significantly improved when using ADS-B due to the accuracy of GPS data. Pilots will not be constrained to the navigational corridors set up by the current network of NAVAIDs. They can take advantage of fuel-efficient routes at altitudes with the most favorable wind conditions. Currently, a great deal of time and fuel is wasted near airports as Air Traffic Controllers maneuver aircraft around to get adequate sequencing and spacing for landing. Certain applications of ADS-B will help pilots and ground controllers predict when each aircraft will arrive at the airports so the spacing can be prearranged before they arrive [13].

Airport ground operations will take advantage of the new system and consequently takeoffs will also be more efficient. Instead of each aircraft having to line up and wait to depart the airfield, the controllers can sequence them much closer together and significantly reduce congestion around airports. Another application using ADS-B will allow pilots to broadcast their intended route of flight. This coupled with weather data, flight plans, and GPS data from other aircraft, will enable controllers to predict when and where to sequence each flight into their destinations [13]. These efficiencies mean aircraft will be on time more often and will burn less fuel waiting to taxi for takeoff or waiting to land, thereby saving money and reducing emissions into the environment.

3 Case Studies

ADS-B implementation in the NAS cannot be fully treated without consideration of the global airspace. International flights commence in one national airspace and terminate in another making it unrealistic to ignore compatibility and exchange issues. In addition, there are lessons to be learned from airspace modernization initiatives, particularly those centred on ADS-B technology, elsewhere around the world. Programs are currently underway on five continents including concentrated regional trials within the United States. Each region has its own set of reasons for adopting. No two strategies are the same. Yet, their varied successes and stumbling blocks combine to provide valuable insight into the dynamics that underlie ADS-B adoption in a nation's (or region's) airspace.

Since the goal of this survey is to identify key observations that can be applied to the NAS, only programs with maturity equivalent to, or more advanced than, the NAS will be examined. Those initiatives are Australia, the Gulf of Mexico, Capstone in Alaska, the United Parcel Service (UPS) tests in Louisville, and different ADS-B efforts around Europe. The cases are described individually and then systematically compared in order to identify transition dynamics.

3.1 Australia

The Australian airspace currently contains pockets that lack radar coverage as shown in Figure 3. This had never previously posed a concern since traffic in these regions had historically been light. However, in recent years, air traffic in these regions has increased many-fold resulting in increasingly large areas of high-density air traffic that are currently out of radar coverage. The problem needed immediate attention. Since ADS-B derives its position data from on-orbit GPS rather than ground based radar, it represented a natural solution to coverage in expansive areas. Furthermore, the fact that ADS-B equipment is cheaper to install and maintain than conventional radars provided even more incentive to adopt ADS-B [14].

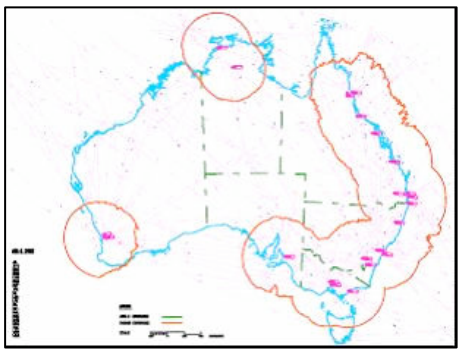

Figure 3 - Existing radar in Australia at FL300 [15]

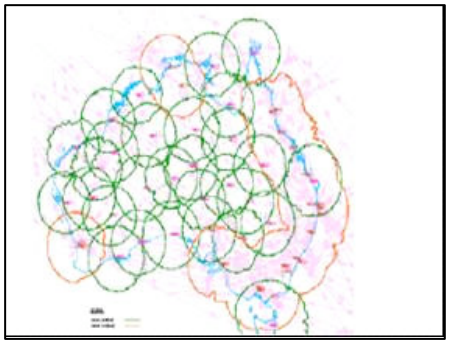

Figure 4 – Future radar & ADS-B at FL300 in Australia [15]

In addition, in the high traffic core of the Australian airspace, where radar coverage is prevalent, terminal area and en-route radars will soon reach their end of service life. It was determined that the most cost-effective solution is to introduce a new technology (i.e. ADS-B) rather than replacing old radars. Further, it is unlikely that there would be another opportunity for transition like this before 2020 [16, 17].

The time critical nature of these two events and the obvious economic benefits they afford Airservices Australia, the administrative body in the region, created a strong impetus for action. In particular, the window of opportunity formed by the need to replace old radar equipment gives Airservices Australia the financial means to incentivize reluctant stakeholders. In this case, the general aviation (GA) community is the group most reluctant to equip with ADS-B because of the significant burden of avionics costs, installation, and certification.

With this potential barrier in mind, Airservices Australia is making efforts to reduce the cost of technology transition for the GA community. Therefore, a subsidy package was proposed to cover the expenses of ADS-B Out avionics, installation, and certification for GA aircraft with a Maximum Takeoff Weight (MTOW) less than 5,700 kg. Other investments have been allocated toward the research and development (R&D) of low-cost ADS-B transmitters and receivers, which will become available within the next two years [16, 18, 19].

Figure 5 - Bundanberg, Burnet Basin, Queensland, Australia [21]

In addition, Airservices Australia has divided the strategy for ADS-B transition into three main phases: the Bundanberg Program in Queensland, the Upper Airspace Program (UAP), and the Australian Transition to Satellite Technology (ATLAS), encompassing the short, medium, and long terms, respectively. Demonstrated success will be used as an incentive for participation in future stages.

Bundanberg (see Figure 5) lasted from 2003 to 2006 and involved 10 aircraft and one ground station. Based on the success of the trials, the Civil Aviation Safety Authority (CASA) approved a 5NM reduced separation minima for ADS-B equipped aircraft in December 2004 – a significant reduction in separation standards [20, 18, 21, and 22].

The second program, the Upper Airspace Project (UAP), will be operational by mid-2007. The project involves 28 ground stations with the objective of providing full surveillance coverage above FL300. UAP will primarily target airlines, although participation will remain voluntary [17, 22, 23, 14]. Figure 4 shows the current radar plus future ADS-B coverage at FL300.

The third program, the Australian Transition to Satellite Technology (ATLAS), is currently pending approval. The goal of this project is to equip the majority of the Australian fleet with ADS-B Out and replace en-route secondary radars with ADS-B ground stations. This is expected to result in a significant reduction of costs for surveillance [17, 14]. Plans for a lower airspace project are under revision.

In order to encourage further participation, Airservices Australia is actively promoting the benefits resulting from adopting ADS-B avionics. Some of these benefits include priority access to airspace, reduced separation minima, increased safety, efficient operations, increased air-to-air situational awareness without ATC intervention, increased ATC situational awareness, and reduced pilot/controller workload.

In addition to positive incentives, different mandate scenarios to require aircraft to equip with ADS-B are under consideration. Three of these scenarios include [16]:

- Replacing radars with en-route ADS-B ground stations along Australian east coast. Only aircraft carrying transponders today will be required to equip.
- Extending surveillance to ten high traffic areas without radar coverage. All of the aircraft operating in these areas will be required to equip.
- Requiring all aircraft carrying VHF radios to get ADS-B.

Other mandate options to adopt ADS-B Out avionics include [24]:

- Duplicating requirements for SSR transponder carriage, plus all aircraft under IFR and UAVs. Expected to begin in 2009 and affecting 58% of the future fleet.
- Same as above plus all aircraft carrying fare-paying passengers.
- All aircraft operating in CTR or MBZ.
- Duplicating requirements for VHF radio, plus all aircraft under IFR, UAVs, and medium/heavy unmanned balloons. Expected to begin in 2012 and affecting 91% of the future fleet.
- Mandating ADS-B equipage for all aircraft.

In Australia, program success is measured in terms of the percentage of the fleet equipped, the cost savings compared to radar operation and maintenance, and the authorization of operational procedures (e.g. reduced separation minima, priority access to airspace, and alternate routes). Based on these parameters, implementation to date has shown promise. Already an estimated 25% of the total Australian fleet has equipped, Airservices Australia has authorized 342 airframes to operate under reduced separation, cost savings are being realized and with the introduction of the subsidies discussed above, a large percentage of the GA aviation community will begin to take advantage of the individual and system benefits as well.

3.2 Europe

In the last decade, air traffic has grown more than 50% and levels are projected to double by 2020. In 2005, there were 9.2 million flights per year while, in 2025, yearly flights are expected to reach 22 million. Predictions indicate that serious congestion will begin in 2015. Another major problem in the European airspace is fragmentation across the multiple sovereignties. More specifically, the European air traffic management (ATM) is made of 100 airport nodes, 600 airspace sectors, and more than 36 air-navigation service providers. This division has lead to non-uniform systems, standards, and procedures, a growing negative stakeholder perception, and inefficient operation. Network inefficiencies cost, on average, two billion euros annually [25, 26].

That being said, because the problems of congestion and inefficiencies are more apparent on a local scale, with each region defining its own problems and priorities, the EU wide thrust is relatively weak. In an attempt to unify to airspace modernization efforts, EUROCONTROL is facilitating the transition through the Single European Sky ATM Research (SESAR) initiative. The sated goal of SESAR is the modernization and unification of the European airspace and air traffic control. Through SESAR, traffic flows and performance, rather than geographic boundaries, will be the basis of the airspace structure.

The notion of a single European sky has emerged since the creation of a single European market in 1985 and the Economic and Monetary Union of 1990 [25, 27]. However, despite the growing European identity, the main challenge for transition within Europe remains the characteristic fragmentation and lack of linkage between economic, commercial, and operational priorities. Additionally, involvement of too many organizations and authorities has resulted in delays in decision making and a lack of sustained stakeholder support. Further, low levels of interoperability, data sharing, and cooperative management will present significant challenges for achieving a uniform participation [26, 28].

Since the late 90s, modernization strategies for the European airspace have emerged in stages. The European Commission sponsored the North European ADS-B Network (NEAN) program 1995 to 1998. In 1999, NEAN was extended under the NEAN update program (NUP). The motivation for both programs was a need for increased situational awareness and traffic management. The goals were simple: ADS-B technology validation, demonstration, and cost-benefit analysis [29, 30]. The NEAN infrastructure was later leveraged as part of the North European ADS-B Application Project (NEAP). Funded by the European Union, the main goal of the program was to evaluate the application of ADS-B in support of precision navigation and enhanced situational awareness for pilot and controllers [29]. Finally, the North Atlantic ADS-B Network (NAAN) was established to extend NEAN/NUP ADS-B infrastructure across the Western North Atlantic [29].

As part of a separate initiative, the Mediterranean Free Flight (MFF) program began in 2000. Sponsored by Italian Air Traffic Services provider (ENAV), the MFF involved the participation of Spain, France, Greece, UK, Sweden, and EUROCONTROL. The specific goals of the program included technical and operational technology evaluation, development of procedures, and promotion of homogeneous technologies [31].

The most recent program, CASCADE aims to plan and coordinate ADS-B implementation in Europe based on ADS-B combined with CPDLC as a communication channel. The CASCADE program hopes to build on the regional infrastructures discussed above to obtain the following benefits from ADS-B: safety (enhanced situational awareness, reduced pilot/controller workload), efficiency (reduced separation minima, less frequent congestions, less position voice reports), cost effective surveillance, and increased access to airspace. Figure 6 shows the countries participating in the CASCADE trials.

