# System Transition:
# Dynamics of Change in the US Air Transportation System

by

**Aleksandra L. Mozdzanowska**

*S.B., Aeronautics & Astronautics, Massachusetts Institute of Technology, 2002*
*S.B., Literature, Massachusetts Institute of Technology, 2002*
*S.M., Aeronautics & Astronautics, Massachusetts Institute of Technology, 2004*

Submitted to the Engineering Systems Divisions
in partial fulfillment of the requirements for the degree of

Doctor of Philosophy in Technology, Management, and Policy
at the
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

June 2008





Author ..........................................................................................
Aleksandra Mozdzanowska
Engineering Systems Division
May 2008

Certified by ..........................................................................................
R. John Hansman
Professor of Aeronautics and Astronautics and Engineering Systems
Thesis Supervisor

Certified by ..........................................................................................
Kenneth A. Oye
Professor of Political Science and Engineering Systems
Thesis Committee Member

Certified by ..........................................................................................
Joseph Coughlin
Director, Age Lab and New England UTC
Thesis Committee Member

Accepted by ..........................................................................................
Richard Larson
Professor of Engineering Systems and Civil and Environmental Engineering
Chair, Engineering Systems Division Education Committee

# System Transition: Dynamics of Change in the US Air Transportation System

by

Aleksandra Mozdzanowska

Submitted to the Engineering Systems Division
in May 2008, in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy in Technology, Management, and Policy

## Abstract

The US Air Transportation System is currently facing a number of challenges including an increasing demand for travel and growing environmental requirements. In order to successfully meet future needs, the system will need to transition from its current state using a combination of technology, infrastructure, procedure, and policy changes. However, the complexities of the air transportation system make implementing changes a challenge. In particular, the multi-stakeholder nature of the system poses a significant barrier to transition.

Historically, many changes in the air transportation system were driven by safety concerns and implemented following accidents which provided the momentum to overcome transition barriers. As a result of past changes, the system has become increasingly safe resulting in the emergence of new drivers for change. Security has emerged as a driver following the terrorist attacks of 9/11/2001 in the US and a number of system changes have since been implemented. Currently, capacity is one of the largest drivers of change. Addressing capacity issues requires solutions that can be accepted by stakeholders, and pass the necessary certification and approval requirements for implementation. The contribution of aviation to global greenhouse gas emissions is also becoming a significant driver for change in the system. The goal of this work is to understand how the air transportation system changes in response to safety, security, capacity, and environmental drivers for transition.

In order to understand the dynamics of transition, historical cases of system change were studied. Twenty seven such cases have been analyzed to construct a feedback process model of transition and to explore specific change dynamics observed. These dynamics include: understanding the role of crisis events as catalyst for change; the effect that timing of solution development has on the overall time constant for change; the role that stakeholder objectives play in the transition process, and the use of approval and certification processes to stall or block change.

Understanding the process of change in the US Air Transportation System can inform future changes in aviation as well as in other systems with similar properties.

Thesis Supervisor: R. John Hansman
Title: Professor or Aeronautics and Astronautics and Engineering Systems

Thesis Committee Member: Kenneth A. Oye
Title: Associate Professor of Political Science and Engineering Systems

Thesis Committee Member: Joseph Coughlin
Title: Director, Age Lab and New England UTC

# Acknowledgments

This work was supported by the FAA under the Joint University Program (JUP) [FAA95-G-017] and the National Center of Excellence for Aviation Operations Research (NEXTOR) [DTFA01-C-00030]. Additional funding was provided by the MIT's Program on Emerging Technologies sponsored by the NSF Integrative Graduate Education and Research Traineeship (IGERT) program.

This thesis would not have been possible without the constant support and encouragement from my teachers, colleagues, friends and family. Professor R. John Hansman has been my advisor since my undergraduate years at MIT and has always had faith in my potential and ability and encouraged and pushed me to always do my best. Over the years, he has helped me develop and revise my research and improve its presentation, sharing his knowledge and experience of the aviation industry and utilizing his amazing ability to see the underlying issues of any problem. My other committee members, Professor Ken Oye and Joe Coughlin, have provided continued support and valuable insights and advice both research related and otherwise.

Professor Annalisa Weigel has been an amazing source of friendly advice and support for both research and non research related issues.

It is a pleasure to have met Professor Karen Marais while in graduate school: with insightful advice and witty humor, she continuously encouraged me and reminded me that graduation is possible. In addition to being a wonderful friend, Karen has been a collaborator in research.

The members of the International Center for Air Transportation at MIT and the occupants of 17-110, especially Philippe Bonnefoy, Masha Ishutkina, and Roland Weibel made coming to work each day a pleasure. They have become like a second family, providing research support, emotional support, lots of laughter, and yummy chocolate. I could not imagine going through graduate school without them.

The support of my family and friends, and their reminders that there is more to life than writing a thesis, helped make my life during graduate school fulfilling and exciting. My husband, Emil Sit, has been a constant source of love and support and has brought immeasurable joy to my life. In addition to supporting me through my studies, he has spend time traveling the world with me and picking up new hobbies and activities. My parents have always encouraged me to do my best and continue finding new things to learn and explore. Their frequent visits have brought energy, excitement, and fun to our house. Last, but definitely not least, I would also like to thank my yoga friends and community, especially Magi Pierce and David Vendetti, for keeping me sane, grounded, and stress free.

# Contents

# List of Figures

# List of Tables

# Chapter 1

# Introduction

## 1.1 The Air Transportation System

The US Air Transportation System is a complex, adaptive, socio-technical system that provides domestic and international flight services for both passengers and cargo. In 2004, the Air Transportation System handled over 70 thousand flights and 146 billion pounds of cargo per day [18]. These operations are enabled by a large infrastructure, numerous stakeholders, and a policy framework. Some of the major components and stakeholders of the system are shown in Table 1-1.

| | |
|---|---|
| Infrastructure | Airports<br>Control towers, control centers<br>Communication, navigation, surveillance equipment |
| Stakeholders | Transportation providers<br>Equipment providers<br>Support service providers<br>Government<br>Public<br>Media |
| Policy Framework | Regulations<br>Procedures |

Table 1-1: Air Transportation System Components

Since its inception in the 1930s, the Air Transportation System has grown continuously and evolved from a luxury and hobby to become an important and necessary part of our economy and lives. Air transportation influences how we conduct business, run companies, visit loved ones, and go on vacation. A study conducted by NASA and the FAA concluded that the air transportation industry contributes about \$80–90 billion a year to the national economy (about 1% of the US GDP) and employs about 800,000 people [19]. As a result, the health of the Air Transportation System and the national economy is highly interdependent. This interdependance can be seen in Figure 1-1 which shows that the Gross Domestic Product (GDP) and the demand for air transportation have been closely coupled for the past 50 years.

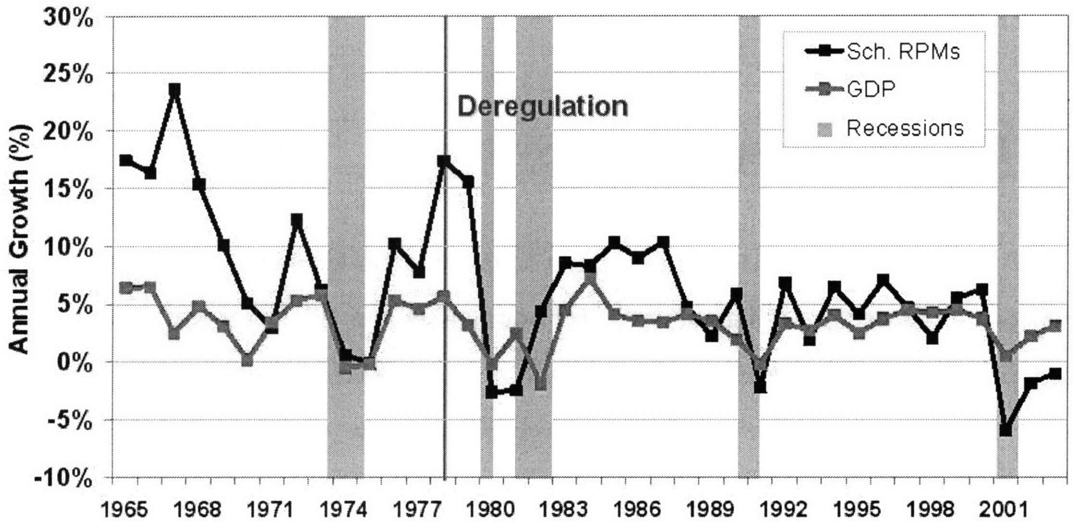


Figure 1-1: Annual percentage change in GDP and scheduled domestic revenue traffic, 1954–2000 with economic recessions [1]. Figure courtesy of R. John Hansman.

Figure 1-2 shows the interaction between the Air Transportation System and the economy, which leads to the interdependence shown above. The transportation system takes as input the demand for travel and movement of goods, and supplies services to meet these demands. The ability of the system to meet these demands depends on the development of capabilities in the transportation infrastructure as well as the financial status of the transportation providers (airlines) and their ability to acquire appropriate aircraft. Thus, while the air transportation needs the economy to supply demand (and hence revenue) in order to continue operating and growing, a healthy Air Transportation System is also vital for maintaining economic growth and competing in the global market.

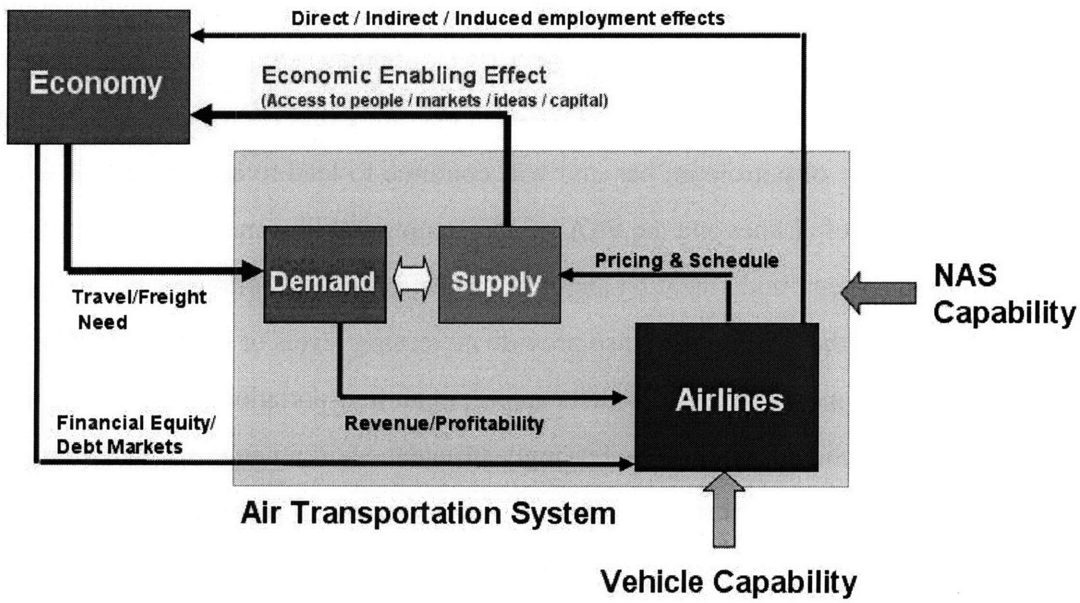


Figure 1-2: Schematic Diagram of Connection between Air Transportation and the Economy [1]. Figure courtesy of R. John Hansman.

In order to continue functioning and providing benefits, the Air Transportation System has to transition to meet changing conditions. Transition is defined as the process of change in a system in response to existing or expected changes in system conditions.

## 1.2 Current Need for System Transition

Today the US Air Transportation System is facing emerging system requirements, growing demand, and the erosion of system components. In order to address these issues and continue meeting needs the system will need to transition.

Demand for passenger and cargo travel has been growing since the creation of the system. Currently the growth of demand is out pacing the available system capacity, particularly airport resources, causing delays and disruptions. However, expanding to meet demand may prove to be more difficult in the future as airports in high-demand areas are already near the limits of currently available resources, and new technologies face barriers to implementation.

The system must also continue to incorporate new technology and respond to changing requirements. Technologies like micro-jets and unmanned autonomous vehicles will share airspace with existing aircraft but have dramatically different operating procedures and requirements. An eventual shortage of petroleum has and will continue to lead to increased fuel prices. Financial difficulties of airlines and the FAA are threatening stability and raising the question of who will fund system modernization and transition efforts [20]. Following the attacks of September 11, 2001 the system must also provide increasing levels of security. In addition, citizens have become more concerned with the impact of air transportation on the environment, requiring that new technologies meet increasingly stringent environmental standards and that procedures to mitigate environmental impacts be developed and implemented.

In addition to planning for future requirements, the current operations of the system need to be maintained. This requires the replacement and updating of infrastructure such as radar, as well as handling the impending controller shortage due to retirement.

These problems need to be addressed while maintaining operations and complying with public expectations. This means the system must continue providing mobility while remaining safe, affordable, and efficient.

While the list of potential issues driving the need for Air Transportation System change is long a few transition drivers stand out. Specifically, **safety, security, capacity, and environmental drivers** for system change were chosen for study as part of this thesis. Safety drivers for change warrant detailed investigation because of the dominant role they have played in past system transition. Safety has been one of the most important and enduring goals of the Air Transportation System. Increasing the security of the system has become an important transition driver following the attacks of 9/11/2001. Capacity is currently a key issue driving the need and plans for modernization and transition of the system. Finally, environmental drivers are foreseen as the future key driver or requirement for the system. These four drivers of system transition will be further explored throughout this thesis.

### 1.2.1 Safety Concerns as Drivers of System Change

Safety has historically been one of the main drivers of change in the Air Transportation System. The importance of increasing system safety was recognized early in the system's history. Initial regulations of air transport included required licensing for pilots, aircraft, and mechanics in order to ensure that both the equipment and pilot were safe and flight worthy. As the system evolved changes such as the addition of air traffic control, radar, collision avoidance systems, weather avoidance systems, the formation of the National Transportation Safety Board (NTSB), and others were added to increase safety and limit aircraft accidents. Many of these changes included new technologies as well as new regulations and operating procedures that together have shaped how the current Air Transportation System is structured and operated.