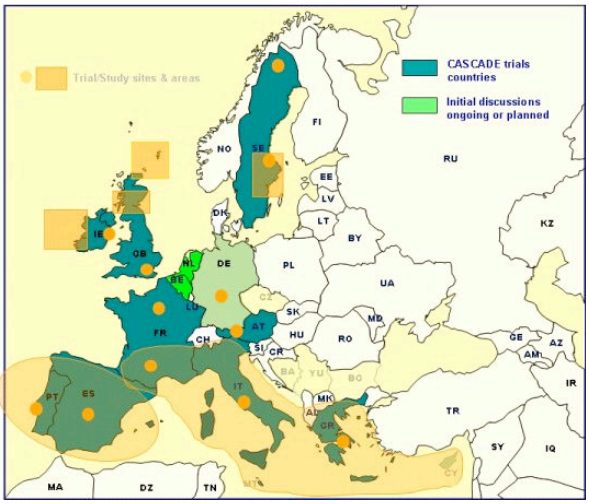

Figure 6 - CASCADE trials [1]

The CASCADE program will have two phases (streams). Stream 1 includes ADS-B surveillance for radar and non-radar areas as well as airport surveillance. Validation trials for stream 1 will continue through 2006. Stream 2 will concentrate on airport and flight operations [32].

Success in Europe will be measured primarily by reduction in congestion and delays. However, because of the nature of the EU as a union, participation from the majority of countries is pivotal. It is too early to comment on the success of ADS-B implementation and ATM unification across Europe, but EUROCONTROL faces a difficult challenge. In the past, similar initiatives have failed because of a lack of commitment of stakeholders and decision makers.

3.3 National Airspace System

Increased air traffic is beginning to cause problems in the NAS. Predictions indicate that the NAS as a whole will be operating at 75% of capacity by 2010 [9] and that the demand for capacity in air transportation will double within a span of 10 to 35 years [33]. Matters are worse in some regions. The northeast corridor is extremely congested and as of 2003, five of the busiest 35 airports in the U.S. were already in need of increased capacity [6]. Figure 7 highlights the non-uniformity of traffic density within the US. The colors indicate the number of airplanes passing though a particular region on a given day. The scale is increasing from white to dark red (via blue, green, yellow, orange, and red) with the dark red dots marking major hubs. It is clear from the figure that "capacity" has more meaning on a local scale.

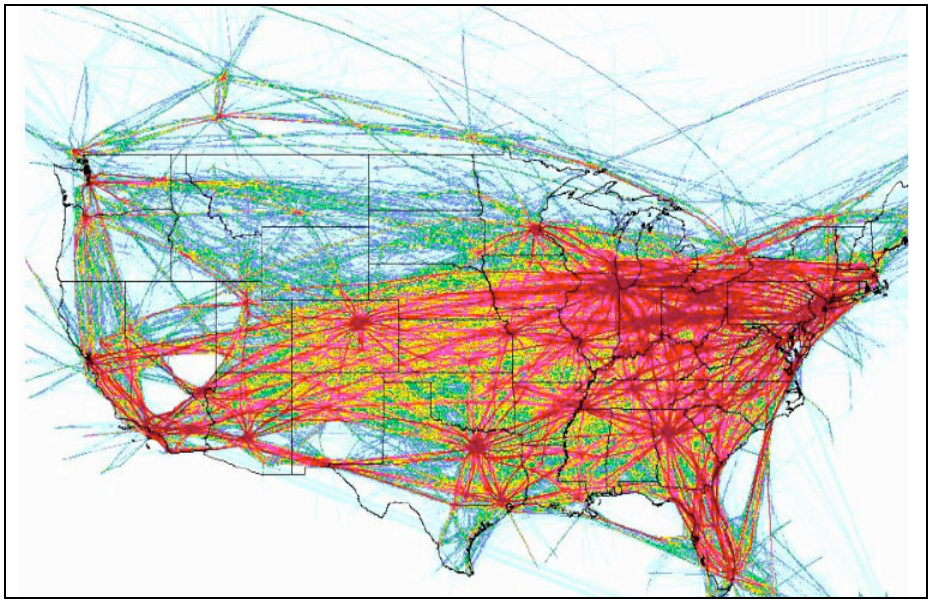

Figure 7 – US Air Traffic Density (11/24/02) [34]

The FAA believes that ADS-B is an important part of the solution to congestion and plans to have the NAS fully equipped by 2025. To this end, they have planned four implementation segments. Segment one, which is ongoing and will last until 2010 is characterized by regional trials including the Gulf of Mexico, CAPSTONE in Alaska and UPS in Louisville. In segment two (2010-2014) the ADS-B adoption will move to a national scale. The FAA's main target for segment two is to accomplish 40% avionics equipage in the NAS. During segment 3 (2015-2020) the FAA will begin targeted removal of legacy radars and aims to achieve 100% equipage. Segment four (2020-2025) will see the completion of the program and the retirement of radars [35]. The FAA aims to install 400 ADS-B ground stations by 2014, while decommissioning more than 125 ATC radars [36].

Deploying the system and retiring radars (which cost three times as much as ADS-B ground stations) could save the FAA as much as $1 billion over 20 years while providing system users, like the airlines, $1.3 billion in user benefits, through savings in jet fuel and more efficient routings. The FAA plans to use two types of data links in its ADS-B implementation: one for general aviation aircraft and another for airlines. GA aircraft will be equipped with Universal Access Transceiver (UAT) equipment, and airline aircraft will use Mode S transponders on 1090 MHz. FAA administrator Blakey has declined to say when such equipment would be mandated for use on aircraft in the U.S., but she said this is inevitable [36].

The following three case studies are part of segment one of ADS-B adoption in the NAS.

3.3.1 Gulf of Mexico

The Gulf of Mexico (GOM) airspace is effectively split between high altitude long distance flights and low flying helicopters (0-5000 ft). There are approximately 300 high-altitude oceanic flights a day, largely air traffic between USA and the Caribbean, Mexico and Central America, and they are increasing at a rate of 8% per year. Because of the lack of radar coverage in the region, the aircraft are restricted to procedural flight rules and often relegated to sub-optimal altitudes.

In the lower altitude airspace, helicopters supporting oil drilling rig operations dominate the traffic. Currently, there are about 650 helicopters that fly to more than 5,000 oil-drilling platforms as far as 250 miles from the coast, making about 7,500 trips per day [37]. In bad weather, a frequent event in the region, the helicopters are unable to communicate with each other or with air traffic control. As a result, on days where the weather requires IFR, there is a massive curtailment of flights. Since flight cancellations lead to losses on the order of several million dollars per day, technology (i.e. ADS-B) that enables bad weather flights is very appealing.

In fact, the clear and immediate economic benefits and increased safety, enabled by ADS-B adoption in the GOM, spurred the Helicopter Association International (HAI) to take action. Although the GOM was not a part of the FAA's original implementation strategy, the need was so great, and the HAI were so convincing that the program is moving forward [38]. Although the FAA (as the administrative body in the airspace) will coordinate and regulate implementation as the program moves forward, in the beginning they were the main barrier. In fact, in the Gulf, it was the HAI that induced the FAA to back the project. They accomplished this by contributing "in-kind" donations of transportation to equipment sites for the FAA personnel required to install and maintain the ADS-B ground segments.

In the Gulf of Mexico, success will be measured by stakeholder buy-in and decline in weather related cancellations. Since implementation will not begin in earnest until next year, it is too soon to report on the level of success. However, already, many of the stakeholders have expressed their support for the program; this bodes well for the future.

3.3.2 Capstone (Alaska)

The FAA Capstone Program, initiated in 2000, is a program to equip aircraft flying in Alaska with ADS-B in an effort to mitigate the region's poor aviation safety record. Alaska was chosen as the ideal location for the Capstone Program due to the regions poor safety record despite everyday dependence of its citizens on aviation. The combination of a limited road infrastructure and numerous remote villages makes travel by aviation a necessity in some situations. Children take airplanes to school in remote villages and patients needing urgent medical care are likely to be moved by airplane. However, the state has sparse radar coverage and a high aviation accident rate. The commercial aviation industry in Alaska had one of the highest rates of workplace deaths from 1993-1998 [39].

The situation provided a strong impetus to find a solution to the safety problems. ADS-B provided the right technology to do so, with the added benefit of providing an IFR approach at 10 new airports [40]. ADS-B gave pilots access to more accurate weather information and allowed them to avoid potentially dangerous conditions. This type of information is crucial to prevent Controlled Flight into Terrain (CFIT) accidents, one of the major hazards in the Alaskan airspace.

The program brought together a diverse set of interests, and many of the strategies and plans are derived from reports from the RTCA, the National Transportation Safety Board (NTSB), the MITRE Corporation's Center for Advanced Aviation System Development (CAASD), and Alaskan aviation industry representatives such as Alaska Pilots Association, Alaskan Air Safety Foundation, and the University of Alaska at Anchorage [41].

The main barrier to wide equipage in Alaska was the cost of the avionics packages. Most of the operators fly privately owned small single and twin prop aircraft, but use them commercially. The program would never reach critical mass if these small business owners were expected to adopt the system voluntarily. Under the Capstone Program however, the FAA paid for the equipment and installation at an estimated cost of $15,000-20,000 per airframe [40].

Other challenges to the implementation of the ADS-B system came from uncertainty about the system performance and safety standards. While the benefits of greater surveillance could be realized immediately, the system did not yet comply with stringent FAA standards [42] for aviation system reliability. The solution initially was to allow use of the system only under Visual Flight Rules (VFR), when weather permitted good visibility for terrain avoidance and visual separation between aircraft throughout the route of flight. As time passed, further certifications were awarded allowing flight along a designated route structure and approaches in Instrument Meteorological Conditions (IMC) [43].

The success of Capstone in Alaska is generally characterized by the overall increase in safety consciousness. The reduction in accident rates, though due to a combination of factors, shows the effectiveness of ADS-B in the area. In comparison to a baseline accident rate study from 1990-2002, by the end of 2004 the accident rates in the Capstone area of Alaska have fallen by almost 40%. In particular, weather and navigation related accidents (those targeted by the Capstone Program) went from 19% of the total in the baseline down to 13% of the total accidents in 2003-2004 [44]. Further analysis will track this trend to see if it continues.

3.3.3 United Parcel Service (UPS) Louisville

Since its naissance in the early 1900's, UPS has been committed to on-time package delivery and has been recognized as a pioneer of new technologies within the industry. In a business where the level of control over one's schedule can make, or break a company, even second-long delays become important. Yet, flight operations at UPS airports are currently unpredictable because they lack complete surveillance, scheduling, and control [45].

In an effort to maintain their competitive edge, the UPS fleet has moved to adopt ADS-B [46]. UPS is uniquely positioned to be able to implement ADS-B on its own. The UPS main hub, in Louisville, Kentucky, is ideal to validate the benefits derived from the technology since nearly all night air traffic belongs to UPS, accounting for approximately 100 flights between the peak hours of 11:00 p.m. to 2:30 a.m., local time. As a result, if all UPS aircraft equip, system benefits will abound almost immediately. By eliminating much of the uncertainty associated with future benefits, this represents a compelling impetus to equip.

Although UPS can control the number of airplanes to equip within their fleet, the FAA still regulates the interface with ATC. As a result, UPS has been working in close collaboration with the FAA in the evaluation and demonstration of ADS-B technology, the development, and approval of procedures, and the logistics involved in the adoption of the technology. UPS understands that they are highly dependent on FAA cooperation and approval; FAA opposition could represent an impenetrable barrier. However, since success of the Louisville demonstration is central to the FAA overall plan, so far their interests have aligned.

UPS flight tests began in 2002 with a demonstration of potential environmental and economic benefits. By April 2003, equipage with CDTI displays for 107 B757s and B767s had begun. Another set of flight tests took place in 2004 with the objective of validating reductions in noise, emissions, delays, and fuel consumption, as well as feasibility of operation in a mixed environment. [45, 47, 46, 48]. For UPS, the biggest incentives for equipage are the multiple benefits resulting from the application of these procedures. There are at least four procedural techniques based on ADS-B avionic proposed by UPS:

- **Merging and Spacing (M&S):** aircraft delivery to a runway will take only a few seconds, making scheduling more precise and potentially increasing capacity by up to 20%.
- **Continuous Descent Arrivals (CDA):** arrival procedures to descend from cruise to final approach with an idle power configuration that allows for 250 – 465 lbs of fuel savings per flight, up to 30% noise reduction, and up to 34% lower emissions.

- **CDTI Assisted Visual Separation (CAVS):** maintained visual approach arrival rates under IMC conditions
- **Surface Area Movement Management (SAMM):** the increased situational awareness leading to reduced runway incursion and traffic conflicts [45, 47].

It is worth noting that none of these techniques will change ATC responsibility, but will allow for a significant increase in capacity and efficiency, especially if applied simultaneously.

For UPS, the success of ADS-B adoption is a function of FAA approval of procedures and future installation of ground stations near other UPS airports. As the eleventh largest airline in the world, the UPS initiative holds a prominent place within the FAA's efforts of NAS modernization. Direct metrics of success of the program include increased flight operations, on-time deliveries, more reliable and predictable schedules, and the operational benefits described in section 1.3.5 [46].

To date, the project has been very successful. ADS-B Out will be operational on all UPS aircraft by the fall of 2006. CDTI displays for ADS-B In on the entire B757, B767, and B747-400 domestic fleets has been 90% available since January 2004 and will reach 100% equipage by the fall of 2008. On the other hand, the A-300 and Boeing MD-11 will equip entirely with ADS-B In by 2009 while the A-380 airplanes ordered will have the necessary avionics installed upon delivery. Ground infrastructure for main UPS airports will be ready by 2008 [45, 48].

3.4 Case Study Summary

Although the cases studied differ from one another in technical and operational context, important lessons can be generalized from their content. In order to facilitate comparison, the various instances of ADS-B implementation were expressed in terms of context, impetus, facilitator, barriers, incentives and measures and level of success.

- The context captures relevant aspects of the state of the airspace pre-implementation.
- The impetus identifies the specific, time-critical factor within the context that initiates adoption.
- The facilitator refers to the particular stakeholder(s) who initiates the process of adoption. Facilitator is intentionally distinguished from the system administrator (e.g. the FAA in the USA) in this context, although in some cases, the facilitator and administration could be same organization. While the administrator would typically lead any new airspace initiative, another party (e.g. the HAI in the case of the GOM) sometimes champions the impetus.
- The barriers and incentives encompass elements that inhibit or encourage adoption respectively.
- Finally, measures of success present a concrete baseline by which to establish a program's level of success.

Table 1 summarizes the case studies, broken down using the framework discussed above.

Table 1 - Case Study Comparison

	Australia	Europe	Gulf of Mexico	Alaska	UPS
Context	Lack of radar in high traffic areas & economics	Negative public perception Congestion Multiple sovereignties	Lack of radar, safety & economics	Lack of radar , poor conditions & safety	Possibility of scheduling improvements & economics
Impetus	*Spark*: End of radar service life (Economic)	*Straw:* Unclear	*Spark*: Flight cancellations (Economic)	*Spark*: Series of accidents (Safety)	*Spark:* FAA subsidy / control case circumstance, (Economics)
Facilitator	Airservices Australia	EUROCONTROL	HAI	FAA / Public	UPS / FAA
Barrier(s)	GA equipage cost	Multiple sovereignties Different resources, needs, & powers	FAA resistance Reluctant stakeholders	Equipage cost FAA system safety Unproven technology	FAA cooperation (procedure approval, infrastructure)
Incentive(s)	Subsidies for GA Procedural benefits	Reduced congestion "Single Sky"	HAI in-kind donations to FAA	Subsidies for GA	Competitive advantage
Measure of Success	Cost savings % equipped aircraft Operational benefits	On time arrivals % equipped aircraft	Continuous operations in bad WX % equipped aircraft Operational benefits	Reduced accident rate	More operations On-time deliveries FAA approval / support Operational benefits Predictable schedules
Level of Success	25% commercial equipage Authorization for reduced separation	Too soon to tell	Too soon to tell	40% reduction in accident rate	Fleet equipage by 2006

The case study comparison presented in Table 1 reveals two implementation scenarios that merit distinct policy treatments. Where adoption was precipitated by a specific, time-critical factor, implementation proceeded more rapidly and with less resistance; analogous to "a spark igniting a field of dry grass". Conversely, other cases, despite significant need, showed that in the absence of a time-critical, compelling catalyst, implementation proved more complicated and progressed slower; this scenario of progressive need leading to adoption can be likened to "a straw breaking the camel's back."

Although *sparks* only occur as an extreme case, historically many technical or policy paradigm shifts have occurred as a result of a precipitating factor. For example, the 1970s oil crisis spawned automobile fuel economy standards and the success of Sputnik spurred a surge in US space funding. This is because precipitating factors facilitate transition; the *explosion* resulting from the *spark* establishes the required momentum for transition. In fact, the winds of change may blow so strong, and the demand for immediate action may be so forceful, that it is difficult to make thoughtful decisions about what changes to make. Sometimes, change can happen too quickly.

Key observation #1: There are two implementation scenarios that merit distinct policy treatments, *sparks* and *straws*

The Capstone case study highlighted this tendency to move quickly when the impetus is strong. The issue of how fast unproven, but potentially lifesaving technology should be approved for use spurred a heated debate in Alaska. Proponents argued that immediate deployment was in order. Opponents felt that FAA reliability standards had been developed for a reason and should be respected regardless of the particular circumstance. In the end, the debate was resolved with a compromise; the avionics could be used under a limited set of circumstances. Nonetheless, this example reveals the power of a *spark* to break down barriers that inhibit change.

Key observation #2: *Spark* dynamics weaken barriers.

On the other hand, while the progressive build-up of need can also instigate change, the system has greater inertia – fundamentally, people resist change. This is not to say that it is desirable for a system to achieve *spark* dynamics, rather than *straw* dynamics; merely that *spark* dynamics create an environment more conducive to rapid change. In the *straw* scenario, because the build-up of need serves as early warning, an attempt is typically made to accelerate change, so the system can be strengthened to prevent breaks. Sometimes, change occurs too slowly. The trouble is that stakeholders are hard to motivate based on future problems; the ability of potential problems to influence stakeholders depends on the uncertainty, magnitude (e.g. risk), and timing (i.e. how far off). This scenario is all too familiar in Europe. While congestion related delays and inefficiencies abound, no country's or stakeholders-within-a-country's function is sufficiently impeded to warrant sacrifice in the name of change.

In addition, whether operating under *spark* or *straw* induced dynamics, the nature of the facilitator can play an important role. *Sparks* initiated both the Gulf of Mexico and Australia; however, their implementation strategies are vastly different. In Australia, the facilitator is also the system administrator – Airservices Australia. They were prompted to act now for financial reasons and as a result, were in a strong position to provide monetary incentives to reluctant stakeholders. Since ADS-B has enormous technical potential, with the economic burden alleviated, the majority of stakeholders are more than happy to equip.

Conversely, in the Gulf of Mexico, the financial benefits are tied to safety rather than a service window. Since the affected party is primarily the HAI, it is they that have brought about ADS-B adoption in the region. In fact, they are so enthusiastic about ADS-B, that the HAI has actually incentivized the FAA. With the impetus being championed by a party other than the system administrator, there seems to be an increased sense of legitimacy to the need. Other stakeholders seem more willing to buy-in to a project that was instigate by "one of their own." Further, in this scenario, the impetus is more likely to affect a whole class of stakeholders (i.e. system users) making external incentives less necessary than in the case of, for example, Australia.

Key observation #3: If a party other than the system administrator fills the role of facilitator, fewer external incentives are needed.

In all cases that are sufficiently mature to measure success, the incremental successes were cast as incentives for future equipage. When program goals are stated in such a way, that it is easy to recognize when they have been met, program enthusiasm has a way of snowballing. In Australia, initial goals were set in terms of number of airplane s equipped and approval of procedural benefits such as reduced separation standards once the first stage was successfully completed. Airservices Australia used this success to springboard the next phase of implementation. A similar chain of events was observed through Capstone in Alaska. Success for the initial phase was measured in reduced accident rates. Although there was initial skepticism regarding the way the program was run, the 40% reduction of accident rates that was measured made the program hard to oppose.

Finally, the UPS Louisville case study is unique in that the stakeholders were effectively reduced to UPS and the FAA. This drastically simplified matters to the extent that Louisville has become a veritable control case for the FAA. The FAA can use the success of the program as an incentive to encourage other stakeholders, in the NAS, to equip. The rationale for this statement is discussed following the treatment of stakeholders and uncertainty later on in the report.

Key Observation #4: If programs are rolled out in phases, and goals are measurable, attained success can be cast as incentives in future stages.

The comparison of case studies led to the development of the transition dynamics model shown in Figure 8. In this model, the context captures relevant aspects of the state of the system prior to transition. The impetus is that element of the context that instigates transition; it can either be a *spark* or a *straw*. This impetus leads one or several stakeholder(s) to take on the role of facilitator and initiate the process of adoption. If the facilitator is not the system administrator, transition tends to proceed more smoothly. Both uncertainty and conflicting stakeholder interests create barriers to transition. Incentives can be shaped to break down identified barriers. Lastly, past successes can be translated into incentives for further technology adoption.