Due to past successes at addressing safety concerns, the safety of the Air Transportation System has increased significantly since its inception. Figure 1-3 shows the trend in accidents between 1959 and 2005. It can be seen that the frequency of accidents both in the US and worldwide has decreased significantly making air transportation one of the safest ways to travel. Because of the significant improvements in system safety, safety has become a less powerful driver of system change and instead other drivers have emerged. However, this does not mean that safety will no longer be important. Safety will continue to play a major role in the system but rather than driving change it will become a requirement for other changes to not compromise system safety. In addition, safety cases can be used to understand how change in the system occurs and what the pattern of change will be for emerging change drivers.

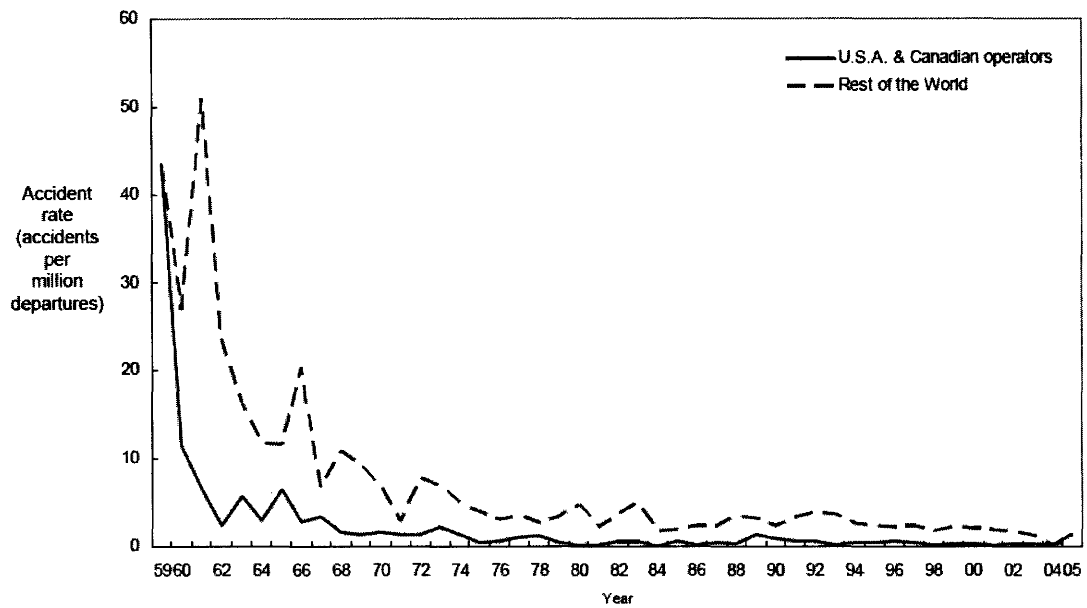


Figure 1-3: Fatal or hull loss accidents of the worldwide commercial jet fleet (1959–2005) [2]

### 1.2.2 Security Concerns as Drivers of System Change

Following the terrorist attacks that occurred in the US on September 11, 2001 the importance of aviation security increased significantly. Previous security breaches, such as hijackings, resulted in system changes; however, the unprecedented death toll caused by the use of aircraft as weapons resulted in tremendous media coverage, public and government awareness, and pressure for response. Rapid changes in national as well as aviation security were implemented following the attacks and have continued. In aviation, creating a more secure system has become an important driver of system change.

### 1.2.3 Capacity Constraints as Drivers of System Change

Among emerging drivers of system transition capacity constraints have become a key issue driving the need to modernize the US Air Transportation System. The current crisis comes primarily from the continued increase in demand for air travel, as shown in Figure 1-4, and the limited runway space at major airports. Figure 1-4 shows the growth in revenue passenger miles, which represents growth of passenger travel, and freight ton miles, which represents the growth in aviation cargo. It can be seen that the system has been experiencing an almost continuous growth in demand since the 1970s. The result of growing demand and limited capacity are increasing delays, shown in Figure 1-5. The figure shows both monthly delays and a moving average. The moving average shows that delays peaked during the summer of 2001, but decreased following the attacks of 9/11 when demand for air travel and as a result the number of operations were significantly decreased. However, currently traffic has returned and surpassed the 2001 levels bringing with it a return of delays. The figure also shows the volatility in delays between summer and winter months. Such volatility indicates that the system is reaching its capacity limits creating unstable delay behavior.

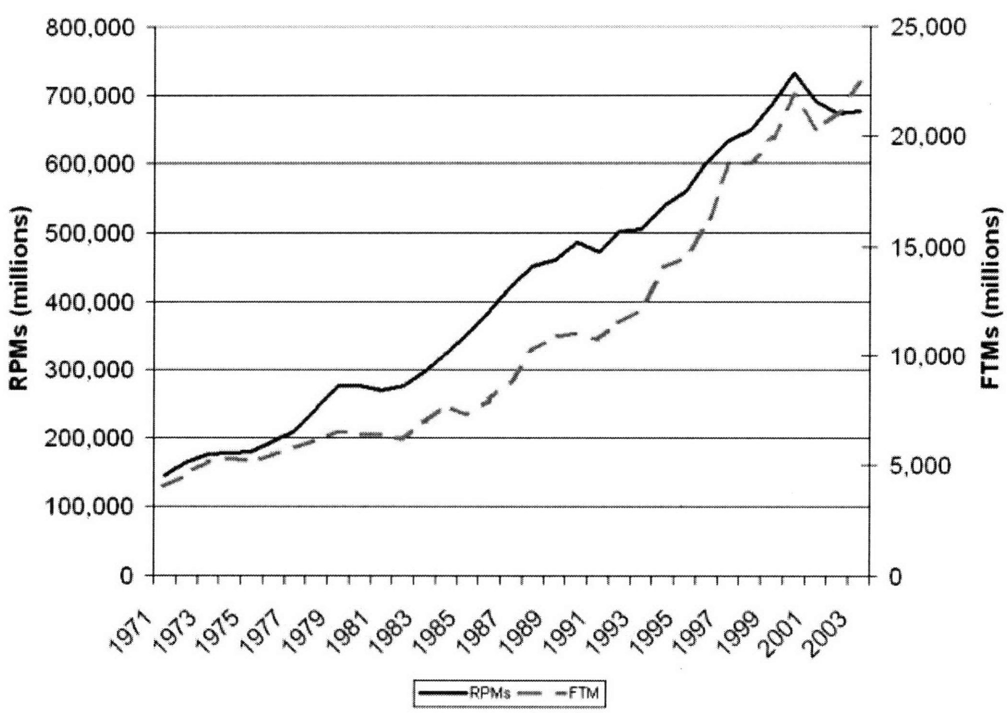


Figure 1-4: Growth of Demand for Air Travel in the US between 1970 and 2005 [3].

Expected future demand for air travel suggests that the problem of delays will continue to worsen as traffic is expected to triple in the next 50 years [21]. Because traffic is not evenly distributed over the US, as shown in Figure 1-6, capacity constraints and the resulting delays

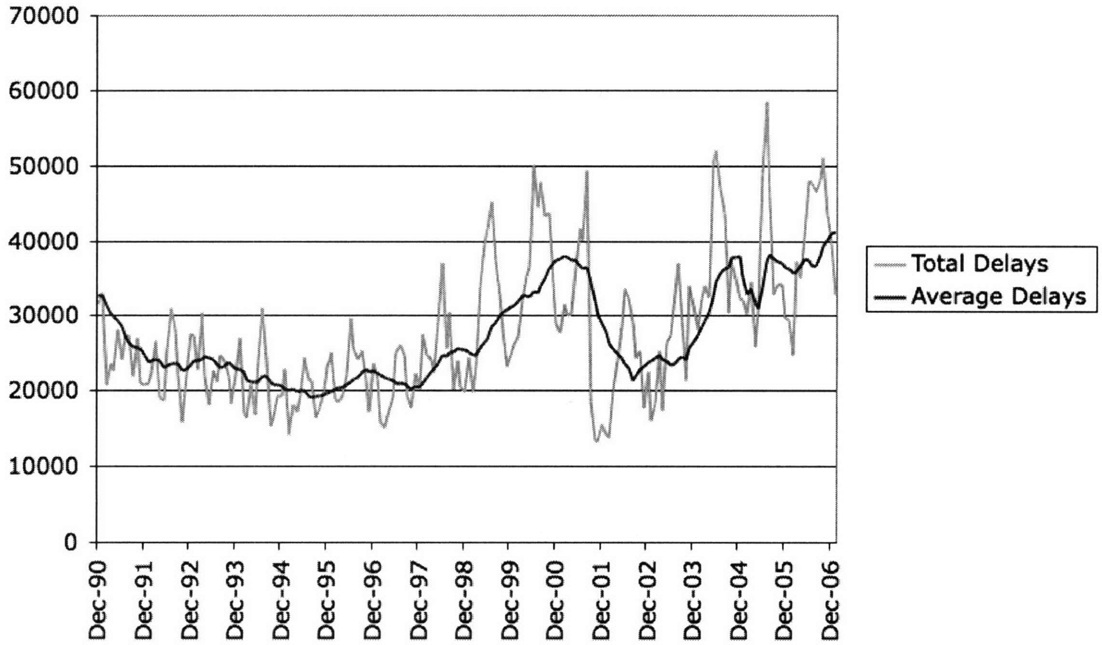


Figure 1-5: Growth of Delays in the US between 1995 and 2006 [4]

manifest primarily at busy airports during peak times. Figure 1-6 shows the density of flights in the US over a 24 hour time period. Delays at key airports, such as Newark International (EWR), or any of the other 70 airports that handle 90% of all flights [4], are a significant disruption to passengers and a financial burden to airlines. In addition, the cascading nature of delays can greatly amplify the effects of a disturbance at an airport—because aircraft are re-used for subsequent flights, the delay of one flight can delay all other flights involving that aircraft and the resources (e.g., gates) that it uses. For example, Figure 1-7 shows the effect that delays at Chicago O'Hare (ORD) had on the entire system in 2003. An approximately 8,000 minute increase in cumulative monthly delays at ORD, contributed to a 15,000 minute increase in national delays. As demand for air transportation outstrips the available capacity, delays can disrupt or cripple operations, and if severe could have a negative impact on the US economy [22].

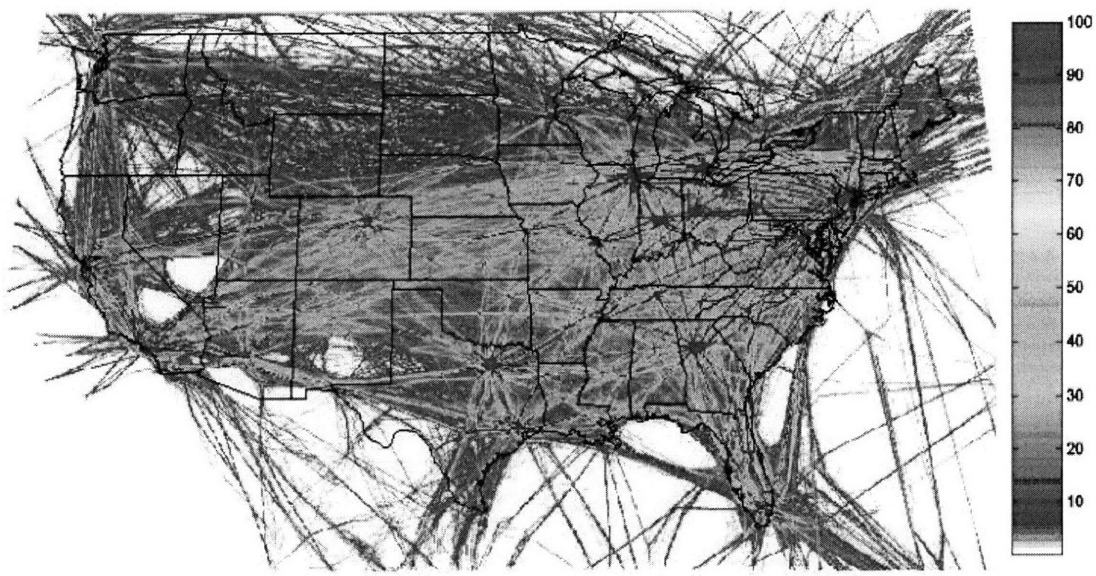


Figure 1-6: Density Map of Flights over the US (24 Hours of Traffic in January 2004) [5]

### 1.2.4 Environmental Concerns as Drivers of System Change

**Emissions** Global warning and green house gas emissions, in particular $CO_2$, are poised to become a significant driver of the need for future change in the US Air Transportation System.

Currently greenhouse emissions by aircraft account for about 3% of total greenhouse gas emissions in the country. As shown in Figure 1-8, the emissions by aircraft have decreased steadily as technology and the efficiency of operations have improved [7]. However, the growth in aviation has outpaced improvements and overall emissions are growing and expected to continue doing so as the number of operations continues to increase. Estimates suggest that these emissions will grow by 60% by 2025 [7].