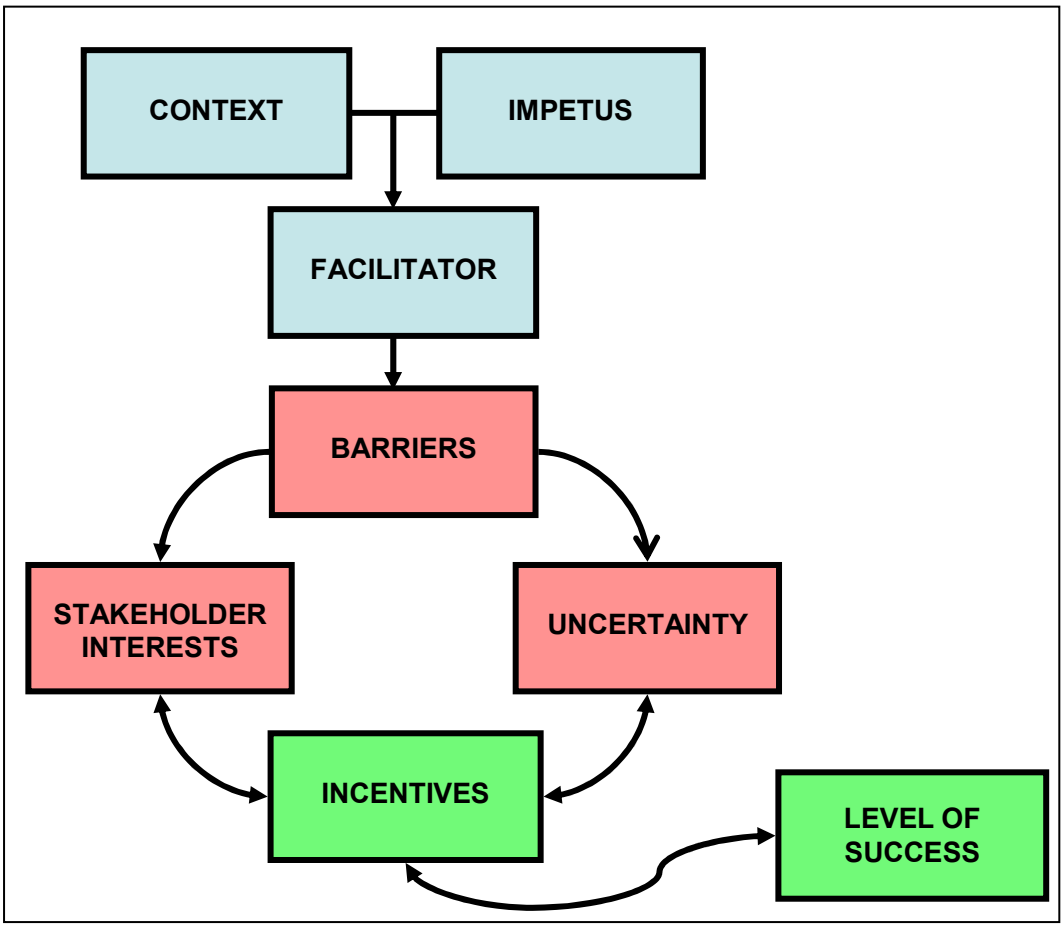

Figure 8 - Transition Dynamics Model

4 ADS-B Adoption in the National Airspace System

This transition model was then used to assess the FAA strategies for ADS-B adoption in the National Airspace System (NAS). Based on the *spark/straw* classification discussed above, the NAS is characterized by "straw piling up on the camel's back". Although, increasing delays, cancellations, airfares, airport congestion, operator workload, and more, combine to create a significant modernization need, which may eventually lead to system failure, without a *spark,* many of the stakeholders remain reluctant to equip. Further, the FAA is both the facilitator and the system administrator in the NAS. This makes the lack of *spark* scenario even more challenging.

To identify barriers faced by ADS-B adoption in the NAS, a stakeholder analysis and mapping must be performed. This is done to gain a better understanding of the needs, values, benefits, and costs of the key players. In addition, since many of the benefits associated with ADS-B will not be realized until the system reaches a "critical mass" with respect to equipage; both pre- and post-critical mass equipage scenarios will be considered. Section 4.1 presents opinions publicly expressed by the various stakeholders. Section 4.2 normalizes and compares these opinions and discusses their significance. Section 4.3 discusses the uncertainty associated with future ADS-B benefits and concludes the discussion of stakeholders.

4.1 Stakeholder Analysis

NAS Stakeholders can be broadly categorized as system users, labor organizations, manufacturers, and regulating bodies. System users include, airlines (represented by the ATA and RAA), general aviation represented by (AOPA and NBAA), military aviation (represented by the DOD) and finally passengers. Regulating bodies include the Federal Aviation Administration (FAA) and the Department of Defense (DOD). Labor Organizations include pilots (represented in the US by ALPA and AOPA) and air traffic controllers (represented in the US by NATCA). They each have different and sometimes conflicting values. As a result, the ADS-B adoption strategy must consider the constraints imposed by the needs and values of each of these groups.

4.1.1 Airlines

Commercial airlines are represented by two groups, the Air Transport Association (ATA) and the Regional Airline Association (RAA). The airlines' needs and benefits coincide on many issues.

The RAA emphasizes its concern that the FAA might shift its direction on the modernization of air traffic control away from ADS-B. Airlines do not want to invest in ADS-B equipment only to be told later by the FAA that the equipment has become obsolete because of new regulations. Furthermore, regional airlines would like to see transparent certification and approval processes developed and put into use along with the implementation of the new equipment [49].

Other raised concerns regarding equipage are affordability, frequency capacity, system redundancy and interoperability [50]. Airlines must receive a return on their equity investments in equipment, planning and training procedures for ADS-B [49]. Furthermore, Airlines would like the equipment and regulations surrounding the implementation of it designed so that the equipment can be easily installed and thus will not require much airplane downtime. The equipage of new airplane s is not as much as issue as large manufacturers like Boeing and Airbus are already equipping new airplane s with ADS-B technology [51].

Airlines are concerned that the proposed Mode S 1090 frequency will not be able to handle the increased capacity used by ADS-B; the frequency is already crowded with communication from airplanes to air traffic control towers. Furthermore, redundancy considerations are always a factor in implementing a new technology and are crucial to the safety of the system. Redundancy must be addressed in FAA's planning process, not only once ADS-B is fully implemented but also all trough the transition process [50].

The ATA adds a strong sentiment regarding the need for international interoperability of the ADS-B system. It is very important to international airlines that equipage standards in the United States are comparable to the rest of the world [50].

Despite their reservations, the two groups agree that ADS-B adoption is in their best interest. Currently, cross-country flights are routed in a zigzag pattern that follows ground radar beacon placement. This elongates the travel path, wasting time, fuel and money [52]. Furthermore, increased situational awareness, and access to real time weather and traffic data, will allow aircraft to optimize their routes. Measures need to be taken to increase airspace capacity to increase safety, reduce delays, and increase efficiency. ADS-B will accomplish some of this; therefore, they provisionally support the implementation of ADS-B.

4.1.2 General Aviation

In the NAS, the general aviation (GA) category includes both private and business aircraft. Private owners are represented by the Aircraft Owner and Pilot Association (AOPA) and business aviation (BA) by the National Business Aviation Association (NBAA). As of 1999, General aviation represented over 90% of aircraft in the NAS [53]. However, this statistic is somewhat misleading since GA makes up a much smaller percentage of total traffic. Nonetheless, from the point of view of equipage, it is important to realize that there are many GA airplane s to equip. In addition, as a group, particularly with BA, they wield considerable resources and power to influence policy in the congressional arena.

Equipage costs related to ADS-B implementation are a major concern for the general aviation [54]. The AOPA considers the current equipage costs for ADS-B to be too high for its members [55] and that they might prove to be a substantial barrier. For a private airplane owner the cost of a new ADS-B system can be substantial compared with other incurred costs. This high proportionality of total costs must be taken into account when deciding on ADS-B adoption procedure and policy and the affordability of certification processes. Moreover, it is important that general aviation will be allowed sufficient time to equip and that installment is easy and reasonably priced.

General aviation shares the airlines' worry about FAA deviation from its current path towards ADS-B. They stress that it is imperative that the FAA verify its unequivocal backing of ADS-B so that their members can rest assured that they will not be stuck with outdated equipment down the road. General Aviation will not go through the expense of upgrading to Cockpit Displays if there is no information to display on them. The FAA must ensure that the infrastructure to provide these services is functioning before they can expect any voluntary buy in from the various stakeholders, and certainly, before they can mandate participation [54, 55].

ADS-B will increase safety for general aviation by increasing information supplied to the aircraft cockpit. The added traffic and weather information will improve situational awareness and facilitate weather and traffic avoidance [55]. These benefits will only be realized with ADS-B In technology in addition to the ADS-B Out technology. General Aviation benefits related to ADS-B Out technology are limited. Aircraft operating in congested areas will benefit from decreased separation standards enabled by ADS-B Out but otherwise the benefits lie mostly with the information obtained from ADS-B In. The AOPA has insisted that free traffic and weather info is provided for all aircraft to augment general aviation's benefits from the new technology [55].

4.1.3 Military

The DOD has very different needs than the other stakeholders. They need unimpeded access to the global airspace, now, during the transition period and in the future airspace. However, they rarely fly in congested airspace and have historically received waivers for expensive equipment upgrades. As a result, they emphasize the importance of a clear and consistent statement of the FAA's plans, particularly with respect to penalties associated with non-compliance. Furthermore, they require preservation of access to Special Use Airspace (SUA) [56].

4.1.4 Public

In this context, the public includes passengers, as well as airport communities. Since their interests, powers, and values differ greatly, they will be discussed separately.

Although the traveling public represents the largest stakeholders, in terms of sheer numbers, they tend to be the least unified and as a result, are only vocal under extreme circumstances. Their main avenue for expression is through ticket sales or the lack thereof. For them, delays are a nuisance, reduced ticket price a strong incentive to travel and apparent safety is paramount. If either delays or ticket prices increase (within reason), travelers may choose alternative modes of transportation for shorter trips. However, if safety is perceived to be compromised, ridership will decrease drastically overall, as evidenced by the post-9/11 period.

Overall, the value distribution associated with ADS-B adoption is skewed in the positive sense from the point of view of passengers. If the professed ADS-B benefits are realized, delays will be reduced, flight times may decrease, and safety will be improved. The system cost of upgrades will only be passed down in a limited way; the public will not tolerate significant increases to ticket prices as mentioned above.

It is difficult to assess the impact that ADS-B adoption will have on airport communities. While environmental impact and noise pollution will be reduced on a per flight basis (more efficient routes will reduce fuel consumption and optimized landing will limit circling pre-approach) the projected increase in capacity may nullify these advantages overall. Since there is no expected airport community cost-impact associated with equipage, NAS modernization is positive-neutral initiative from their perspective.

4.1.5 Federal Aviation Administration (FAA)

As a government organization, the FAA is concerned with system level issues. The NAS needs to achieve a higher level of capacity and efficiency (without compromising safety), in the next few years, or there will be a serious reduction in system performance. They aim to accommodate the needs of the various stakeholders. Although the FAA theoretically has the power to impose regulations on all system users, they need to be wary of abusing this power. In the past, there have been instances when they have attempted drastic technological changes and failed to follow through with the support infrastructure. Such was the fate of the Advanced Automation System (AAS) program, which was an effort to completely modernize the air traffic control computer systems. AAS was a major strategic and financial fiasco because the FAA grossly underestimated the technical complexity and the resources needed for the program. Even more, the overambitious goals set for AAS never materialized because AAS never reached a solid state of completion. As a result, stakeholders are now reluctant to purchase expensive equipment without firm commitments from the FAA.

Currently, the FAA maintains the ground segments of the NAS surveillance system (including mainly radar stations in this context). Radar stations are more expensive to install initially and are more mechanically complicated than ADS-B ground stations. As a result, they are also more expensive to maintain. ADS-B therefore makes sense for the FAA in financial terms. In any case, FAA benefits should be measured in terms of system benefits (which are clearly positive for ADS-B). In addition, ADS-B ground stations are smaller, less unsightly and have a lower environmental impact compared to radar.

4.1.6 Department of Defense (DOD)

The needs and interests of the DOD were discussed from a user point of view in section 4.1.3. In addition to being a user, the DOD is also an administrator, in that they regulate ATC at their own airstrips. To this end, their primary concern is with interoperability with the rest of the NAS. Therefore, for them, a clear statement of FAA objectives is key.

4.1.7 Pilots

Pilots can be broadly divided into the two categories of GA pilot/owners, as represented by AOPA, and commercial pilots, as represented by the Airline Pilots Association (ALPA). AOPA interests will not be discussed here because they have already been covered as part of GA.

ALPA are adamant that the first priority should be terminal capacity, believing that not only is this the main bottleneck in the system, but also that the terminal area represents the biggest area for safety concerns. Although they will likely not be directly affected by any monetary cost-benefits, they will be intimately involved in implementing any procedural changes. As a result, their union will be vocal if they are not satisfied. They believe that further human factors research is necessary before the safety impacts associated with procedural changes can be understood. They would like to see better coordination/communication between FAA facilities and between ATC service providers and system users [57].

4.1.8 Air Traffic Controllers

Air traffic controllers, as the group that actually confronts capacity constraints on a daily basis, know better than anyone the need for modernization in the NAS. However, while they support proposed improvements in theory, they have some very real concerns about practical safety considerations.

Anthony Smoker expressed the perspective of the International Federation of Air Traffic Controllers' Association (IFATCA) when he spoke at the most recent Airborne Separation Assistance Systems (ASAS) workshop. Their primary concerned was with increased workload. He explained that, while a more efficient system would reduce controller workload on a per flight basis, with an increased number of flights, the workload might be higher overall. They feel that while "tighter coupling" in the system, could theoretically improve overall efficiency, they question where human cognitive limits lie; they believe that more human factors studies are required in order to understand the safety implications of increasing complexity in the system. Last, they are concerned about the lack of clarity regarding what NAS modernization actually entails. For example, they feel that increased information sharing and better localization of aircraft are both very positive, but are extremely wary of relinquishing any control over the system [57]. The National Air Traffic Controllers Association (NATCA) echoes these sentiments, emphasizing the need for FAA consultation with technical experts and air traffic controllers throughout the ADS-B implementation process [58].

From the air traffic controller's perspective, economic factors are not particularly important. They will not spend money on system upgrades in any direct way. In addition, they will not be rewarded, in any measurable way, by improvements in the system. They can expect new procedures, training and increased complexity in their jobs. However, if the system is safer, more efficient and has an increased capacity, they consider the overall trade to be a positive one.

4.1.9 Manufacturers

Although GAMA, avionics and airframe manufacturers represent different sectors of the airline industry, their interests with respect to ADS-B adoption are compatible. Safety is of primary concern because of liability issues, but overall, manufacturers want a guaranteed steady flow of business as well as satisfied customers.

Garmin, one of the key avionics manufacturers, has already invested substantially in ADS-B related R&D over the last 10 years. They have a certified and fielded line of products for both air transporters and general aviation, and are the only manufacturer with suitable equipage for GA. In addition, they are currently developing forward-fit and retrofit compatibility within their product line. Needless to say, they have fully committed to making the ADS-B initiative work [59].

Rockwell Collins and Honeywell, two other avionics manufacturers, are more reserved in their optimism. They believe that there are several key issues that need to be resolved by the FAA before they are willing to pour more resources into product development. In particular, they are concerned that the FAA implementation plan is may not be completely compatible with that in Europe and Australia. Further, the lack of clearly defined operational benefits and payback is making it difficult for them to gauge which products to develop. They only see minimal value in ADS-B Out although enhanced situation awareness (associated with ADS-B In) is viewed as very positive. Yet it seems that ADS-B Out is planned as an intermediary step on the part of the FAA. Last, they understand that most of their customers can't afford multiple changes. As a result, FAA commitment to a plan is extremely important to them. That being said, Collins and Honeywell will develop whatever equipment is necessary to meet the FAA's plans and have already engaged in significant R&D to that effect [60, 61].

Boeing, as an aircraft manufacturer, sees operational applications as the key to ADS-B success. They favor procedures and standards that integrate all users and urge that regulations be made with the inevitable ADS-B Out/In transition in mind. Specifically that ADS-B In must not "re-do" ADS-B Out. Further, they emphasize that while ADS-B Out is a logical first step for GPS equipped airplanes, most users benefits will be enabled by ADS-B In (suggesting that the intermediary ADS-B Out step might not be appropriate for non-GPS airplanes). Last, international compatibility of standards is quite important to Boeing because their products will operate in multiple international airspaces.

Compatibility is less of an issue for the General Aviation Manufacturers Association (GAMA) since most GA airplane s stay within their home regions. For them, safety is paramount, as a reflection of the interests of their customers. They, like Boeing, are also interested in the certification procedures [59, 60, 61].

4.2 Stakeholder Mapping

The above sections summarize the sentiments that each of the stakeholders have publicly expressed with respect to ADS-B. They reflect the contents of presentations given in forums such as the FAA ADS-B Industry Days, the ASAS TN workshop series or recent media statements. While this survey is not exhaustive, since these events represented an opportunity for the groups to have their opinions heard, it is believed that the issues of importance to each stakeholder are captured above.

In order to compare and map the various sentiments expressed by each stakeholder, their interests where divided into two main areas of concern: economic and performance. These broad topics were further distilled in terms of 11 issues: clarity and commitment to goals, affordability, interoperability, downtime, on-time operations, reduced separation, access, safety, workload, technical implementation, and reduced environmental impacts.

The issue matrix in Figure 9 captures the frequency and intensity with which particular issues were raised as well as an indication of whether the issue is individual (to a particular stakeholder) or systemic (experienced by the system). The contents flow directly from the above stakeholder discussions. Wherever a stakeholder emphasized the importance of a particular issue, a filled in circle was included in the matrix; when an issue was raised but not stressed, an empty circle was used.

		Stakeholders									
	Issue	Commercial Airlines	General Aviation	Military	Public	Air Traffic Controllers	Pilots	Manufacturers	Aviation Agencies	System	Individual
Economic	Clarity and committment to goals	●	●	●		○		●			X
	Affordability	○	●	○				○	○		X
	Interoperability	●		●			○	●			X
	Downtime	○	○								X
Performance	On time operations	○			○				○	X	
	Reduced separation/flexible routes	○				○	○		○	X	
	Access	○		●							X
	Safety	○	○		○	●	●	●	○		X
	Workload					●	○				X
	Technical implementation	○	○			○	○	○		X	
	Reduced environmental impacts	○			○	○	○	○	○	X	

● Emphasized
○ Mentioned

Figure 9 - Summary of stakeholder interests

Before the issue matrix can be meaningfully discussed, the precise intent of each issue must be clarified:

Economic burdens are typically experienced individually. Although there are certainly system costs associated with ADS-B implementation in the NAS. The concerns raised by stakeholders were exclusively introspective. For this reason, economic issues are considered individual.

- **Clarity and commitment to goals** is grouped in the economic section because the stakeholders are largely concerned with the financial risks associated with changes to future mandates. For example, while it may be economically viable to invest in ADS-B now (with the expectation of future benefits) if regulations are changed in the future and old equipment becomes obsolete, the initial investment would be lost. Although the request for clarity and commitment to goals was directed expressly at the FAA, it applies to uncertainty in general.
- The term **affordability** is not intended to be a measure of absolute cost; clearly, a particular piece of equipment has a fairly defined cost. However, the value of said cost can differ greatly from user to user. For example, the cost of equipage to a Cessna owner may be great relative to their initial investment, where for a major airline, the per-plane cost of equipage is negligible.
- **Interoperability**, as the name suggests, raises the importance of being able to use the same equipment in multiple airspaces. This is primarily a concern for international flights. Interoperability is grouped with economics because it is the prohibitive costs associated with redundancy that are of primary concern.
- **Downtime** is essentially an extension of affordability. For commercial aviation, the bigger financial concern is lost-time associated with upgrading/replacing avionics. As a result, they hope that ease of physically equipping the plains will be considered.
- The distinction between individual and system cost/benefits in the realm of **performance** is less clear-cut. Most aspects of system operational performance improvements will be realized, at least to a certain extent, individually. For each issue, the relative dominance of system versus individual affect will be discussed.
- In this context, **on-time operations** only include delays resulting from in-flight capacity constraints, pre-landing cues and sub-optimal routing assignments rather than long lines of passengers at security checkpoints. As a result, while delays are certainly experienced individually, the underlying issue is very much a system problem.
- In the same way, while **reduced separation** yields marginal benefits to individuals, it is at the system level that significant increases in efficiency are achieved.
- **Access** can be interpreted in two distinct ways. First, in terms of an optimized use of the airspace as a whole; this concept is captured under the guise of reduced separation. The second interpretation, and the one that is intended here, refers to the possibility that certain airspaces may be restricted based on level of equipage. This issue is of primary concern to the Military, for example, because the ability to fly wherever they need whenever they require is pivotal to their mandate. While the first sense of "access" is a system issue, the second is clearly individual.
- ADS-B is expected to improve **safety** in two main ways. First, the surveillance derived from the GPS signal will be more accurate than the current radar system; better information for ATC theoretically leads to better decisions. However, in order to increase system capacity, the accurate positional knowledge will be translated into reduced separation, thereby nullifying the safety improvement. The second aspect of safety stems from increased coverage in areas of rugged terrain and improved weather knowledge. These clear safety improvements will be experienced on an individual level. For these reasons, safety will be considered to have individual impact.

- **Workload** is an extension of safety in the way that downtime is an extension of affordability. If, for example, ATC workload is increased to the limit of human cognitive abilities, system safety will be compromised significantly. However, this is an extreme case. Realistically, workload is of concern individually, primarily for ATC.
- **Technical implementation** captures concerns relating to how ADS-B will be implemented within the system. For example, Mode S operates on a frequency that is already crowded leading to concern that ADS-B will be restricted by transmission capacity. These concerns are explicitly at the system level.
- **Environmental impact** includes concerns from excess emissions to noise pollution. Although the environmental impact is primarily local, the source of improvements with respect to environmental impact will be improved system efficiency. In the context of ADS-B implementation, this issue is relatively minor.

The one overwhelming trend that is apparent in Figure 9, is that individual impacts illicit a much stronger response than system level ones. In fact, all the filled in circles correspond to individual issues. Nonetheless, the majority of the benefits projected by the FAA will be experienced at the system level. This represents a fairly significant disconnect. Despite the fact that many of the problems that the FAA hopes to address with ADS-B adoption are systemic, they require the participation of individual groups. As a result, the FAA should be conscious of framing prospective benefits in terms of individual interests.

Key observation #5: Individual impacts illicit a much stronger response than system level ones

Further, Figure 9 reveals that there is a disagreement between system users (i.e. airlines, GA, and military) and system operators (ATC, pilots) regarding what is important. Not surprisingly, for the system users, the focus is financial, while the operators emphasize performance. This reflects their relative objectives as well as how the mechanics of ADS-B adoption will affect them. Where system users will be asked to front an initial investment but have not yet been confronted by prohibitive performance constraints, the system operators (excluding administrators) will not pay anything for the upgrade but deal with performance constraints on a daily basis. Although users and operators do not align in terms of what they emphasize, it is reassuring to note that their interests are not conflicting. They identified most of the same concerns, but articulated opposite emphasis. These differences are certainly reconcilably.

It is interesting to note that manufacturers align with system users; for them, corporate success is determined largely by customer satisfaction (i.e. the users). So far, in the NAS public perception has not had a significant impact with respect to ADS-B. While people complain extensively about delays, the frustration is currently focused on airport security, rather than in-flight issues. Lastly, as might be expected, the FAA aligns almost exactly with the system needs. It, after all is expected to represent the interests of the system.

4.3 Uncertainty

Uncertainty associated with ADS-B adoption in the NAS is significant for many of the stakeholders. Opinions are fairly well formed about both the current state of the system, and a system in which ADS-B has been fully implemented. However, the implications of mixed-equipage during the transition are not well understood. The concept of "critical-mass" has been used extensively. Loosely, the phrase refers to that point when a sufficiently large portion of the air traffic in a given region has equipped in order for the system to experience the benefits of ADS-B. Although this definition is admittedly vague, (a quantitative definition is the subject of current research) it is useful in defining phases of adoption in a functional sense and will be used as such.