The understanding of greenhouse gases and their connection to the global climate has been increasing creating consensus that these gases are directed responsible for the change in global climate. As awareness and urgency grow the pressure to reduce greenhouse gas emission is growing as well. In aviation, this pressure has been focused on $CO_2$ emissions produced by aircraft. As demand continues growing, projected increases in aircraft emissions will

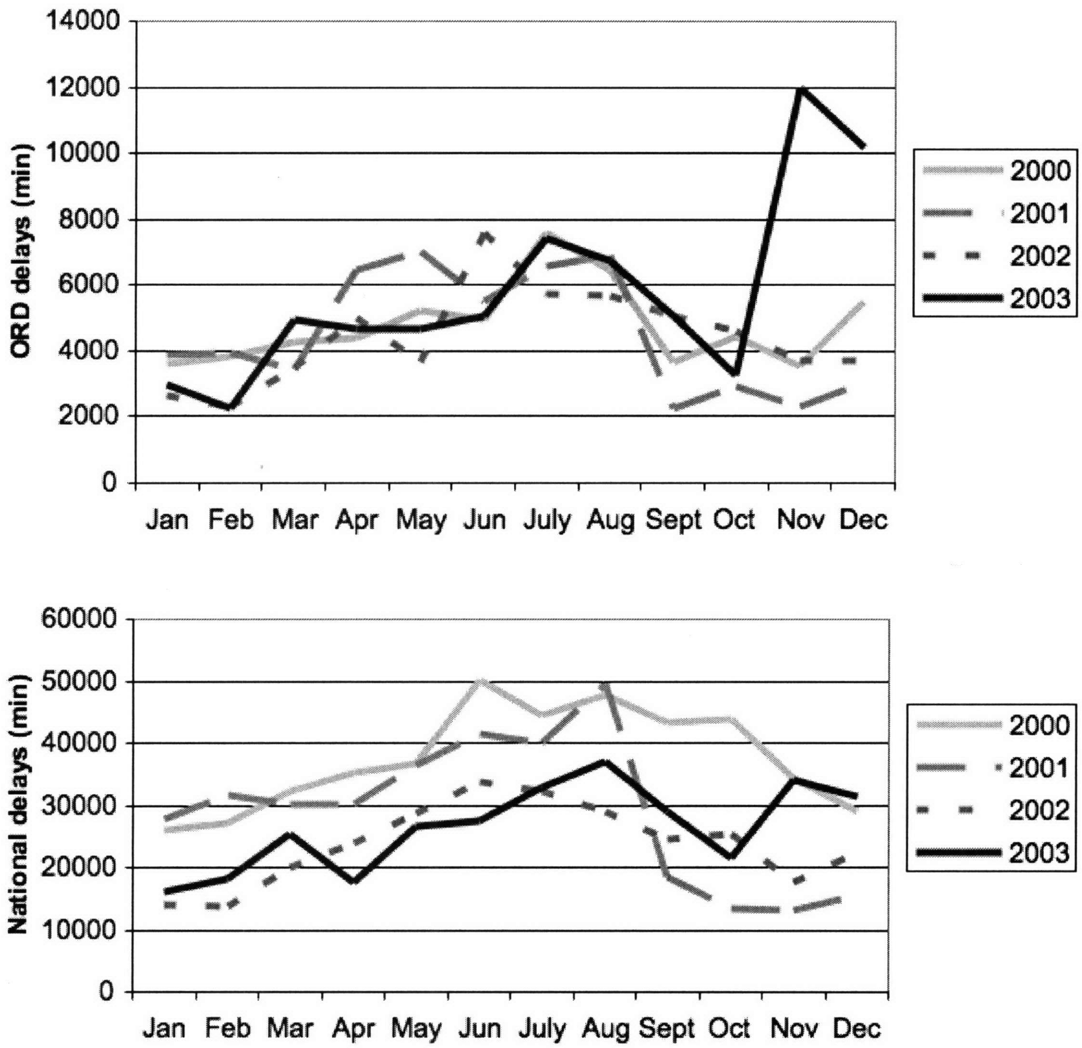


Figure 1-7: Effect of Delays at Chicago O'Hare in 2003 on National Delays [6]

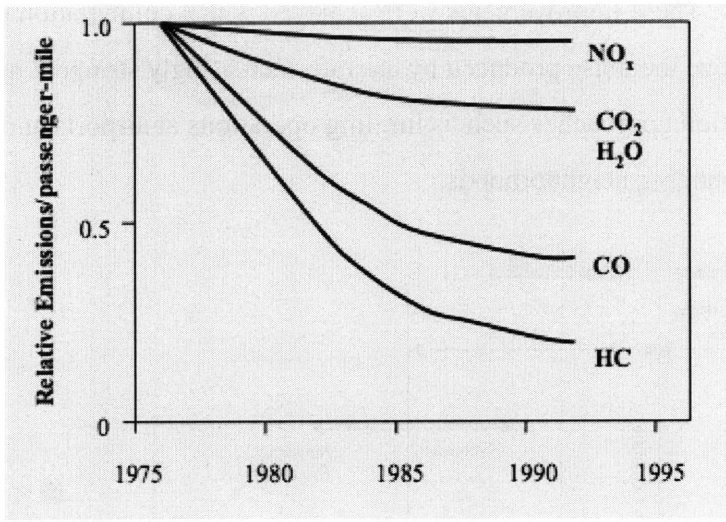


Figure 1-8: Relative Aircraft Emissions per Passenger-Mile [7]

clash with the need to need to reduce greenhouse gases. Pressure is already growing in Congress to address the general issue of climate change and the Lieberman Warner bill, proposed in 2007, proposes a cap and trade market mechanism to limit emissions from major industries including aviation. Europe is also putting pressure on the airline industry to reduce their carbon contribution by including air transportation in the European Union Emissions Trading Scheme, a cap and trade program for emissions, starting in 2010 [23]. The EU also wants to incorporate the international community into their plan and proposed a plan to The International Civil Aviation Organization (ICAO) for incorporating foreign carriers into the program [23]. It can be expected that pressure will continue to mount.

**Noise** In addition to emissions, noise is also also classified as an environmental issue. Noise concerns are most often raised by communities surrounding airports where people hear departing and arriving aircraft. Such complaints have played a significant role in limiting and stalling airport expansion projects. As a result, a number of actions have been taken to reduce noise impacts.

Figure 1-9 shows the trend over time in the number of people exposed to significant noise due to aircraft operations. As can be seen the number of people has declined sharply even while traffic levels grew. These improvements were achieved with a combination of technological solutions to improve the noise produced by aircraft, increasingly stringent noise regulations, as well as mitigation approaches such as limiting operations at airports and soundproofing buildings in surrounding neighborhoods.

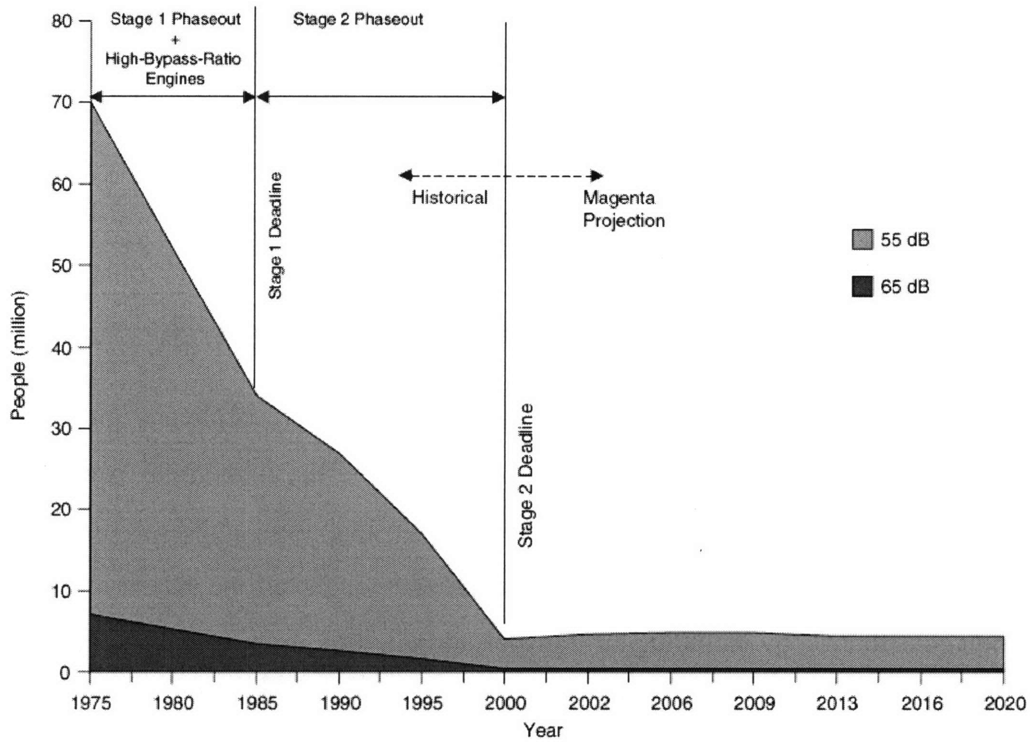


Figure 1-9: Estimated Trends in the Number of People Affected by Aircraft Noise in the US [8]

Although the number of people exposed to significant levels of noise has decreased the outcry against noise by local communities has not. In fact studies have shown that it is becoming increasingly difficult to expand airport infrastructure and opposition to increased noise is one of the primary reasons [24]. While noise is not expected to be a primary driver of change within the Air Transportation System, it is a significant barrier to increasing capacity and accommodating more demand within the system. As a result, noise is included in this thesis not as a transition driver, but as a relevant issue to associated with capacity drivers for change.

## 1.3 Past Efforts of System Modernization

The problems driving the need for system transition are recognized among the aviation community. The FAA has a number of program planned in the Operational Evaluation Plan (OEP) in order to modernize the system [25]. In addition, the Joint Program Development Office (JPDO) has developed the NextGen Plan (formerly NGATS) which outlines the goals for changing the current operating paradigm of the system [21]. However, recognizing the need does not guarantee successful system transition and many past attempts to modernize the system have failed.

Past failures and delays occurred because system transition faces significant barriers. The multi stakeholder nature of the system means that many parties have to come together to make a system change possible. However, these stakeholders often have competing objectives. In addition, many of the stakeholders wield significant political power and as a result a clear and powerful leader that can override objections to changes does not always exist. Conflicting stakeholder interests can result in grid lock and revet attempted changes to the status quo. In addition, in order to change the system viable solutions must be available. However, such solutions must be certified and approved and the safety certification and approval process is difficult and not guaranteed. As a result, it may be difficult to receive approval for selected solution to be implemented. Finally, changes need to be financed, but money is limited since aviation problems compete with other, sometimes conflicting, notational objectives. Because funding is limited, decisions between investing in system operation vs. modernization must be made.

In the past, the FAA has not always successfully dealt well with barriers to change and has received sharp criticism. A number of studies of FAA practices have been done by the General Accounting Office (GAO). These studies have analyzed and criticized the FAA's modernization plans, practices of technology and equipment acquisition, the development and acquisition of software, the development and implementation of specific projects, and the FAA's relationships and dealings with industry, NASA, MITRE, and other contractors.

These studies claim that the FAA has been slow to make changes, hesitant to implement requirements that the rest of the aviation community may oppose (even if they are beneficial and necessary for the system as a whole), unable to stay committed to projects once they are started, unable to coordinate research and development projects with contractors and other institutions, and unable to solve problems even with ample warning. [20, 26]

One of the significant failures for which the FAA has been sharply criticized is the Advanced Automation System (AAS). First announced in 1983 with an estimated completion in 1996 and a cost of $2.5 billion, the goal of AAS was to upgrade all computer hardware and software used by controllers in the towers, TRACONs, and enroute. These upgrades were expected to provide increased automation possibilities to deal with predicted increases in traffic. In addition, they would allow for consolidation of 230 terminal and enroute facilities into 23 area control facilities there by reducing FAA costs. [27]

However, developing the system proved to be more technically challenging than expected and after significant time delays and cost overruns the program was canceled in 1994 [27]. At the time costs had approached $6 billion with limited realized results. The blame for the failure was placed on both the FAA and IBM, the contractor hired to develop the system, but it was the FAA that suffered a significant loss of credibility. A GAO report blamed over ambitiousness of original plan, poorly specified requirements, and poor FAA oversight for the failure. [28] Following the failure of AAS the FAA lost credibility as an organization capable of implementing system change.

Current need to modernize the system and past difficulties of doing so show a clear need for better understanding the processes by which transition in the US Air Transportation System occurs. While the FAA has been blamed for a number of past failures, the process of implementing system change is more complex and involves more stakeholders than just the FAA. As a result, understanding transition at the system level and identifying why and how difficulties and barriers arise is essential to improving understanding of system transition and providing recommendations for the improvement for planned and future system changes.

## 1.4 Objective

The goal of this research is to contribute to the understanding of the process by which transition occurs in the National Air Transportation System by utilizing a combination of policy and systems perspectives. In addition, this work seeks to identify important transition dynamics and their impact on system transition and to provide insights that may help in the planning and execution of future system transitions. In particular, such an understanding may help guide research and development efforts, investment decisions, and policy development. While this thesis focuses on the study of transition in air transportation the results can inform changes in other similar systems.

# Chapter 2

# Research Approach

This research seeks to identify and understand the key factors that impact system transition. In addition, it seeks to identify specific dynamics which occur during the transition process. In order to identify such factors and dynamics a case study approach was taken. In addition, because there is limited existing theory on system transition a grounded theory or exploratory research approach was utilized. Such work seeks to generate new theory rather than work to prove or disprove hypotheses generated on the basis of existing theories [29]. Cases of past transitions and transition efforts were used to make observations about the processes and dynamics involved in system change. A feedback framework was adopted to represent system transition and expanded to include insights from relevant literature and transition behaviors observed in case studies. The following is a list of the steps taken in the approach:

- Conducted historical survey of significant changes in air transportation in order to identify potential case studies and major system trends
- Reviewed literature relevant to system transition
- Adopted control theoretic representation of system transition
  - Represented transition as a feedback process
- Conducted case study analysis of past and pending system transitions

  - 27 case studies were conducted 7 of those in detail

- Used case studies to identify transition dynamics and refine control theoretic view of system change

- Evaluated impact of observed dynamics for current and proposed system transitions

## 2.1 Topic Exploration

Topic exploration included a survey of air transportation history as well as a literature review.

In order to become familiar with historical examples of transition in the Air Transportation System and to identify potential case studies, research on aviation history was conducted. In addition, trends in available data were investigated. These trends include traffic growth, the development of infrastructure such as airports, runways and towers, instances of accidents, trends in emissions, and others.

In addition, a literature review of topics relevant to system transition was conducted. This literature is presented in Chapter 3. Findings from literature provided information about existing understanding of system transition and its processes and were incorporated into the understanding of transition developed in this thesis.

## 2.2 Feedback Representation of System Transition

This thesis develops an understanding of transition processes based on literature and case studies of past changes in the Air Transportation System. In order to develop this understanding, ideas from policy literature and engineering systems thinking were combined to frame the agenda setting literature (as reviewed in Chapter 3) in the context of a closed feedback control loop. This section introduces the structure and major components of the feedback model framework adopted as part of this work.

### 2.2.1 Feedback Model Framework

Based on the observation that system transition is a iterative process that corrects undesired system behaviors, a feedback framework was selected to frame and understand transition processes. In this process, stakeholders, driven by problems, attempt to implement changes that bring the behavior of the system to a more desirable state. Such a response is consistent with the control theoretic idea of closed loop control. Applying this to the Air Transportation System produces a feedback model framework upon which a model of system transition can be developed. The model framework is depicted in Figure 2-1. Boxes in the diagram represent processes while arrows represent the resulting states.

In closed loop control, a controller monitors system behavior and applies feedback or corrections to system inputs in order to bring the outputs back in line with a reference desired behavior. In Figure 2-1, the National Air Transportation System (NATS) represents the system that is being controlled, or the plant. The outputs of the NATS feed into an awareness building process, analogous to measurement; in the awareness process, deviations from desired system behavior are detected. Such awareness drives the change process, which acts as the controller and determines how the deviation should be addressed. Finally, the implementation process is analogous to an actuator which enacts the decided-upon changes to fix the discrepancy between desired and measured system behavior.

The Air Transportation System is represented as a process in the model, the output of which is system behavior. These outputs are monitored as part of the awareness building process during which stakeholders develop and share an understanding and definitions of problems or opportunities present in the system and potential actions to address them. These ideas, captured in the awareness building process, are consistent with agenda setting literature [30].

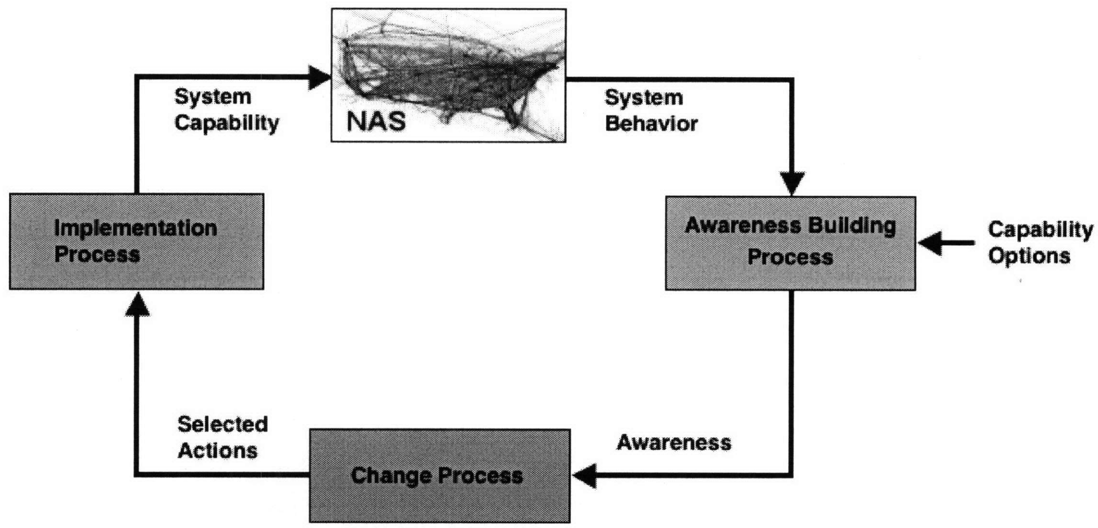


Figure 2-1: Feedback Model Framework

Once awareness of a problem or opportunity and potential actions exists, stakeholders engage in the change process. Here, stakeholders evaluate the projections for the future and develop preferences for action to be taken based on their individual objectives. In some cases stakeholders can proceed directly to the implementation process if they can take an independent action that does not effect others. However, in most cases stakeholders engage in a collective decision making process where the decision to address a problem is made and an action is selected. During this process, individual preferences can be modified as stakeholders act and interact. The change process terminates when an action to address an issue is selected, either by consensus or by the stakeholder with authoritative power. The change process captures ideas both from agenda setting literature [31], stakeholder literature presented in Chapter 3, and observed system behavior.

Once a decision is made, it proceeds through the implementation process. In this process, stakeholders carry out the necessary certification and approval processes and, if needed, refine the details of the chosen solution or action. The result of implementation is a new system capability, which brings system performance closer to a desired state.

## 2.3 Case Studies

To understand transition processes, technical, social and political concerns must be analyzed and understood. In order to investigate these aspects of transition, case studies were conducted. A case study was defined as a planned or implemented change in response to an identified problem. A total of 27 cases were reviewed and are shown in Table 2-1. Of the 27 case studies, 7 were selected as detailed cases and studied in depth. These cases are highlighted in the table. Cases studied included major problems that have been addressed and significant changes that have occurred in the US commercial Air Transportation System since 1950s. In this context, significant was defined as any change with a lasting or potentially lasting effect on the system. Chapter 4 introduces all the case studies and provides detailed background information of each detailed case.

In order to ensure that the cases covered a breadth of change dynamics, variations in the driver of transition (safety (SA), security (SC), capacity (CA), environment (EN)), the problems being addressed, the primary type of action implemented or attempted (technology, infrastructure, policy/procedure), and the outcome (implemented, pending, or failed) were explored. The drivers of change were chosen to represent the top drivers of transition identified in the system. Different problems were selected to ensure that more than one type of system problem was studied for each driver. In addition, different action types were selected to ensure a span of different changes implemented in the system. Finally, implemented, pending, and failed changes were selected for study to ensure that in attempting to understand transition a variation in possible outcomes was analyzed. In this context, implemented changes are those that that were implemented, pending changes are those that have not yet been fully carried out, and failed changes are those that were planned, but not implemented.

While all the case studies provided insights into understanding transition, 7 detailed case studies were chosen in order to highlight specific aspects of transition and were investigated in depth. In addition to meeting the above stated criteria, each detailed case needed to have moved far enough in the policy life cycle (all the processes of the model) to have an

| Case | Driver | Problem | Selected Action | Primary Action Type | Outcome |
|---|---|---|---|---|---|
| SA1 | Safety | Controlled Flight Into Terrain Accidents | Ground Proximity Warning System (GPWS), Enhanced Ground Proximity Warning System (EGPWS), Pilot training | Technology | Implemented |
| SA2 | | Microburst Accidents | Terminal Doppler Weather Radar (TDWR), Low Level Windshear Alert System (LLWAS), In-situ radar, Pilot training | Technology | Implemented |
| SA3 | | Mid-air collisions | Positive radar control, Traffic Collision Avoidance System (TCAS) | Technology | Implemented |
| SA4 | | Runway incursions | Airport Surface Detection System Model X (ASD-X), Runway status lights | Technology | Pending |
| SC1 | Security | Insufficient system security (Post Cuban Hijackings) | Criminalization of hijackings, air marshals, passenger and baggage screening | Policy/procedure | Implemented |
| SC2 | | Insufficient system security (Post 9/11) | Airspace restrictions, cockpit door reinforcing, scanning technologies | Policy/procedure | Implemented |
| CA1 | Capacity | Antiquated air traffic control system | Advanced Automation System (AAS) | Technology | Failed |
| CA2 | | En-route weather delays | Cockpit Weather Information (CWIN) | Technology | Implemented |
| CA3 | | Lack of all weather capability at airports | Microwave Landing System (MLS) | Technology | Failed |
| CA4 | | Insufficient airport capacity | Depeaking of schedules | Policy/procedure | Implemented |
| CA5 | | Insufficient airport capacity | Secondary airports | Policy/procedure | Implemented |
| CA6 | | Insufficient airport capacity at ATL | ATL Runway | Infrastructure | Implemented |
| CA7 | | Insufficient airport capacity at BOS | BOS Runway 14/32 | Infrastructure | Implemented |
| CA8 | | Insufficient airport capacity at LGA | Slot restrictions | Policy/procedure | Implemented |
| CA9 | | Insufficient airport capacity at ORD | Slot restrictions | Policy/procedure | Implemented |
| CA10 | | Insufficient airport capacity at ORD | ORD Runway expansion | Infrastructure | Pending |
| CA11 | | Insufficient en-route capacity | Reduced Vertical Separation Minima (RVSM) | Policy/procedure | Implemented |
| CA12 | | Insufficient terminal airspace at BOS | Boston RNP route | Policy/procedure | Pending |
| CA13 | | Insufficient terminal airspace at NY | NY airspace redesign | Policy/procedure | Pending |
| CA14 | | Outdated ATC surveillance system | Automatic Dependent Surveillance Broadcast (ADS-B) | Technology | Pending |
| CA15 | | Outdated controller terminals | Standard Terminal Automation Replacement System (STARS) | Technology | Implemented |
| CA16 | | Schedule disruptions due to weather | Collaborative Decision Making (CDM) | Policy/procedure | Implemented |
| CA17 | | Terminal weather delays | Integrated Terminal Weather System (ITWS) | Technology | Implemented |
| CA18 | | Unacceptable passenger treatment | Passenger bill of rights | Policy/procedure | Failed |
| EN1 | Environment | Aviation noise | Continuous descent approaches | Policy/procedure | Pending |
| EN2 | | Aviation noise | Stage 2 and Stage 3 engines | Technology | Implemented |
| EN3 | | Growing international aircraft emissions | ICAO Carbon Cap and Trade program | Policy/procedure | Failed |

Table 2-1: List of Safety (SA), Security (SC), Capacity (CA), and Environment (EN) Case Studies. Detailed Cases Highlighted in Gray.

action selected. Recent and current cases were selected in order to explore modern transition dynamics and provide relevant insight into pending and future system changes. Finally, data availably and access to experts played a role in case selection.

The model framework shown in the previous section was used to guide inquiry into detailed case studies. As a result, each case study documents the historical context of the transition, from the development and recognition of the problem through successful or failed implementation of a solution. The specifics of how the solution was developed and how implementation was attempted or conducted were included. Each case study also included the analysis of the relevant regulatory history and policy decisions as well as the positions and interactions of the various stakeholders.

Case study information was obtained from a number of sources including both qualitative and quantitative data sources. Quantitative data included information on accident statistics, traffic patterns, delays, fleet composition, and noise patterns. In addition, journal and conference papers, theses, patents, newspaper articles, General Accounting Office (GAO) reports, and transcripts of congressional hearings pertaining to specific case studies, and relevant regulations were used. Interviews were carried out to gain more insight into detailed case studies.

### 2.3.1 Interviews

Semi-structured interviews were carried out in order to inform detailed case studies. These interviews were conducted to incorporate the perspective of the various participants involved in transitions and to gain insight into the overall transition process. Individuals with direct involvement and experience in past transitions were interviewed and are listed in Table 2-2.

The interviews were approved by the MIT Committee on the Use of Humans as Experimental Subjects (COUHES), in accordance with Federal Common Rule 45 CFR 46.

| **Interview Participant** | **Place of Employment** | **Topics or Cases Discussed** | **Case #s** |
|---|---|---|---|
| Don Bateman | Honeywell | Controlled Flight Into Terrain accidents | SA1 |
| Tom Bock | Port Authority of NY and NJ | Insufficient airport capacity at LGA | CA8 |
| Carl Burleson | Federal Aviation Administration Office of Environment and Energy | Growing international aircraft emissions | EN3 |
| Vincent Capezzuto | Federal Aviation Administration | Outdated ATC Surveillance system | CA14 |
| Patty Clark | Port Authority of NY and NJ | Insufficient airport capacity at LGA | CA8 |
| James Evans | Lincoln Labs | Microburst accidents | SA2 |
| Jane Garvey | Former FAA administrator | Insufficient airport capacity at BOS<br>Controlled Flight into Terrain accidents | CA7<br>SA1 |
| Flavio Leo | Massachusetts Port Authority | Insufficient airport capacity at BOS | CA7 |
| Richard Marchi | Airports Council International | Insufficient airport capacity at BOS | CA7 |
| Lourdes Maurice | Federal Aviation Administration Office of Environment and Energy | Growing international aircraft emissions | EN3 |
| George Naccara | U.S. Department of Homeland Security | Insufficient system security (post 9/11) | SC2 |
| Paul Polski | Transportation Security Administration | Insufficient system security (post 9/11) | SC2 |
| Fred Salvucci | Former Massachusetts Secretary of Transportation | Insufficient airport capacity at BOS | CA7 |
| Dennis Treece | Massachusetts Port Authority | Insufficient system security (post 9/11) | SC2 |
| Ray Valeika | Retired Senior VP of technical operations at Delta | Controlled Flight Into Terrain accidents<br>Microburst accidents | SA1<br>SA2 |
| Mark Webber | Lincoln Labs | Microburst accidents | SA2 |
| Nancy Young | Air Transport Association of America | Growing international aircraft emissions | EN3 |

Table 2-2: Interview Participants

# Chapter 3

# Related Work and Literature Review

This thesis draws on a broad field of work as the basis for the development of a general model of transition and for understanding transition processes. The model developed in this thesis incorporates insights from the policy realm, in particular Kingdon's work on policy change and agenda setting, as well as insights from stakeholder theory, and previous efforts to understand system transition.

## 3.1 Models of Policy Change

Literature understanding and explaining policy change was used as a starting point for investigating system change. Parts of this literature were influential in the development of the transition model presented in this thesis.

### 3.1.1 Rational Choice

The rational choice model of policy and decision making assumes that problems are solved in a series of steps. First the goal and objectives that the policy needs to address are identified. Next the situation is assessed in terms of what resources will be needed. Options to address the problem are then identified and the costs, benefits, and likelihood of success assessed for each option. Finally the best alternative for addressing the problem is chosen and implemented. [32]

The problem with the rational choice model is that most cases of policy making do not have the information necessary to make decisions in this way. In many cases not much is known about possible solutions and even the definition of the problem may change through the policy making process. In addition, choices are often limited so decision makers have to do the best they can with what is available. Policy makers don't always care about the optimal solution to a problem, rather they are trying to satisfy constituents and look for agreement and consensus between different stakeholders. Finally, rational choice assumed that once a policy is decided on the implementation goes as planned and no revisions need to be made. In reality, as implementation proceeds problems and issues reemerge and need to continuously be addressed.

In the Air Transportation System, the rational choice model may apply during the late phase of specific programs and operations where the range of options has already been narrowed. However, most problems in air transportation do not proceed in a linear fashion from problem identification to implementation of a solution. Rather, stakeholder interests and partial information can result in significant amount of iteration. As a result, this model provides limited opportunity for understanding change in the Air Transportation System.

### 3.1.2 Incrementalism

The model of policy making sees the process as experimentation where each incremental change makes progress toward a goal. The model states that innovation is limited by constrained resources such as people, money, and technology. Lindblom [33, 34] introduced the idea of muddling though, an incremental approach to problem solving. He states that problems are so complex, and the time that the government can devote to studying and solving them so short, that small changes are made based on what information exist. Policies therefore are the result of a number of incremental suboptimal changes.