In the stakeholder discussion above, two main sources of uncertainty were stressed. First, whether the FAA will follow through with its long-term plan of ADS-B adoption and second, whether the proposed benefits of ADS-B adoption will be realized and if so, when; money now, is better than money later. The timely benefit uncertainty is complicated and requires precisely the understanding of critical mass that is currently unavailable. As a result, it will not be addressed here, except to say that the FAA should recognize this barrier and shape incentives with the intent to minimize benefit postponement.

The uncertainty associated with FAA commitment is fundamentally a question of perception. The FAA issuing long-term plans, keeping to the adoption schedule and developing procedures for certification, can mitigate this uncertainty. In order to understand the significance of this uncertainty to the various stakeholders the concerns expressed in Figure 10 were examined in terms of implementation phase. Phase here does not necessarily refer to a project phase, rather the maturity of implementation within the airspace. The reference is critical mass (CM) defined above; therefore, the phases are ADS-B Out pre-CM, ADS-B Out post-CM, ADS-B In pre-CM and ADS-B In post-CM. Further, these phases are not necessarily sequential in time. They are presented this way because they roughly capture the full gambit of equipage scenarios.

Many benefits will not be fully realized until ADS-B equipage has reached critical mass. During the transitional phases, between the start of equipage to critical mass realization, benefits will increasingly come into action. Consequently, those who equip later are more likely to get benefits right away while those who equip early will have to wait before they benefit. The issues most affected by phase are the operational benefits categorized under performance in Figure 10.

Figure 10 Correlates benefit realization to the implementation phases. The results from the matrix were then related to how important each issue is to various stakeholders. As noted in the legend, a filled in triangle denotes a fully realized benefit, while outlined triangles mark partial benefits. Operational benefits in the NAS are not uniformly an increase in some quantity; in some cases, for example workload, a decrease is advantageous. To differentiate between these two types of issue, up-pointing triangles were used to denote positive impacts while down pointing represents negative impacts.

	Issues	System: ADS-B Out Pre CM	System: ADS-B Out Post CM	System: ADS-B In Pre CM	System: ADS-B In Post CM
Performance	On Time Operations	△	▲	▲	▲
	Reduced Separation/Flexible Routes	△	▲	▲	▲
	Access	Regulation Dependent			
	Safety		△	△	▲
	Workload ATC	▼	▽		
	Workload Pilots			▽	▼
	Technical Implementation	Regulation Dependent			
	Environmental Impacts		△	△	△

△ Positive impacts starting to be realized
▲ Positive impacts realized
▽ Negative impacts partially in effect
▼ Negative impacts in effect

Figure 10 – Phased Dependeance of Performance Issues

The matrix analysis shows that most benefits are not realized until ADS-B Out post-CM.

- On time operations and reduced separation benefits will not be fully realized until ADS-B Out post-CM because ADS-B equipped aircraft must still maintain currently regulated separation when other aircraft in their vicinity are not equipped.
- Access to airspace is not time dependent but the FAA has an opportunity to change regulations once ADS-B is implemented. It is unclear at this point if they will do so, and if so, when and how.
- Increased safety, as defined in chapter 4.2 will not start to be realized until post ADS-B Out critical mass equipage.
- Air Traffic Controller workload will only be affected to a limited extent by the implementation of ADS-B In, only ADS-B Out. During the transition phase Air Traffic Controller workload will inevitable increase due to mixed equipage and consequently they will be under more pressure. Post critical mass equipage air traffic controllers' workload may increase because of added airspace capacity.
- Workload on pilots will not be affected by the implementation of ADS-B Out but the implementation of ADS-B In will increase their workload. Once a cockpit is equipped with ADS-B In pilots will have more data to process because of the added information supplied by the system.

- Positive environmental impacts might be realized once aircraft can better optimize their routes because of the global positioning technology imbedded in ADS-B. Never the less this positive impact is yet to be proven and added airspace capacity might reduce this positive effect by allowing for more aircraft in the sky. Therefore the environmental impacts are shown as never being completely realized.

It is clear from Figure 10 that benefits are not uniform with respect to level of equipage. In most cases, the full extent of the positive impact is not realized until ADS-B Out has reached critical mass. This highlights the need to identify the correspondence of issues emphasized by particular stakeholders with delayed benefits. Of the performance issues, only three were stressed: access, safety, and workload.

Access, in the way it was defined in section 4.2, is primarily applicable to the Military. However, their motivations are very different from the rest of NAS users and complicated by exemptions. For these reasons, they are outside the scope of this discussion.

The stakeholders unanimously identify safety as an issue and it is the most widely emphasized of the performance issues. Yet, as can be seen in Figure 10, safety enhancements require the most advanced level of ADS-B adoption; the full benefits will not be realized until after ADS-B In has exceeded the critical level of equipage.

Key Observation #6: Safety is a powerful lever.

Workload is an issue emphasized by air traffic controllers that also affects pilots. For ATC, mixed equipage is synonymous with increased workload; until the new equipment is fully adopted, separate flight rules are required to deal with the various classes of avionics. Even post-critical mass, ATC workload may be elevated compared to current levels. While a more efficient system would reduce controller workload on a per flight basis, with an increased number of flights, the workload may be higher overall. These negative impacts last throughout the transition phase. For pilots, once a cockpit is equipped with ADS-B In, more data will need to be processed because of the added information supplied by the system.

While all stakeholders express a positive sentiment towards ADS-B adoption, many remain only guardedly optimistic. The delay of benefits inherently associated with a staged transition is the source of much of this hesitation. Some stakeholders are not convinced that their return on investment in ADS-B will be positive if the gap between costs and benefits is too wide. Although some delay is unavoidable, the FAA should recognize this concern when determining appropriate incentives.

Key Observation #7: The delay between investment and rewards is very important to the stakeholders.

5 Discussion

In the preceding sections, a set of key observations that describe the dynamics of technology transition in regional/national airspaces were identified. The observations were used to build a transition dynamics model that was applied to the ADS-B implementation in the NAS. This section delves a farther into the transition dynamics model and discusses how it can be used to guide technology transition in complex systems. As a reference, Figure 8 is repeated below.

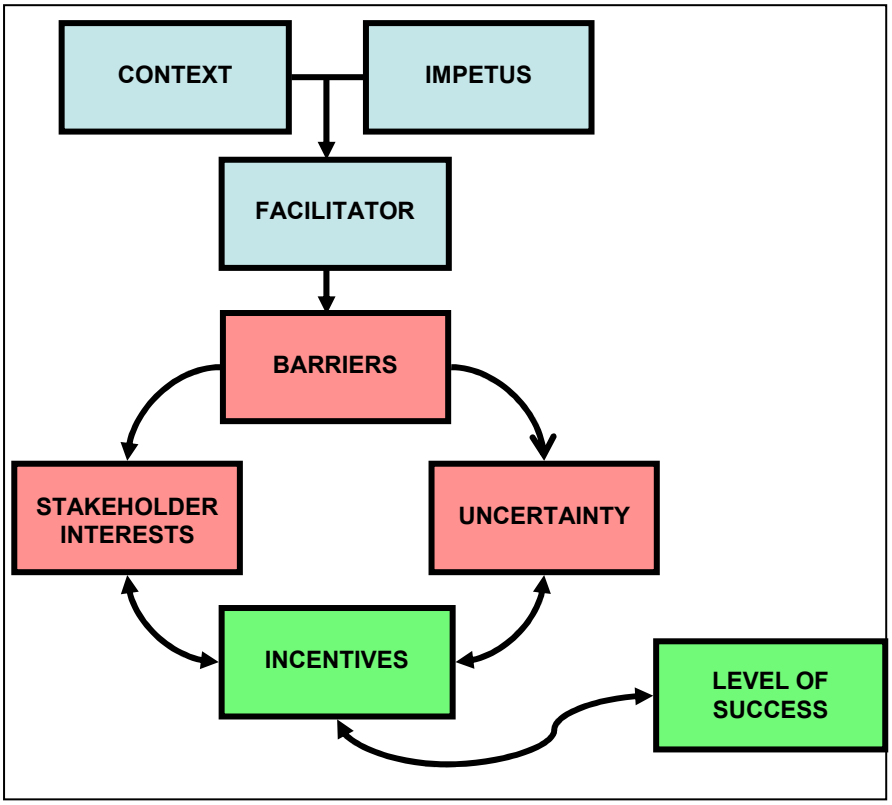

Figure 11 - Transition Dynamics Model

Step 1: The first step in informing the implementation strategy is to take stock of the health of the current system by exploring the context.

Step 2: After that the impetus must be identified. Two distinct paradigms for technology adoption in a complex system were identified; "A spark igniting a field of grass" and "straws piling up on a camel's back". The *spark* scenario is characterized by a precipitating event. Implementation proceeds rapidly and with little resistance. A *straw* scenario on the other hand, is more complicated and progresses slower even in the presence of significant built-up need. The absence of a time-critical, compelling catalyst slows down adoption and limits stakeholder buy-in. Although *sparks* only occur as an extreme case, the majority of the case studies presented herein were characterized as such. This is not surprising since the regional US cases were specifically chosen for their impetus. However, since the NAS as a whole epitomizes the *straw* scenario, the dynamics were studied in detail through a stakeholder analysis and mapping.

Step 3: The next step is to determine whether the facilitator of change is the system administrator or some other party. With the impetus being championed by a party other than the system administrator, there seems to be an increased sense of legitimacy to the need. Other stakeholders seem more willing to buy-in to a project that was instigated by "one of their own." Further, in this scenario, the impetus is more likely to affect a whole class of stakeholder (i.e., system users) making external incentives less necessary. On the other hand, if the facilitator is the administrator, it is pivotal to understand the distribution of views among the stakeholders. In terms of ease of implementation, *straw* coupled with administrator facilitator is the most difficult combination; this is the case in the NAS.

Step 4: At this point, the barriers, uncertainty, and incentives must be understood. Largely, this aspect is a question of perception – issues can be framed in many ways. *Straws* can be cast as mini-*sparks* and urgency can be emphasized as appropriate. For example, instead of the FAA projecting that the NAS will be operating at 75% of capacity by 2010, they can publicize the fact that 5 of the top 35 airports in the US are already in need of extra capacity. The ability of potential problems to motivate stakeholders to equip depends on three things; the uncertainty, magnitude, and timing associated with the particular instance of implementation.

Uncertainty in this context encompasses the fear that the FAA will renege on their commitments and the potential economic downside if the time delay between costs and benefits is too wide. These concerns stem from the fact that most benefits are not fully realized until after ADS-B Out critical mass is achieved. The UPS case study demonstrates the power of this barrier. UPS airplanes represented such a significant portion of the total Louisville traffic, that critical mass could be achieved purely through ADS-B adoption by the UPS fleet. Since this almost completely mitigated the uncertainty of delayed critical mass and subsequently benefits, equipage proceeded smoothly.

Magnitude embodies the notion that obvious or large gains provide a compelling reason to adopt. For instance, the opportunity to reduce unacceptably high accident rates in Alaska enabled the rapid certification of modified ADS-B technology. In fact, the FAA was concerned that rash decisions were being made as a result of the magnitude of the impetus. In the end, a compromise was reached whereby the most pressing safety issues could be addressed immediately. In the Gulf of Mexico, the massive economic losses resulting from weather cancellations catalyzed the HAI to take action. The HAI was so motivated that they actually incentivized the FAA. This would never have happened had the potential gains been smaller.