The idea of incrementalism or muddling through can provide insight into part of the process of Air Transportation System transition. It accounts for the fact that changes are often made under incomplete and uncertain information, and under a constraint of available resources. This represents an improvement over the rational choice model. One of the major flaws of the incremental model is that it assumes that policy problem definitions are selected based on the concerns of those in the legislature, interest groups, and bureaucrats (Iron triangle) [35]. This list leaves out important stakeholder such as the public and media. In addition, the model fails to account for periods of rapid change, such as the ones that occur in air transportation following an airline accident: accidents and other catastrophic events generate attention and often lead to actions.

### 3.1.3 Agenda Building

The agenda building model of policy making states that policy decisions are the product of a dynamic competition and conflict between issues and within issue areas. Policy makers are continuously choosing what problems to deal with, and innovation occurs due to trigger events that open a window of opportunity during which a problem can be fixed. Finally, conflict over issues continues from the start of the policy debate through implementation.

Research conducted by Cobb and Elder [30] provides insight into how agenda building occurs, and why and how some topics and problems get public attention and gain access to official government agenda and others don't. Cobb and Elder divide the public into 4 groups: identification groups, attention groups, the attentive public, and the general public. They discuss how a problem is identified by the identification group and is redefined and reshaped to appeal to a broader audience. If the redefinition process is successful, awareness of the problem may spread from the identification group to the attention group and further. The authors also discuss the qualities of a problem that lead to border awareness, and how likely the issue is to be placed on the official government agenda depending on how far awareness of the problem has spread.

The work done by Cobb and Elder can be supplemented by the work of Kingdon [31] who discuses agenda building in terms of policy streams. Kingdon breaks the policy making process into three processes: problems, policies, and politics. These processes are treated as independent streams, which have to cross for a policy change to occur. The first process includes mechanisms for problem recognition and how that recondition and awareness spreads. The second process includes the generation of policy proposals. These are the different approaches, proposed in the legislative branch, to solving the problem. Finally, the third process includes political events such as elections or swings in national mood and opinion. Kingdon discuss how such changes effect which problems and solutions are of interested both to the public and to the government.

Kingdon's model describes the development of policy not as one where a problem is identified and a solution found and implemented, but as one where problems are continuously being identified, and solutions continuously presented. For a change to occur, a solution needs to be matched to a problem and presented at a time when a window of opportunity for change exists. In order for this to occur, solutions must exist and be ready for implementation when a problem is defined and a window of opportunity for change exists. This is a modified version of the Garbage Can Model developed by Cohen, March, and Olsen [36].

The agenda building model is the most relevant to understanding how change occurs in the Air Transportation System. The model captures the dynamic nature of change in the system where solutions and problems are likely to continue changing and evolving as policy debates start and all the way through implementation. In addition, stakeholders are likely to define and redefine topics as they emerge during the transition process.

In addition, the agenda building model accounts both for process of slow change as well as for times when policy changes rapidly. In cases, where windows of opportunity do not open or when problems are not correctly matched with solutions little change occurs. However, in times when attention is focused on aviation, problems are identified, and solutions exist changes can be implemented rapidly. Such focus is often created by aircraft accidents. These events engage the attention of the media and public creating a window of opportunity for change. However, this window doesn't stay open for long. Newspapers will not continue to publish stories about the accident and public attention will disappear. Policy makers are also busy and their attention will soon turn to other more pressing problems. In order to take advantage of the window for change the aviation community needs to know what problem it wants to fix and what solution it would like to implement.

The literature on agenda building is very relevant to research on transition as it provides insight into the conditions that are necessary for problems to be recognized as important and eventually solved. However, these studies focus only on changes implemented by the national government, while the goal of this work is to understand change in the Air Transportation System as a whole. As a result, the agenda setting model can be build upon and combined with other ideas to understand transition in air transportation and other socio-technical systems.

## 3.2 Stakeholder Dynamics

Stakeholder dynamics play a large role in any changes that occur in large socio-technical systems. As a result, literature exploring stakeholder dynamics was investigated.

### 3.2.1 Stakeholder Relationships

The role of stakeholder relationships has been broadly studied in the context of the corporation. Work has been broken down into understanding how to identify stakeholders, determining the goals of stakeholders and then how these goals are achieved. Frooman proposes that the underlying goal of stakeholder theory is to manage "potential conflict stemming from divergent interests" [37]. A comprehensive study into the identity of stakeholders was conducted by Mitchell et al, who used urgency, legitimacy and power to characterize and distinguish stakeholders [38]. The relative amounts of these attributes is used to understand the importance of each stakeholder.

In studying how stakeholders achieve their objectives, Frooman identifies four key strategies that are used between stakeholders: direct withholding, direct usage, indirect withholding and indirect usage. He develops propositions governing when particular strategies are chosen, depending on the power relationships (e.g., resource dependency) between the stakeholders.

The ideas discussed in this body of literature apply to understanding the role that stakeholders play in system change. Who they are, how they interact, and the impact that they can have on influencing the course and outcome of a transition.

In addition to the more traditional stakeholder literature, specific work has been done on stakeholder interactions in the context of air transportation. Marais and Weigel developed a framework for analyzing cost benefit dynamics through the use of cost benefit matrices, and illustrated its application in the case of ADS-B [39]. The works points out that while a proposed system change may provide a positive overall cost benefit analysis, there is no guarantee that individual stakeholders will derive value from the transition. Some stakeholders may reap a disproportionate share of the benefits, while others may incur a disproportionate share of the costs. Stakeholders who are asked to bear a disproportionate share of costs while reaping little benefit may be expected to be reluctant or unwilling to cooperate with a technology transition effort. Ensuring a successful technology transition therefore requires looking at the cost and benefit distribution between stakeholders. The work of Marias and Weigel is used and extended in this thesis on order to understand stakeholder actions in particular cases of transition.

### 3.2.2 Lock-in

The phenomenon of lock-in refers to the case when it is difficult or impossible to make a change or update to an existing system: it is possible to decide on a change but find that it can't be implemented because of lock-in. Lock-in occurs due to high switching costs or perceived switching costs of changing the system from a current to a new state. Technical and organizational lock-in are two types that can occur. While the sources of lock-in don't necessarily deal with stakeholder dynamics, this literature is included in this section because ultimately stakeholders are the ones who object to a proposed change and take actions to prevent it. It is such actions that result in lock-in.

Technical lock-in occurs when a standard or way of operating (e.g., a de-facto standard or a "consensus standard") is well adopted and embedded in the system. Over time other changes to the system are made to be compatible with this standard further ingraining it into the structure of the system [40, 41]. If a change has to be made that is not compatible with the standard significant changes to many areas of the system would have to be made to accommodate this change resulting in high switching costs. Stakeholders can be resistant to changes involving high costs especially since they are often financially invested in the existing state of the system.

Policy lock-in comes from the resistance of individual stakeholders, bureaucracies or even whole industries to making changes to policies that they are invested in. Policies may need to be changed or updated since new information, new technologies, and new methodologies are certain to emerge as time passes; such advances may allow for better policies or may simply obsolete existing ones. Another possibility is the need to adopt new policies that will interact with old ones.

However, the existing policies are in place as a result of time and resources invested by organizations in developing policies, ensuring that they are passed, adopted, and implemented and organizations may resist further change [42]. It takes effort and time to convince others that a policy should be passed and how it should be implemented. Once the organization or bureaucracy has managed to convince the right individuals to back their ideas they do not want to repeat the process and spend resources on the same problem. Yet, adapting the policy would be seen as spending time and resources on a problem that was already tackled. Having to correct the policy after it has been implemented can be seen as failure of the organization to do the job correctly on the first attempt. As a result, making corrections can delegitimize the importance of a policy. Since the organization invested time and money in getting the policy implemented, any action that would take legitimacy away from it would clearly not be in their interest. In addition, given the limited resources and attention span of those working in government, selling the policy or idea for a second time and getting individuals to back it again will be harder than the first time.

As Stigler points out, policies also lock-in because they support or create an industrial structure [43]. As part of this process some companies and industries benefit and survive or thrive, while others die. It is in the best interest of the companies that are surviving or thriving, under the current regulatory structure, to make sure that that structure does not change. Manufacturers of an aging but entrenched technology, for example, may not want to see a policy that will effectively shut down their market. Organizations are also likely to resist changing and implementing a new or updated policy because this would require a change in operating procedures, and a reallocation of resources either within the organization or between organizations. This puts the organization at risk of having its funds diverted or having to learn new procedures for doing their work. To avoid such risks, companies engage in regulatory capture where they lobby and strive for regulation that benefits them. It is possible that a change in policies might actually make some companies better off, but those who are currently doing well will lobby for policies that help them stay in their current state. These companies are likely to form a concentrated and powerful lobbying group and as a result have more influence than those being hurt by the current regulatory structure. A change in policy would create a new regulatory environment and, since policy can be viewed as experimentation, there is uncertainty associated with what this new environment will be. As a result, the currently powerful companies would rather protect the current environment where they are doing well, than risk being one of the companies who doesn't make it under new conditions.

Literature on lock-in provided a starting point for understanding why system transition is difficult. However, for the purpose of this thesis an understanding of Air Transportation System dynamics was needed to understand where lock-in and other barriers to change occur.

## 3.3 Existing Efforts at Understanding System Change

### 3.3.1 Complex Adaptive Systems

The study of complex systems looks at large scale systems. A complex system can be defined as one where understanding of system components is not sufficient to understand the behavior of the whole. Rather, emergent system properties become evident as time passes and system components interact [44]. The idea of complex adaptive systems adds the notion that such systems are not static, but change and evolve over time. The study of complex adaptive systems combined ideas from systems thinking with ideas from evolutionary biology and Darwinism to study various dynamics observed in such systems including: self organization, coevolution, and emergence. In particular much of current studies focus on understanding the network nature of many systems and how the networks structure and topology influences adaptation over time [45]. In addition, the role that agents acting independently and with imperfect information have on system adaptation has also been the object of significant interest [46]. Both these concepts and others included in the study of complex adaptive systems are directly related to the study of system transition. However, the filed of complex adaptive systems has been mainly focused on mathematical modeling where as this thesis is based on a qualitative case study approach. As a result, general ideas from the study of complex adaptive systems can be applied, but the two approaches diverge.

captures many important ideas, but field moved into detailed mathematical modeling which was not the chosen methodology for this work because would have had to pick a much smaller subset of stuff to study.

### 3.3.2 Socio-technical System Transition

Work on transition dynamics is being conducted at the Dutch Research Institute for Transitions at the Erasmus University in the Netherlands. This work focuses mostly around environmental case studies, but also discusses transition dynamics in general terms. A paper by Rotmans and Kemp introduces the idea that transition occurs at three different levels: the micro, meso, and macro [47]. At the micro level, people make local changes as the system breaks down. At the meso level there are competing emerging ways of doing things a new way, and finally, at the macro, level one new operating paradigm emerges. While the authors claim that the model can be applied for bottom up and top down transition, it seems to represent a bottom up approach much more accurately and falls short in describing top down transitions.

Both the Rotmans and Kemp paper, as well as another by Van der Brugge [48], introduce the idea that each transition has four phases: predevelopment, take-off, breakthrough, and stabilization. These phases are represented on an S-curve where the level of change in the system is the $y$-axis and time the $x$-axis. This idea appears to be borrowed from literature on product development [49]. Van der Brugge also adds the idea that transition can have four different outcomes depending on the level of success of the transition. The possible outcomes include system breakdown, backlash, lock-in, or stabilization at a new operating paradigm.

Finally, Loorbach builds on the work of Rotmans and Kemp by adding the idea that governance occurs at three levels in the system [50]. The three levels correspond to the micro, meso, and macro levels presented by Rotmans and Kemp and are the operational level, the tactical level, and the strategic level. Loorbach states that transition processes and innovation can occur independently at each of these three levels, but unless they interact and reinforce one another a system level transition will not occur.

While this work looks at transition in large scale systems it does not capture the feedback that occurs in such systems. In addition, other dynamics not captured by this literature were observed as part of this work.

### 3.3.3 Climate Change and Adaptation

Those studying climate change have a need to predict and analyze the impacts of potential adaptations carried out by effected communities. As part of this work efforts to categorize and differentiate adaptations have been made. In this case adaptation is similar to system transition in that in studied change made.

Smit *et al* [51] provide an anatomy of adaptation by focusing on several basic questions: what is the adaptation in response to? Who or what adapts? How does adaptation occur? In answering these questions the authors develop a topology of types of adaptation emerges and they characterize a spectrum of terms used to express four key ideas: purposefulness, timing, temporal scope and spatial scope.

Purposefulness refers to the idea of planned versus unplanned or passive adaptation. In one case, a problem is identified and a response planned and implemented; in the other, adaptation occurs without the awareness of those who change. In socio-technical systems most adaptations are planned, but in nature many are autonomous. Timing refers to whether an adaptation occurs in response to a problem that can be observed or one that can only predicted. Temporal scope refers to short term versus long term adaptation, but also pertains to the difference in problems that manifest in a slow cumulative manner and those that are instantaneous. This would be the difference between the slow increase in global temperature and an aviation accident. Spatial scope distinguishes between localized and global adaptations.

Discussion of adaptive capacity or what factors make some communities or regions better able to adapt to climate change also takes place. In particular economic resources, technology, information and skills, infrastructures, institutions, and equity are listed as important factors influencing adaptive capacity [52]. While this literature refers to these qualities as being possessed by a nation or community the idea can carried over and applied to air transportation. When financial resources are available to address aviation problems they are likely to be solved more successful. Similarly the availability of skills and information as well as technology allows for an understanding of the changing conditions being faced and for the generation of solutions. Infrastructure and institutions are necessary to direct change, make decisions, and flow through on selected solutions.

While this work does not model system change it did provide a preliminary way to categorize the different types of adaptation that occur.

## 3.4 Air Transportation System Change

Some work has been one to study change specifically in the Air Transportation System. This work falls largely into three categories: plans for implementing a selected change, criticisms of plans or ongoing changes, and evaluations or assessments of implemented changes.