Timing is a measure of the proximity of imminent system failure due to the identified problem. In Australia, the impetus was clearly time-dependent. An equivalent opportunity to replace aging ground infrastructure, would not present itself again until 2020. Further, it was apparent that the increased air traffic in areas with insufficient radar coverage would exceed capacity in the near future. This demonstrates that factors, that might otherwise be considered *straws,* can produce *sparks,* if the urgency is sufficiently time critical. In Europe and the NAS, although increasing delays, cancellations, airfares, airport congestion, operator workload, and more, combine to create a significant modernization need, the projected system failure is still many years away. As a result, stakeholders are not yet motivated to take the difficult steps towards change.

Step 5: The last step is to shape incentives so that they break down the barriers to adoption. Incentives should be focused towards minimizing uncertainty and addressing issues raised by stakeholders. Once success is achieved it can be leveraged to encourage increased participation in later stages. When program goals are stated in such a way, that it is easy to recognize when they have been met, program enthusiasm has a way of snowballing. In Capstone (Alaska), the goal for the initial phase was expressed in terms of reduced accident rates. Although there was initial skepticism regarding the way the program was run, the 40% reduction of accident rates that was measured made the program hard to oppose. Once a system reaches critical mass, benefits are self-reinforcing and encouragement is no longer necessary.

6 Conclusion

The assessment of ADS-B adoption in the National Airspace System has revealed that the FAA is doing well in many areas. They are taking advantage of regional sparks by allowing segment one to be solely comprised of regional trials. In that manner they will be able to use measured successes from these trials to incentivize ADS-B adoption later on. Furthermore, they are trying to keep stakeholders informed about their plans and goals by presenting their implementation timelines and goals at Industry Days and other venues. However, more can be done to ease the transition process.

The FAA is caught in the most difficult scenario for change; there is no *spark* and it – the system administrator – is the facilitator. The NAS stakeholders were analyzed in order to identify areas for better publicity/incentives. It was determined that the strategy of regional trials is very positive. Even though there is no nation-wide *spark*, there are multiple regions, like Alaska and the Gulf, where there exist regional *sparks*. A next local *spark* may be the congested northeastern corridor; this region will exceed capacity much sooner than the system as a whole, thereby adding the time critical factor. However, it appears that the FAA intends to complete the current set of trials and then implement ADS-B on a nation-wide scale. This seems unwise. The NAS is huge. Interests are not just distributed across stakeholders, but also regionally. While regulations must eventually be nation-wide, it makes sense to structure the implementation plan according to idiosyncrasies of the system.

Recommendation #1: The FAA should leverage regional *sparks* and allow the implementation plan to follow the National Airspace System's natural structure.

Further, regional implementation *sparks* will ignite a nation-wide fire through the commercial airlines. Since they frequent multiple airspaces, they will receive benefits from one pocket of critical mass and spread them to others. This will have the effect of normalizing the benefit delays. Moreover, achieving critical mass in regional pockets will serve to prove the benefits, which to this point, remain theoretical.

Recommendation #2: The FAA should use regionally demonstrated benefits to mitigate the uncertainty associated with future rewards.

The stakeholder issues analysis revealed that individual impacts elicit a much stronger response than system level ones. Yet many of the ADS-B benefits espoused by the FAA will be experienced at the system level. This is simply a matter of understanding your audience and framing the information so that it will be best received.

Recommendation #3: The FAA should frame benefits in such a way that individual stakeholders can relate to them.

Clarity and commitment to goals is the concern most emphasized by the stakeholders despite the fact that the FAA has remained transparent about their plans and goals by presenting their implementation timelines and goals at Industry Days and other venues. The uncertainty associated with FAA commitment is fundamentally a question of perception. This uncertainty can be mitigated by the FAA continuing to issue long-term plans, keeping to the adoption schedule and developing procedures for certification.

Recommendation #4: The FAA needs allocate effort to convincing the stakeholders that they are committed to ADS-B adoption.

By paying special attention to these four areas, the FAA may see less resistance from key stakeholders in the future.

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[23] "ADS-B Upper Airspace Program (UAP)." http://www.airservicesaustralia.com/pilotcentre/projects/adsb/adsbuap.asp, Airservices Australia, 2006. This reference also comes from the official ADS-B website that AirServices Australia sponsors. It provides a review Australia's second stage of ADS-B implementation: the Upper Airspace Project.

[24] "Discussion Paper: Carriage and Use of the Automatic Dependent Surveillance Broadcast (ADS-B) Avionics," Civil Aviation Authority, Australian Government Document DP 0410AS, December 2004. This is a unique reference by the Australian Civil Aviation Authority because it discusses several mandate options for an ADS-B nationwide deployment in Australia. No other case reviewed in the TBAT report had gone as far as considering leverage strategies to encourage adoption.

[25] "The Single European Sky." http://www.eurocontrol.int/ses/public/standard_page/sk_ses.html, Eurocontrol, 2006. This is a website sponsored by EUROCONTROL describing the rationale behind the need for a "Single European Sky." t was a great resource for background information on the context of Europe's air transportation system.

[26] J. Guy, "The Air Transport Framework and Air Traffic Management Framework from a Business Perspective." http://www.sesar-consortium.aero/events2.php, 2006. This website provides a series of presentations of the members of the SESAR consortium in Europe throughout 2006. This was a good resource to help us identify Europe's shortfalls in their Air Traffic Management system.

[27] "SESAR." http://www.eurocontrol.int/sesar/public/subsite_homepage/homepage.html, Eurocontrol, 2006. This program is equivalent to NGATS in the U.S., and it was useful understand the current plans for modernization of their Air Traffic Management system in Europe.

[28] P. Bosman, "The Institutional View of ATM." http://www.sesar-consortium.aero/events2.php, 2006. This was a great source to obtain material presented at the D1 SESAR Forum in Geneva. This particular presentation was helpful to help us understand the challenges faced in Europe for transition to a Single European Sky.

[29] "Projects." http://www.aatl.net/projects.htm, Advanced Aviation Technology, Ltd., 2006. This website gives a quick overview of six of the ADS-B programs that have been tested or are currently undergoing in Europe. Although this is not a source that provides a lot of details, it was useful to get an overall sense of the main goals and accomplishments of each program.

[30] H. Malen, "NEAN Update Programme Phase 2." http://www.nup.nu/asp/fraIndex.asp, 2004. This is the official website of the NUP program in Europe. This is the best source to get familiar with the program in more detail, as it contains information regarding technical, operational, and organizational complexities regarding implementation. It has a good number of technical documents reviewing different stages of deployment.

[31] "Mediterranean Free Flight." http://www.eurocontrol.int/eec/public/standard_page/SSP_mff.html, EUROCONTROL, 2004. This is the official website of the MFF program sponsored by EUROCONTROL. It gives an overview of the context, objectives, and approach of Europe's Mediterranean Free Flight ADS-B program.

[32] "CASCADE." http://www.eurocontrol.int/cascade/public/subsite_homepage/homepage.html, EUROCONTROL, 2006. CASCADE is the most recent of ADS-B programs in Europe. This official website, sponsored by EUROCONTROL, provides a look at service description and validation activities. It also presents a business and a safety case, as well as multiple documents regarding different levels of implementation.

[33] K. Marais and A. Weigel, "Encouraging and Ensuring Successful Technology Transition in Civil Aviation," Department of Aeronautics and Astronautics, MIT, Cambridge, MA 2006. This is a study conducted at MIT's Aero/Astro Department. It was helpful at the beginning of our research to help us identify challenges in technology transition. This report was fundamental to our problem definition.

[34] R. J. Hansman, "16.72 Air Traffic Control Overview," MIT ICAT, Department of Aeronautics and Astronautics. This is a presentation from Prof. John Hansman, Director of MIT's ICAT to the Air Traffic Control class during the fall 2006. It was a good source to shape our background on some of the most important problems in air transportation.

[35] B. Nichols, "Implementation Lead, Surveillance and Broadcast Services," October 3, 2006. The presentation was an excellent source to get familiar with the FAA's plans for ADS-B adoption in the NAS.

[36] D. Hughes, "FAA Administrator Says ADS-B Going Nationwide By 2014," in *Aviation Daily*, 2006. In another affirmation of the FAA's support, this article from Aviation Daily gives more details about the FAA's plans. The article recounts the words of the FAA administrator regarding the short and long term plans for ADS-B adoption in the NAS.

[37] "Wingman: Gulf of Mexico ADS-B Demonstrates How Need Creates Action." http://www.flttechonline.com/Current/Wingman%20Gulf%20of%20Mexico%20ADS-B%20Demonstrates%20How%20Need%20Creates%20Action.htm, 2006. In preparing our stakeholder analysis, we prepared case studies to determine what the driving forces have been in previous ADS-B deployments. HAI's taking the lead in GOM showed the value of a stakeholder as facilitator.

[38] "HAI, FAA, and Gulf of Mexico Operators Sign MOA." http://www.rotor.com/Default.aspx?tabid=510&newsid905=52286&, 2006. GOM ADS-B, though not originally in the FAA's plan early on for ADS-B deployment, was enacted sooner because of active stakeholder interest. This article provides an overview of the partnership.

[39] "Healthy Alaskans 2010: Volume 1," Alaska Dept. of Health and Human Services 2002. The Alaska Department of Health and Social Services created Healthy Alaskans 2010 as a framework for creating a healthier population in Alaska. Healthy Alaskans 2010 emerged from the Alaska Public Health Improvement Process and is a state-focused

adaptation of the national planning process called Healthy People 2010, sponsored by the United States Department of Health and Human Services. This reference is from the published document and is used to report workplace accident data.

[40] "Capstone Program Frequently Asked Questions 2005." http://www.faa.gov/about/office_org/headquarters_offices/arc/programs/capstone/index.cfm?Template=dsp_faq.cfm, 2005. The answers to many questions about Capstone can be found directly in the FAA's Capstone documents. They were an excellent source for the facts behind the program.

[41] N. Monaco, "Taming the Air in Alaska's Vast Frontier," *The MITRE Digest*, 2002. This piece by MITRE gives the narrative of the Capstone program. Studying the process lent great insight to a stakeholder and enterprise model.

[42] D. Phillips, "FAA Sees Future In New Satellite Guidance System," in *Washington Post*. Washington, D.C., 2001, pp. Page A01. Another article about Capstone gives the perspectives of various stakeholders in the program. Also includes a brief discussion of future plans for Capstone and ADS-B.

[43] D. Streeter, "FAA Alaska Capstone Program," SatNav News Volume 20, 2003. SatNav News is an online periodical published by the FAA Satellite Production Teams. Donald Streeter works in the FAA, Flight Technologies and Procedures Division (AFS–400). This reference was from the June 2003 issue of SatNav News reviewing the progress made in Alaska under the Capstone program and is used to show the progressive nature of the certification process in Alaska.

[44] "Implementation Progress of Capstone Phase II, Summary for 2004," MITRE Corporation July 2005. An in-process document, this report provided a valuable example of the workings and decision-making of a complex ADS-B regional programme.

[45] B. Hilb, "Dramatically Improving Gate-to-Gate Operations." http://www.adsb.gov/pdfs2/UPS.pdf., United Parcel Service, 2006. This is a presentation by Bob Hilb, UPS lead for the company's ADS-B program. This source gave us a great insight into their ADS-B implementation strategy.

[46] E. Opidee, A. Patel, and S. Davis, "United Parcel Service." http://supernet.som.umass.edu/visuals/UPS_Final.pdf, 2003. This was a presentation useful to get us familiar with the company's context, history, priorities, and challenges.