Plans for changes focus around describing a desired future state of the systems and the potential technologies, procedures, and other changes that can be implemented to reach this state. The notable current such plan is the Next Generation Air Transportation System (NexGen) which outlines planned changes for the system [21]. However, some work also exists in panning on how to move from the current state to the planned future states. Such work includes research on solution development, funding specific changes [53], as well as how to incetivize stakeholders to act [39, 54]. However, this work is focused on specific cases and does not create a generalized understanding of transition in the system.

The second category of existing literature deals with criticizing plans for change or ongoing changes. Much of this research is conducted by the General Accounting Office and as a result often deal with FAA programs that are under performing. The GAP has criticized the FAA's modernization plans, practices of technology and equipment acquisition, the development and acquisition of software, the development and implementation of specific projects, and the FAA's relationships and dealings with industry and other contractors [20, 26].

The third category of literature deals with conducting evaluations of implemented changes also exist. Such studies look at how actual benefits of a change compare to the predicted or expected benefits that were anticipated. A recent example includes the evaluation of Reduced Vertical Separation [55].

While most of the above mentioned literature deals with single case evaluations, The Transition Working Group (TWG), a subcommittee of the FAA's Research, Engineering and Development Advisory Committee (REDAC) conducted a study of transition in the Air Transportation System. As part of this study a number of cases were analyzed and relevant stakeholders and experts consulted. The group identified patterns of behavior that lead to transition difficulties and provided recommendations to the FAA for addressing some of these issues. The findings of the TWG working group are summarized in [56].

In addition to the above literature extensive literature on specific aspects of the Air Transportation System was used. Of particular relevance was work related to history of and trends in the system as well as literature specific to the case studies used in this thesis. This literature is included throughout the thesis and in the summaries introducing each case study.

# Chapter 4

# Case Studies

This chapter provides background information on the case studies used in this thesis. While all changes studied contributed to the work presented in this thesis, 7 case studies were selected for more in depth investigation. This chapter presents detailed background information for each of these 7 cases.

## 4.1 Overview of Case Studies

### 4.1.1 Safety Case Studies (SA)

**SA1: Controlled Flight Into Terrain** Controlled flight into terrain (CFIT) occurs when perfectly operating aircraft collide with ground or water, and was one of the most pervasive causes of accidents until corrected [10]. The solutions implemented to address this issue include the Ground Proximity Warning System (GPWS) and the Enhanced Ground Proximity Warning System (EGPWS). GPWS is a cockpit based technology that warns pilots if a crash into terrain is likely. EGPWS is similar to GPWS, but added the capability to look ahead for potential head-on collisions with terrain. Both technologies were mandated for implementation following large accidents at Dulles in 1974 and Cali Columbia in 1995 respectively [27]. In addition to GPWS and EGPWS, pilot training and an incident reporting system for pilots were both implemented in response to CFIT accidents [27].

The responses to CFIT accidents occurred rapidly and reactively in response to the awareness and pressure created by the crashes. Rapid reaction was possible in part to the existence of solutions when pressure for change manifested. Following the implementation of changes, the number of CFIT accidents was significantly decreased.

**SA2: Microburst accidents** A microburst is a category of windhear and is a rapidly evolving weather phenomenon that poses a threat to aircraft during take-off and landing. First discovered by Dr. Fujita following an accident at Kennedy airport in 1975 a number of research programs and a significant amount of time were needed before the phenomenon was well understood and solutions developed [27]. A number of solutions were deployed until the problem was sufficiently addressed. The first solution was the Low Level Windshear Alert System (LLWAS), which is a ground based technology used to detect windshear. Alone this technology was not sufficient to address the problem and in-situ radar as well as Terminal Doppler Weather Radar (TDWR) were also implemented. In-situ radar are mounted on aircraft and detect windshear aloft and TDWR are located near windshear prone airports and detect the phenomenon from the ground. No winshear accidents have occurred at airports equipped with TDWR since its installment. However, in addition to technology, pilot training played a very large role in addressing this issue since pilots have to behave counter to intuition when encountering a microburst in order to endure it safely [57]. While the research and development was ongoing, specific changes to the system were implemented reactively following accidents.

**SA3: Mid-air collisions** A mid-air collision over the Grand Canyon in 1956 resulted in a mandate for Positive Radar Control [27]. Prior to this time, pilot used visual verification of other aircraft to conduct self separation. However, an increase in traffic made such practices dangerous. This accident caused significant pressure for change and because radar already existed it could be rapidly deployed in the system. The implementation of radar has shaped how surveillance and air traffic control are carried out in the Air Transportation System to this day.

While radar control helped address the dangers of mid-air collisions it did not eliminate them entirely, particularly since traffic levels continued to increase making the skies more crowded. In 1986 a collision between a commercial and general aviation aircraft occurred near Los Angeles airport [27]. In response the Traffic Collision Avoidance System (TCAS) was mandated for commercial aircraft [27]. TCAS is an aircraft based technology that detects and warns pilots of potential midair collisions.

**SA4: Runway incursions** Runway incursions occur when aircraft collide with each other or terrain while maneuvering on the airport surface and are currently an important safety problem. The world's deadliest accident was a runway incursion and occurred in March 1977 at Tenerife, Canary Islands, resulting in the deaths of 583 passengers and crew [27]. The NTSB placed the need to address runway incursions on its most wanted list in 1990 and it has remained there since [58]. A number of steps have been taken to address this issue.

The Airport Movement Area Safety System (AMASS) provides information about possible incursions to controllers who then relay that information to pilots. However, it was found that the reaction time to inform everyone using this system is insufficient to prevent dangerous situations. The Airport Surface Detection Equipment Model X (ASDE-X) is a surface radar that provides controllers with information to better track the ground movements of aircraft. The system is currently implemented at a limited number of airports and more implementations are planned. [59] Runway status lights are another potential solution for preventing runway incursions [60]. Developed by Lincoln Labs, the system provides a green or red light, essentially a traffic light, to pilots before they attempt to cross a runway. These lights would be green when crossing a runway is safe and red otherwise. The runway status light system is being used and tested at Dallas Fort Worth airport with potential for further deployment at other locations. While no final set of solutions has been adopted to address this issue the pressure for action mounts with every event. Interestingly, while in the past accidents were often needed to spur action, in the case of incursions known near misses seem sufficient to raise awareness and increase pressure for change. As a result, this is potentially a predictive rather than reactive system change.

### 4.1.2 Security Case Studies (SC)

**SC1: Insufficient system security (Post Cuban Hijackings)** Security measures were first introduced into the Air Transportation System during the 1960s following a series of aircraft hijackings to Cuba [27]. In response to these threats Congress and the FAA worked to amend criminal laws in order to make hijacking punishable by law [27]. In addition, changes, such as employing air marshals and requiring the screening of passengers and luggage, were made. Improvements in technology have also played a role in security changes by providing better detection and scanning technologies as well data gathering and mining capabilities. These changes were made reactively in response to hijackings that acted as catalytic events.

**SC2: Insufficient system security (Post 9/11)** The hijacking of aircraft and subsequent attacks that occurred on 11 September 2001 created tremendous pressure for a response. In the aviation sector, this pressure was focused on augmenting security procedures and infrastructure to prevent similar attacks from succeeding. At a large scale, the Transportation Security Administration was created, placing a new federal emphasis on security [61]. The TSA introduced new policies and required new technologies for airports. The changes that followed 9/11 were largely reactive, targeting specific vulnerabilities demonstrated by the hijackers and subsequent plotters (such as Richard Reid, the shoe bomber in 2001, and the people behind the liquid bomb plot in 2006) [62, 63].

### 4.1.3 Capacity Case Studies (CA)

**CA1: Antiquated air traffic control system** During the 1980s the FAA undertook a major effort to modernize an antiquate air traffic control system which was resulting in inefficiencies. The program called the Advanced Automation System (AAS) is one of the significant failures for which the FAA has been sharply criticized. First announced in 1983 with an estimated completion in 1996 and a cost of $2.5 billion, the goal of AAS was to upgrade all computer hardware and software used by controllers in the towers, TRACONs, and enroute, and to reduce costs for the FAA. However, due to continuing delays in delivering AAS and mounting costs the program was ultimately canceled in 1994. At the time costs had approached $6 billion with limited realized results. [27] The blame for the failure was shared between FAA and IBM, the contractor hired to develop the system, but it was the FAA that suffered a significant loss of credibility. A GAO report blamed over ambitiousness of original plan, poorly specified requirements, and poor FAA oversight for the failure. [28]

**CA2: En-route weather delays** Pilots do not always have access to timely weather information while en-route. As a result, situational awareness is diminished and decisions about re-routing can be difficult to make. The Cockpit Weather Information system (CWIN) is one of the ways in which this problem can be addressed. CWIN is a decision support tool that integrates weather information from multiple sources to provide enroute weather information to pilots. It was implemented to reduce en-route inefficiencies caused by adverse weather. [64]

**CA3: Lack of all weather capability at airports** The Microwave Landing System (MLS) was proposed in the early 1970s to replace the Instrument Landing System (ILS) for instrument approaches. MLS had significant technical advantages over ILS—for example, compared to ILS, MLS did not require that aircraft maintain line of sight and had smaller, easier to deploy antennas—but MLS was ultimately never deployed in the US. By the time MLS was ready for testing, ILS was already available at all major airports and GPS was becoming more available with broader deployment and better accuracy. This case demonstrates the difficulty of implementing change when technology development can make it obsoleted; it also highlights the importance of timing for solution development. [27]

**CA4: Insufficient airport capacity** Limited airport capacity can lead to delays and service disruptions. However, in some cases small actions by airlines can help reduce the impacts of capacity limitations. One problem faced by airlines is insufficient capacity at peak travel times—by wanting to minimize layover times, airlines often scheduled many flights to arrive and leave an airport in a short time causing delays when runway and gate capacity was limited. Schedule de-peaking is an example of a change that airlines were able to implement on their own, without consulting with other stakeholders, in order to reduce delays. By spreading arriavls and departures more uniformly throughout the day, airlines reduced delays by eliminating peaks in demand. As a side-effect, airlines were able to reduce airport staff, since fewer busy times occured. This change occurred mostly at hub airports where airlines were not facing sever competition from other carriers and had more capability to change their schedule without loosing business. [1]

**CA5: Insufficient airport capacity** Limited airport capacity can lead to delays and service disruptions. The shift to secondary airports, smaller under utilized airports in the vicinity of large airports, also allowed airlines to encounter fewer delays but still serve a similar population area. This was another approach to avoid delays that could be implemented by an airlines without consulting other stakeholders. This has resulted in the growth of secondary airports and has increased capacity available in metropolitan areas. [4]

**CA6: Insufficient airport capacity at ATL** The construction of runways adds extra airport capacity, which is much needed at many airports in the country that cannot handle the demand they are seeing. However, such projects are often difficult to complete and take a significant amount of time. In Atlanta, Runway 10/28 is the newest and 5th runway, that was constructed to increase the capacity of the airport. The runway took under 10 years to complete and opened in May 2006. This is one of the more rapid instances of airport infrastructure expansion. The speed of Runway 10/28's deployment may have been due to its support for more southbound tracks that impacted few local communities, resulting in less overall opposition to the change [65].

**CA7: Insufficient airport capacity at BOS** Boston Logan Airport has limited capacity during north west wind conditions. As a result, delays can mount on days where no storms are present. The construction of runway 14/32 at Boston Logan airport (which opened in November 2006) addresses this problem. This case is an example of a runway that took decades to complete. Disputes between the local port authority and surrounding communities over noise and usage took years to settle and resulted in restrictions on the use of the new runway. [66] This case provides and example of the stakeholder barriers that can arise in response to airport runway projects and the use of the environmental review process to block such changes.

**CA8: Insufficient airport capacity at LGA** At New York City's LaGuardia airport (LGA), delays caused by limited capacity peaked following the removal of slot restrictions due to the Aviation Investment and Reform Act for the 21st century (AIR 21). The unrestricted growth in demand led to unacceptably high delays and is an example of a capacity catalytic event that forced an immediate response. However, because expanding ground infrastructure or using technology to increase airport capacity both take a significant amount of time, the only feasible rapid response was to reinstate demand management at the airprot. As a result, in response to awareness and pressure generated by growing delays, The New York Port Authority and the FAA quickly re-instated slot restrictions at LGA to limit the number of operations and reduce delays. [67]

**CA9: Insufficient airport capacity at ORD** Chicago O'Hare airport is facing demand in excess of what it can support resulting in delays. In order to fix this problem, the airport is currently in the midst of carrying out an extensive plan to reconfigure the airport's existing runways and add two additional runways. The changes are anticipated to increase the capacity of the airport by 60% and allow for the removal of slot restrictions [68]. The plan is approved by the FAA, but faces community opposition.

**CA10: Insufficient airport capacity at ORD** Although ORD has extensive plans to significantly increase the capacity of the airport, such plans take time to carry out. In the mean time the demand for the airport is higher than what can be accommodated. As a result, slot restrictions are in place to limit the number of operations allowed at Chicago O'Hare airport [69]. However, these restrictions may be removed once reconfiguration and expansion of the airport adds sufficient new capacity.

**CA11: Insufficient en-route capacity** In order to increase en-route capacity, initially in oceanic airspace and later in domestic as well, Reduced Vertical Separation Minimum (RVSM) was implemented. RVSM reduces the required vertical separation between aircraft from 2000 to 1000 feet in en-reoute airspace thereby increasing the capacity of the system [70]. While largely a procedural change, RVSM was first considered when the 2000 ft separation standards were agreed upon but took time to become possible because it required the development of other technologies (notably more accurate altimeters) before it could be safely deployed.

**CA12: Insufficient terminal airspace at BOS** The FAA is attempting to improve terminal airspace usage in the BOS airspace with a new Required Navigation Performance (RNP) route; planned for operations out of Logan, the route is being contested by the city of Marshfield, Massachusetts. This case is of interest because it involves a change that is not subject to the environmental review process and does not require the FAA to produce an Environmental Impact Statement (EIS). However, the City of Marshfield argues that a local environmental review should be required even though the change would be carried out by the FAA (a federal institution) not Massport. The case is in litigation and should Marshfield succeed it will open more projects previously exempt form the environmental review process to increased scrutiny and as a result increased delays. [71]

**CA13: Insufficient terminal airspace at NY** The airspace surrounding the four major airports in the New York City area is often congested; the current FAA plan to redesign this airspace would greatly improve the efficiency of airspace utilization and result in fewer delays. However, the redesign would cause changes in the noise patterns of the area. As a result, communities surrounding the airspace are challenging the redesign [72]. This further demonstrates the importance of stakeholder relations and the power of community stakeholders in affecting system transition.

**CA14: Outdated ATC surveillance system** The existing Air Traffic Control (ATC) system has been blamed for causing inefficiencies resulting in delays. The Automatic Dependent Surveillance-Broadcast (ADS-B) is a planned surveillance technology that broadcasts aircraft position and other information to ground-based receivers and other aircraft. This technology would enable new capability in the system and is the backbone for many changes planned as part of NexGen [21]. It is often presented as a way to increase the efficiency of the system and enable it to handle more flights. Currently, the change is pending and faces challenges in passing the safety approval process as well as gaining acceptance from stakeholders.

**CA15: Outdated controller terminals** Controller terminals were deemed outdated and a decision to update them was made. Coming out of the failed AAS project, the Standard Terminal Automation Replacement System (STARS) resulted in updated controller terminals which provide controllers with better tools to monitor aircraft positions and created better controller situational awareness [73]. While ultimately implemented, the case was a bystander to an example of the safety veto: during contract negotiations that coincided with STARS certification, the Professional Airways System Specialists (PASS) union questioned the safety of the system until it could negotiate a more favorable contract [74].

**CA16: Schedule disruptions due to weather** Adverse weather conditions decrease airport operations and result in flight cancellations and delays. In order for airlines and air traffic controllers to best react to decreased capacity conditions Collaborative Decision Making (CDM) was implemented. CDM was a decision support tool implemented to increase the exchange of information between airlines in order to improve traffic flow management. Airlines use the tool to decide how to adjust their schedule when weather or other constraints limit capacity [75].

**CA17: Terminal weather delays** In parts of the US, terminal airspace can become congested resulting in delays. In particular, during inclement weather using terminal area resources efficiently is impoartant. The Integrated Terminal Weather System (ITWS) is a tool that integrates data from multiple sources to provide weather information used for panning of terminal operations [76]. This change has been successfully implemented and provides increased safety during adverse weather as well as increased efficiency and reduced controller workload. It was a change with clear benefits to the stakeholders involved.

**CA18: Unacceptable passenger treatment** For various logistical reasons, often due to inclement weather, several instances have occurred in the past decade where passengers were stranded on aircraft for many hours—in some cases without food, water or working toilets [77]. In response to the outraged passenger complaints, some Congressmen and Senators introduced bills that would establish a passenger bill of rights [78]. These cases show the potential for capacity catalytic events to cause change. However, due to political pressure from airlines, no such bill has actually been passed. Airlines argue that they can handle and avoid such treatment with voluntary actions; for example, following such a situation in 2007, JetBlue introduced its own statement of passenger rights, explicitly enumerating compensation to passengers under specific conditions [79]. However, with every new event the pressure for Congressional action increases.

### 4.1.4 Environment Case Studies (EN)

**EN1: Aviation noise** Noise is a significant rallying point for communities and often leads to barriers to increasing system capacity. Continuous descent approaches are an innovative approach being developed to reduce engine noise during approach. The proposed change would adjust the descent profile of aircraft into an airport to be more uniform, removing the need to change engine power as frequently [80]. Such approaches are being tested and developed, and implemented in a few locations in the US.

**EN2: Aviation noise** Noise is a significant rallying point for communities and often leads to barriers to increasing system capacity. In order to limit noise, over the past 40 years, engines have been subject to increasingly strict requirements, ranging from Stage 2 engines adopted in the early 1970s to Stage 3 engines that were mandated in 2000 [81]. Stage 3 engines are required to be 12% quieter than Stage 2 engines [82]. The development of these standards proceeded with significant industry consultation but was ultimately adopted by a mandate.

**EN3: Growing aviation emissions** In the US, there has been a growing awareness of emissions and their role in environmental problems. While changes to reduce $CO_2$ emissions in the US have been made many innovative solutions are still a long way from implementation. In addition to taking steps to reduce carbon emissions in the US international efforts will need to be made since this is a global problem. In 2007, the European Union attempted to engage the international community to address aviation emissions with a carbon cap and trade program introduced to ICAO [83]. The proposal faced strong opposition and was ultimately rejected [84]. This particular case demonstrates the problem of achieving consensus when disagreements exist between stakeholders and there is no authority to shift the situation with a mandate.

## 4.2 Detailed Case Studies

### 4.2.1 Detailed Safety Case (SA1): Controlled Flight Into Terrain Accidents

The effort to decrease or eradicate Controlled Flight Into Terrain (CFIT) accidents was chosen to be studied as an example of adaptation for a number of reasons. The decrease in CFIT accidents is considered to be one of the most significant safety changes in past 30 years. In addition, this case provides the opportunity to study and understand an event driven and successful safety adaptation. Finally, to reduce the frequency of CFIT accidents ground proximity warning system (GPWS), a device that warns pilots of a possible impending CFIT, and later the enhanced GPWS (EGPWS) were implemented. As a result, this case provides the opportunity to examine how the same problem was addressed on two separate occasions and how the means to address it evolved.

In addition, this case provides insight into the the following aspects of system transition:

- role of data in spreading awareness of a problem
- role of a project champion in building awareness and generating pressure for change
- role of a mandate in bringing about change
- role of the state of technology in developing a solution
- role of the state of solution when pressure for change arises
- role of catalytic events in raising awareness of a problem and generating pressure for change

- role of aviation community vs. public awareness in bring about change
- role of stakeholder objectives in bringing about and blocking change

**The CFIT Story**

CFIT accidents occur when correctly operating aircraft are unintentionally flown into ground or water. Causes for such accidents include crew error, instrument error, air traffic control error, and poor weather conditions [85]. Historically, CFIT accidents have been one of the most frequent source of airline crashes in the world [10].

Work to reduce CFIT accidents began during the 1960s. This work was done in large part by Don Bateman an employee of Sunstrand Inc. which later became Honeywell. The initial program involved the participation of PanAm, Braniff, Boeing, and Douglas [86]. The development of a warning system was not due to any outside pressure, but was motivated by two crashes in 1975 and a belief, on the part of the companies involved, that a significant benefit could be achieved [86, 87].

In order to better understand the problem, Bateman began analyzing National Transportation Safety Board (NTSB) accident reports identifying a series of accidents in which an aircraft malfunction did not lead to the accident [88]. In many cases such accidents are attributed to pilot error and according to Bateman the predominant attitude was that they had not been fit to fly. However, an analysis of all accidents spanning 20 years showed that, while pilot error was often cited as the reason for the crash, many of these crashes had a number of common characteristics: aircraft and crew were completely airworthy, pilot error tended to be listed as probable cause, crew did not realize until too late how close they were to terrain, 2 out of 3 occurred at night, the rest in cloud or fog, 1 out of 5 occurred during descent/approach in rain/snow with continuous suspicion of barometric error, 1 out of 5 involved sinking back into terrain after takeoff or missed approach, all were over water or unlit terrain at night, all accelerated back into terrain but were capable of climbing, 3 out of 4 accidents: excessive sink rate, 3 out of 4: gear was not down at impact [87]. In addition, the study of past accidents showed that during the 20 year period about 300 CFIT crashes occurred leading to over 4000 lives lost and more than $400 million of financial lesses [87].

In order to help address the problem of CFIT accidents Bateman began work on the GPWS which is an example of a Terrain Awareness and Warning Systems (TAWS). The goal of the system was to help in the situations listed above by providing the pilot with both an aural and visual warning that a collision with terrain may be imminent.

GPWS works by measuring the distance that an aircraft is from the ground as well as monitoring its movement and issuing an auditory warning if the aircraft is in danger of striking terrain. The danger of striking terrain is assessed by monitoring and analyzing the rate at which the aircraft's distance above ground is changing. A radar altimeter measures the distance of the aircraft above ground level by timing the return of a radar pulse beamed at the ground directly below the aircraft [89]. Because the radar pulse is beamed at the ground below the aircraft, GPWS does not warn pilots of a possible collision with terrain that is ahead; Figure 4-1 illustrates this limitation. EGPWS was later developed by Honeywell in the 1990s to improve on GPWS. This technology added a look forward capability in order to prevent CFIT collisions with terrain ahead of the aircraft.

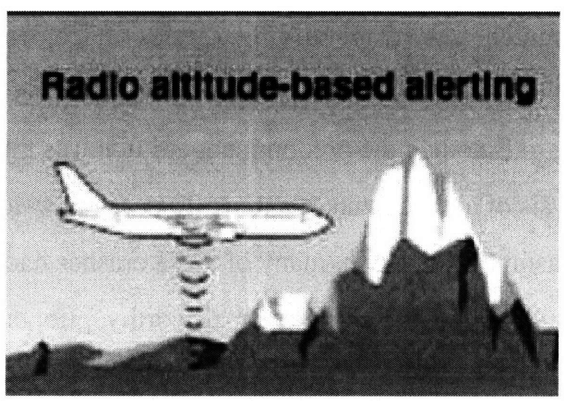


Figure 4-1: Illustration of Primary GPWS Limitation [9]

The development of the GPWS was enabled in part by the introduction of the radio altimeter in the 1960s. As part of the development the flight path of aircraft involved in CFIT accidents was studied to improve GPWS performance [90, 91]. This technology made it possible to measure the distance between the ground and the aircraft making a warning system feasible. Sunstrand filed for a patent on GPWS on August 11, 1970 and received it February 6, 1973 [92].

In 1971 Scandinavian Airlines (SAS), CPAir, Maersk Air, Braniff, and Pan American voluntarily began equipage with GPWS [90]. By 1974, 15 international and 2 US airlines were equipping with the technology. Boeing also began installing GPWS on new aircraft. Initially the installation was a recommended option and in 1974 it became standard to all models [90].

During this time Sundstrand was analyzing past accidents and determined that the existing version of GPWS would provide accurate warnings in about 33% of cases. Work contined to improve the sucessful warning rate, whcih was increased to 47% by 1972, 75% by 1973, and as much as 90% by 1974 [87].

During this time, as the performance of GPWS was improving and more airlines and manufacturers were voluntarily equipping their aircraft, pressure on the FAA to mandate the equipage of GPWS on all commercial carriers was growing. The FAA had received demonstrations from Sunstrand as well as GPWS units for testing; however, the FAA seemed to show little interest citing the position that as long as pilots were well trained and followed proper procedures no addition technology to prevent flight into terrain was necessary [87]. The position of the FAA may have been influenced by the Air Transport Association (ATA), which is a powerful lobby and at the time did not want a mandate for equipage with GPWS [93].

Overtime CFIT risk became incorporated into calculations of aircraft insurance. Given that CFIT accidents resulted in heavy losses of life and that a GPWS unit at the time cost about \$2000 to \$3000 dollars and a human life was valued at \$1.25 million the business case for equipage became stronger [93].

While the problem of CFIT was already recognized, a solution had been developed, and pressure on the FAA to mandate equipage was mounting, it was an accident in 1974 provided the catalyst for an FAA to finally act.

On December 1, 1974 a Trans World Airlines Boeing 727 crashed near Berryville VA while approaching to land at the Dulles International Airport. The accident killed all 92 passenger on board the aircraft [27]. Following an NTSB investigation it was determined that the accident occurred because pilots were unfamiliar with the terrain surrounding the airport and because of miscommunication that occurred between them and a controller. A controller cleared the flight for a VOR/DME approach on a non-standard vector. The TWA captain interpreted the controller's "cleared for approach" instruction to mean that he could descend to the final approach altitude of 1,800 feet immediately, although his chart indicated mountain peaks and a prescribed minimum altitude of 3,400 feet. The controller had assumed the pilot knew he was not to descend to 1,800 feet until he had cleared the mountains. As a result of the misunderstanding the pilots descended too early and crashed.

Following the media coverage of the accident, awareness of the CFIT problem spread rapidly among to the non-aviation community leading to a high pressure on the FAA for action. The number of casualties, the loss of prominent individuals on board the aircraft, and the location of the crash all contributed to its high public visibility. The FAA was already under scrutiny for a previous safety problem dealing with doors on the DC-10 and for not mandating GPWS sooner. This accident added to the harsh criticism of the FAA [27]. As a result, following the accident the FAA took a number of actions to reduce CFIT risk.

Procedural changes to address CFIT accidents were implemented following a crash at Dulles in 1974. These changes resulted in the addition of a glossary to the aeronautical information manual and better charting. This glossary was published by the FAA in 1976 based on a previous recommendation from the NTSB and was 4 times the length of the previous one. [27]. That same year on January 1 the FAA also issued a new Air Traffic Control handbook combining manuals for handling both en route and terminal flights. In addition, the FAA changed Part 91.175(I) of the Federal Aviation Regulations (FAR) clarifying the responsibilities of pilots vs. controllers during approach and on unpublished routes [94]. This ruling required that pilots maintain an assigned altitude until a new one was issued or until they were following an official published route'[27], a requirement precipitated directly by the causes of the Dulles accident.

In addition to the above change the FAA mandated equipage with a terrain warning system. The rule requiring equipage was published on December 24, 1974 only 23 days after the Dulles accident and required that large turbojet and turboprop be equipped by December first 1975. This gave airlines less than a year to comply with the new regulation which proved to be too stringent a requirement and the deadline was subsequently extended. All airlines were in compliance by the end of 1976 [27].

As a result of the actions in the aftermath of the Dulles accident all US carrier aircraft were equipped with GPWS by September 1976. For Sundstrand this mandate led to a number of new entrants into the GPWS market, which froze the design of the technology for a number of years [86]. Sunstarnd captured about 25% of the TAWS market [90].

In the years following the Dulles accident and response, the mandate to equip with GPWS was extended to include additional aircraft. On December 1, 1978 a revision of Part 135 of the FARs extending the GPWS requirement to some commuter aircraft. On March 17, 1992 the rule was extended once more, this time to all turbine powered aircraft with 10 or more seats.