[47] B. Hilb, "Continuous Descent Approaches: FAA COE Noise Study Projects." http://www.aiaa.org/events/aners/Presentations/ANERS-Hilb.pdf, UPS Airlines, Partner Louisville (KSDF) CDA Team, 2005. This is a presentation by Bob Hilb that includes a lot of technical detail on the research on Continuous Descent Arrivals performed by UPS in collaboration with MIT (PARTNER), NASA, Boeing, the FAA, and the Louisville Regional Airport Authority.

[48] "Performance Metrics Results to Date: April 2005." http://www.faa.gov/and/and500/docmgr/docs/T0381.pdf, Air Traffic Organization Technology Development, 2005. Fifth semi-annual report on the Air Traffic Organization (ATO) Technology Development performance metrics. This report provided information for the UPS case study.

[49] S. Foose, "Regional Airline Association," presented at FAA ADS-B industry day #2, 2006. The presentation by S. Foose was a clear and concise source for RAA's opinions regarding ADS-B implementation in the NAS.

[50] "Automatic Dependent Surveillance Broadcast (ADS-B): ATA Issue Brief," 2006. ATA's issue brief published on their web site was a good source for ATA's interests in ADS-B adoption in the NAS.

[51] R. Pool, "ADS-B Going Nationwide." Air Traffic Control Reform Newsletter. http://www.reason.org/atcreform30.shtml#feature3, 2005. The article is a short overview of ADS-B adoption in the NAS and was a source for information on equipage of new Boeing and Airbus aircraft.

[52] "History of Growth." http://www.smartskies.org/challenge.html, 2006. An overview of the challenges facing ATC today and a call for action to implement new technology to mitigate problems faced by the NAS. Used as a source for potential environmental gains from ADS-B.

[53] K. V. Hollinger, J. D. Nickum, D. T. Peed, and T. M. Stock, "A Predictive Model of User Equipage Costs for Future Air Traffic Services and Capabilities: An ADS-B Example," MITRE Corporation 2006. An extensive report detailing equipage costs for ADS-B adoption in the NAS. Used as a source for the size of the GA fleet operating in the NAS.

[54] B. Lamond, "NBAA," presented at ADS-B Industry Day, 2006. Bob Lamond is the director of air traffic services for the NBAA. Lamond presented NBAA's views on ADS-B adoption in the NAS at the FAA Industry Day.

[55] A. Cebula, "ADS-B Industry Day, The General Aviation Perspective," presented at FAA ADS-B industry day #2, 2006. A. Cebula presented on behalf of AOPA as executive vice president of government affairs. His views gave us insight into how AOPA feels about ADS-B.

[56] A. Haraldsdottir, M. S. Alcabin, J. A. Brown, and R. W. Schwab, "National Airspace System Stakeholder Needs," Boeing Commercial Airplane Group 1997. The report published by Boeing Commercial Airplane Group, although out of date with respect to stakeholder views, gave us a starting point from which to develop a framework for our stakeholder analysis.

[57] A. Smoker, "Controller's Perspective," presented at ASAS-TN2 Second Workshop, 2006. Anthony Smoker captured the ATC point of view, when he spoke at ASAS-TN2 on behalf of IFATCA.

[58] "NATCA Alaskan Region Vice President Rick Thompson Testimony before the Senate Committee on Commerce, Science, and Transportation," in *Senate Committee on Commerce, Science, and Transportation*, *United States Senate*. Washington, D.C., 2005. The contents of this transcript contained some of the key views of NATCA with respect to ADS-B.

[59] Garmin, "AT SBS Briefing," presented at FAA ADS-B industry day #2, 2006. This presentation was thought to capture Garmin's views with respect to ADS-B adoption.

[60] Rockwell, "Rockwell Collins Perspectives," presented at FAA ADS-B industry day #2, 2006. This presentation captured Rockwell Collin's perspective on ADS-B.

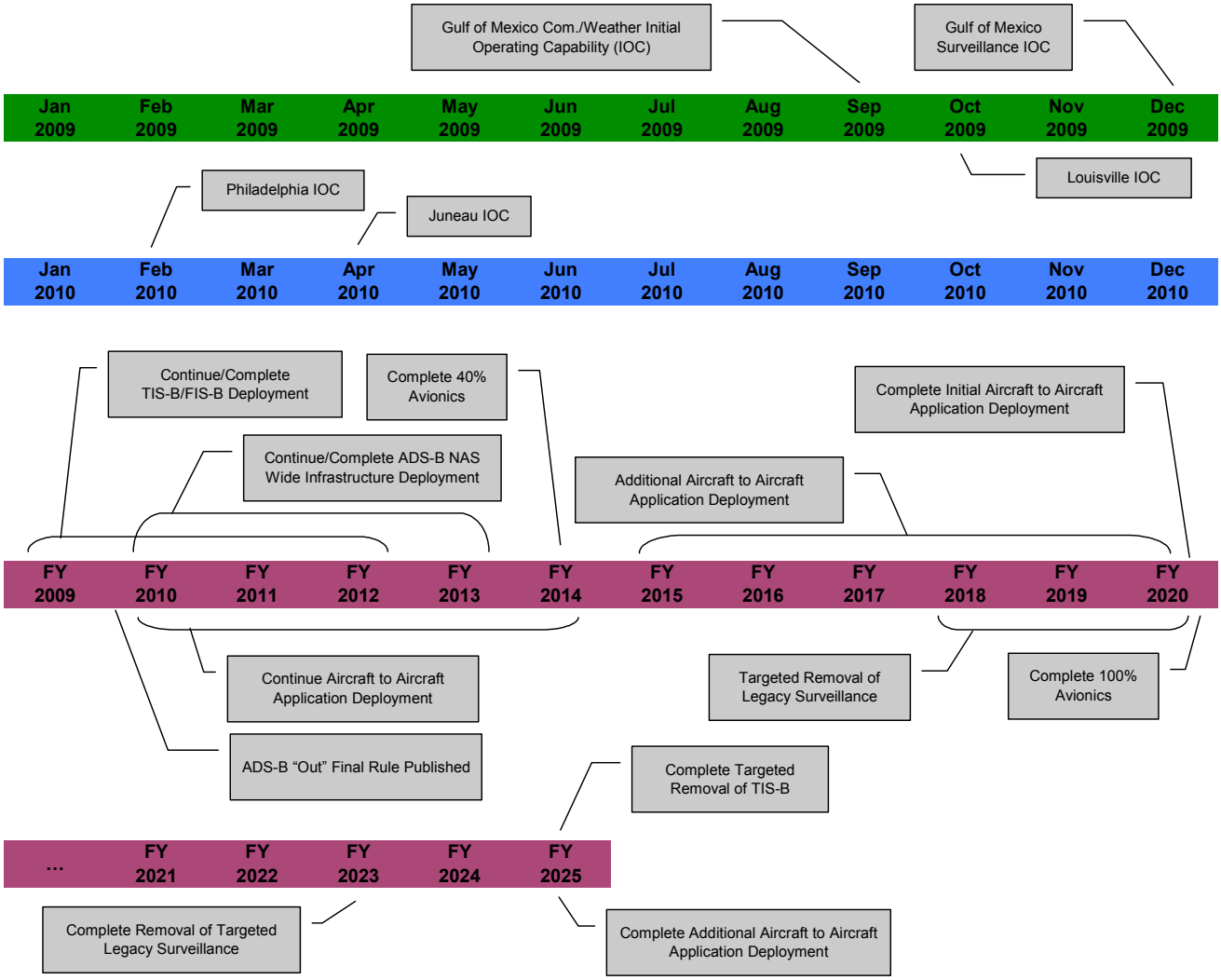
[61] T. Henderson, "ADS-B Industry Day," presented at FAA ADS-B industry day #2, 2006. Ton Henderson expressed Honeywell International Surveillance Products division's views on ADS-B adoption.

Appendix A: Acronym List

AAS	Advanced Automation System
ADS	Automatic Dependent Surveillance
ADS-B	Automatic Dependent Surveillance — Broadcast
ADS-C	Automatic Dependent surveillance — Contract
ALPA	Airline Pilots Association
AOPA	Aircraft Owners and Pilots Association
ASAS	Airborne Separation Assistance System
ATC	Air Traffic Control
ATA	Air Transport Association
ATFM	Air Traffic Flow Management
ATLAS	Australian Transition to Satellite Technology
ATM	Air Traffic Management
ATMCP	Air Traffic Management Operational Concept Panel
BA	Business Aviation
CAASD	Center for Advanced Aviation System Development (Mitre Corporation)
CASA	Civil Aviation Safety Authority
CAP	Controller Access Parameters
CDTI	Cockpit Display of Traffic Information
CFIT	Controlled Flight Into Terrain
CNS	Communications, Navigation and Surveillance
CPDLC	Controller-Pilot Data Link Communications
CTR	Control Zones
DLIC	Data Link Initiation Capability
DOD	Department of Defense
ELT	Emergency Locator Transmitter
ETA	Estimated Time of Arrival
F&CM	Flow and Capacity Management
FAA	Federal Aviation Administration
FANS	Future Air Navigation Systems
FIS-B	Flight Information Service — Broadcast
FL	Flight Level
FMS	Flight Management System
GA	General Aviation
GAMA	General Aviation Manufacturers Association
GNSS	Global Navigation Satellite System
GOM	Gulf of Mexico
GPS	Global Positioning System
IATA	International Air Transport Association
GPW	Ground Proximity Warning
HAI	Helicopter Association International
HF	High Frequency
HMI	Human-Machine Interface
IAF	Initial Approach Fix

ICAO	International Civil Aviation Organization
IFATCA	International Federation of Air Traffic Controller's Associations
IFR	Instrument Flight Rules
IMC	Instrument Meteorological Conditions
MBZ	Mandatory Broadcast Zone
MSAW	Minimum Safe Altitude Warning
MTCD	Medium Term Conflict Detection
MTOW	Maximum Takeoff Weight
NAS	National Airspace System
NATCA	National Air Traffic Controllers Association
NAVAID	Navigational Aid
NBAA	National Business Aviation Association
NGATS	Next Generation Air Transportation System
NM	Nautical Miles
NTSB	National Transportation Safety Board
OPLINKP	Operational Data Link Panel
PSR	Primary Surveillance Radar
RAA	Regional Airline Association
R&D	Research & Development
RTCA	Radio Technical Commission for Aeronautics
SAR	Search and Rescue
SARPs	Standards and Recommended Practices
SESAR	Single European Sky ATM Research Program
SMC	Surface Movement Control
SSR	Secondary Surveillance Radar
STCA	Short Term Conflict Alert
TIS-B	Traffic Information Service — Broadcast
TN	Telecommunications Network
UAP	Upper Airspace Project (Australia)
UAV	Unmanned Aerial Vehicle
VFR	Visual flight rules
VHF	Very High Frequency
VMC	Visual Meteorological Conditions

Appendix B: FAA ADS-B Implementation Timeline



Appendix C: Committee Charge

The goal of this study is to identify the dynamics of technology transition in a complex system so that they may be applied to the particular case of ADS-B adoption in the NAS. In order to accomplish this, the committee will select mature cases of ADS-B implementation from around the world, review, compare and generalize lessons from them. These lessons will then be applied to an assessment of the FAA ADS-B implementation strategy for the NAS.

Specific goals include:

1. Brief survey of ADS-B technology. (background level of detail)
    a. Look at current surveillance system.
    b. Look at capabilities of proposed technology.

2. Examine cases of ADS-B implementation strategies being implemented around the world
    a. Identify similarities in overall strategies
    b. Identify incentives and barriers and how they were overcome

3. Perform detailed stakeholder analysis within the NAS