A significant decrease in CFIT accidents was achieved as a result of the requirement for GPWS as can be seen from Figure 4-2, which shows the number of US and world CFIT accidents between 1945 and 1995. The number of CFIT accidents in the US decreases significantly in the late seventies and in the rest of the world in the mid 80s as different parts of the world passed rules to equip their aircraft. While GPWS and other measures to reduce CFIT contribute greatly to the improvement in accident rates technologies such as ILS, better altimeters, map displays, radar coverage with altitude reporting, and the Min Safe Altitude Warning System (MSAWS) all contributed to the decrease in accidents [91].

Although large improvements were made CFIT remained the number one cause of airliner accident fatalities in the world, as can be seen from Figure 4-3, which shows the world airlines fatalities by accident category between 1986 and 1995. In addition to the fatality data, studies done by ICAO and Volpe determined that further improvement was necessary [95, 96].

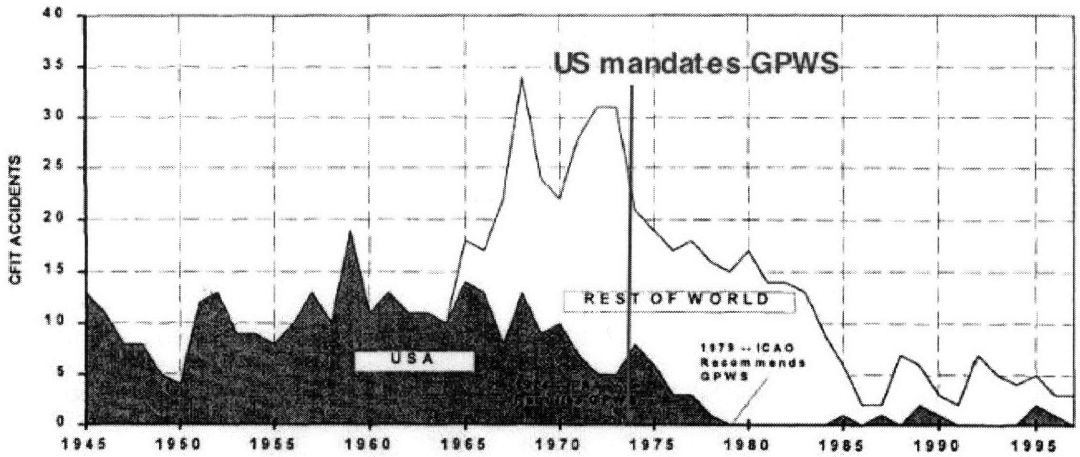


Figure 4-2: Controlled Flight into Terrain Accidents between 1945 and 1995 [10]

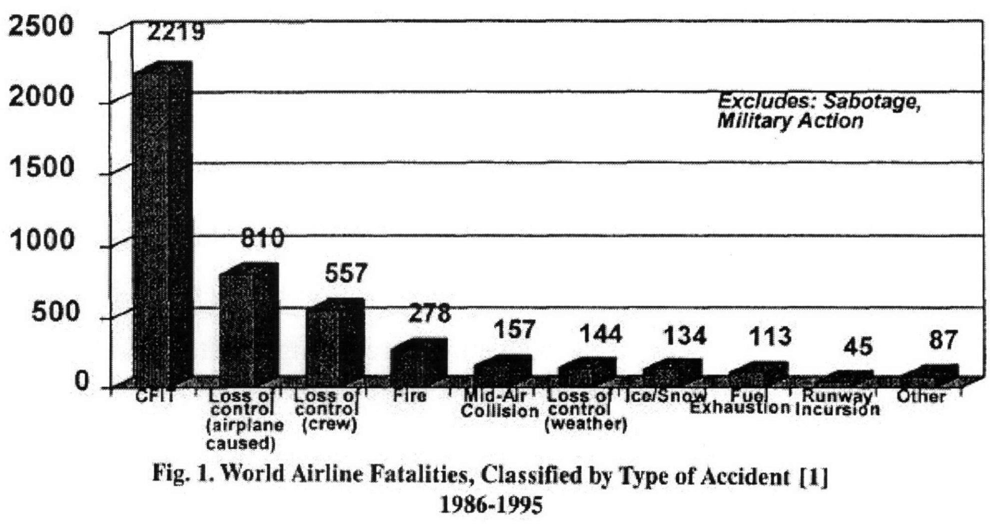


Figure 4-3: World Airline Fatalities, Classified by Accident Type 1986-1995 [10]

To bring about further improvements in reducing the CFIT risk, technology needed to be further developed. During this time period GPWS continued to improve adding more modes and better functionality. In addition, development of EGPWS continued at Honeywell still led by Don Bateman. The breakthrough that allowed for the development of a forward looking radar came after the end of the cold war. At this time Sundstrand was able to obtain, through intermediaries, terrain maps created by the former USSR. The maps had been developed in the 1920s, but proved to be advanced. The USSR had developed a standardization protocol so all the maps were standardized and also in color. The acquisition of these maps led directly to the creation of terrain maps which allow for the look ahead capability of EGPWS [93]. The maps, coupled with new advances in data storage technology, made it possible to store detailed maps of terrain in a small instrument that could be located on the aircraft. Today, due to political situations around the world, some areas are still not mapped, but a great number of airports and surrounding areas are included in the database. In addition, developments in flash memory and computer processing allowed for the efficient storage and display of large amounts of map data. Finally, improved computer technology allowed for better auditory warnings. Instead of a limited amount of warnings based on analogue tones voices could be synthesized from digital data [93].

It is important to point out that in addition to technology and procedures,education also played a large part in reducing the number of CFIT accidents. According to Don Bateman, the individual credited with the development of GPWS, education of pilots has played a large and crucial role in reducing the number of CFIT accidents [90]. In addition to airlines the FAA, Boeing, and AOPA all provide training materials for airlines and pilots to inform them about situations that my lead to CFIT accidents and how they can be avoided [97].

As technology improved and data on the effectiveness of GPWS was collected, Bateman worked on spreading awareness of the continued need for improvement in preventing CFIT accidents. With the improvement in accident rates following the Dulles accident public and aviation community interest in the issue diminished and other issues took precedent. In order to spread awareness and regain interest Bateman wrote papers, gave talks, and put together a book of over 150 CFIT accidents and incidents to show that the problem sill existed [91]. Bateman was advocating for continued equipage with GPWS in other parts of the world as well as in smaller aircraft. In addition, he pushed for the replacement of old GPWS technology, and for education programs for pilots to learn about conditions under which CFIT accidents were likely. Work also needed to be done to insure that pilots did not turn off the GPWS because of nuisance warnings, but improvements in the technology continued to reduce the number of false alerts [91].

Although Bateman was advocating for more change another accident was needed before improved technology was mandated. The catalyst for the next stage of change in the US was an accident that occurred near Buga Columbia on December 20, 1995. An American Airlines Boeing 757 crashed into a mountain while approaching Cali Columbia. The Colombian authorities conducted the accident investigation with the assistance of the NTSB. It was determined that the crew and controller had a miscommunication and the pilots were confused about which VOR they were to proceed to. In addition, the pilots had entered incorrect data into the Flight Management System causing the aircraft to go off track. The on board GPWS issued a warning, but improper response to the warning coupled with a lack of knowledge of the mountainous terrain led to a crash [85].

Pressure to reduce CFIT accidents was once again increased as a result of the accident. Don Bateman and his group began working toward rushing EGPWS into production. However, at the time the technology was not yet certified. In addition, because Secretary of Commerce Brown and other business leaders were on the aircraft pressure to reduce CFIT was also generated on capital hill. Among those vocal for equipage with EGPWS was Al Gore who at the time was the vice president [93].

As a result of the crash and previous studies on March 23, 2000 the FAA mandated that all turbine powered aircraft with six or more passenger seats were to be equipped with an FAA approved terrain awareness and warning system (TAWS), also known as the enhanced ground proximity warning system EGPWS . Aircraft manufactured after March 29, 2002 had to include the system, and aircraft already in service have to comply with the order by

March 29, 2005. The ruling required that the warning systems provide forward looking terrain avoidance, a premature descent alert, a terrain display, and an imminent contact with ground warning.

Unlike in 1974 it took 5 years between the accident and the mandate. This is in part to the fact that EGPWS needed to be certified for equipage, which it was on November 6, 1996. Even with the approval 4 years passed before an official mandate. During this time airlines such as American and United began equipping voluntarily, and Airbus decided to make the equipment standard on all its aircraft [98].

As with the implementation of GPWS, the mandate of EGPWS resulted in a guaranteed market for the technology, and companies entered the TAWS market in order to take advantage of the opportunity. Universal Avionics, Sandel Avionics, Goodrich, and Aviation Communications and Surveillance Systems all entered the market following the mandate and about four years after Sundstand received its EGPWS patent. As part of this entrance Sunstrand (now Honeywell) filled patent infringement suits against the four other companies in 2002, but lost the case in 2003. While both in 1970 and 1990 Sundstrand lost substantial parts of the total markets when new companies entered, they did still have an advantage in being the first developers. Because their technology was the only available solution at the time when FAA was mandating equipage it was used as the basis for what capabilities airlines were required to poses.

Work on eliminating CFIT still continues. On July 12, 2006 the NTSB issued a recommendation, following their investigation of 11 CFIT accidents, to improve CFIT safety conditions. The recommendations target air traffic controller training, warning systems, and MSAWS [99]. In addition, Don Bateman continues to push for efforts to further eliminate CFIT accidents [90].

## Conclusions

The case of addressing CFIT accidents can be considered a success. The actions taken have significantly reduced CFIT accidents and because CFIT represented about 50% of all accidents these actions greatly increased the safety of air transportation. There were a number of factors which contributed to helping solve this problem, such as a strong project champion and a solution that was ready to implement when pressure for implementation was generated. However, in both the 1970s and 1990s an accident was a necessary catalyst for the implementation of solutions even though the problem of CFIT was widely recognized within the aviation community.

The collection of data and analysis of accident reports was necessary in order to identify and understand the extent of the CFIT problem. The NTSB conducted accident investigations which could than be used by Don Bateman and others to identify CFIT as a specific type of accident with specific causes. Without this data the problem would have been much more difficult to identify. In addition, this data helped in the development and improvement of GPWS. The data also helped to spread awareness of the problem to the aviation community and policy makers. However, the data was not sufficient to cause all air carriers to equip with the technology.

Without the leadership and commitment of Don Bateman neither GPWS nor EGPWS would exist. Bateman worked on collecting data to show the extent of risk posed by CFIT accidents. He also worked to develop the technology to warn pilots of possible collision with terrain. During the course of developing both technologies Bateman was told a number of times to shut the project down. However, he believed that what he was working on was important and was prepared, along with others, to leave the company and develop the technology without Sundstrand's support [93].

The leadership of Honeywell as company also contributed to the development of both GPWS and EGPWS. Honeywell internally funded the research and development process leading to these technologies. Because the FAA insisted for a number of years that such a technology was not necessary no government funding was available for this work.

Don Bateman's commitment was reinforced by the existence of early adopters who wanted to equip with GPWS and EGPWS. Without such adopters the development of the technology would have been difficult to sustain. These companies believed that CFIT accidents were costly both in terms of lives and money and wanted to reduce their risk of accident. As the risks became better defined they became incorporated into insurance premiums for aircraft making the business case for equipage with GPWS and EGPWS more clear. These early adopters also put pressure on other carriers to equip because these carriers could not afford to be perceived by the flying public as being less safe. Carriers that are perceived as not safe will loose passengers when there are other options available.

However, not all carriers and pilots wanted to equip with GPWS and EGPWS. In the 1970s the FAA was strongly opposed to the technology claiming that as long as pilots followed proper procedures and were well trained there was no risk of them flying a normally operating aircraft into terrain. This opposition prolonged the implementation of solutions to address CFIT accidents even though at this time it was known that these accidents were highly prevalent and in mostly cases deadly to all passengers on board an aircraft.

As a result of this opposition, visible and large accidents were necessary to bring about implementation. The Dulles and Cali accidents generated public pressure as well as pressure in some parts of the government to address the problem. In 1970s the pressure was increased by the fact that a solution exist and the FAA had been refusing to implement it. This fact made the agency look bad during hearings prior to the accident and resulted in an outcry following the accident. As a result, the FAA moved rapidly to implement a number of measures to reduce CFIT. In the 1990s an accident was also necessary, but in this case the EGPWS was not yet ready for implementation. Following the accident it took a year to certify EGPWS for implementation. Following the certification a number of airlines equipped, but it took a number of years for a mandate. In this case the pressure on the FAA to act was alleviated as they worked on certification and as the accident was forgotten.

Having a solution or solutions that are ready for implementation when pressure for action is created helps to bring about a speedy implementation. However, in order to create these solutions the state of technology and problem understanding needs to reach a level where such development is possible and where the technology can be made cost efficient enough for implementation to make sense. In the case of GPWS altimeter technology needed to improve to a level where distances between the aircraft and terrain could be accurately measured. For EGPWS maps of terrain were necessary as well as the computing and memory power to store and present such maps. Without these other advances in technology technical solutions to CFIT accidents would not have been possible.

A mandate was necessary to ensure that all carriers, and later smaller aircraft, equipped with GPWS and EGPWS. Although, the majority of large carriers would have most likely equipped with the technologies as the financial benefits and pressure from the traveling public increased, it would have taken a much longer time before the entire fleet was equipped. However, equipage of smaller aircraft would most likely not have taken place without a mandate.

### 4.2.2 Detailed Safety Case (SA2): Windshear and Microburst Accidents

Weather has posed a threat to pilots since the start of aviation. In the early history of air transportation many pilots lost their lives due to poor visibility resulting form fog, rain, snow, or other meteorological phenomenon. Today adverse weather causes grounding of aircraft to avoid dangerous flying conditions. During the 1970s a significant amount of work was undertaken to both understand and address the dangers posed by microbursts.

This case was chosen due to the fact that it required significant research and solution development efforts before it could be addressed. This is in contrast to the controlled flight into terrain story where a solution existed when pressure to implement manifested. This case also spans both safety and capacity improvements and hows how addressing system problems can be coupled.

In addition, this case provides insight into the the following aspects of system transition:

- role of research in problem understanding
- role of a project champion in building awareness and generating pressure for change
- role of a mandate in bringing about change
- role of the state research in solution development
- role of the state of solution when pressure for change arises
- role of catalytic events in raising awareness of a problem and generating pressure for change (multiple times)
- role of bring together a number of solutions to address an issue

**The Windshear Story**

A microburst is a particularly dangerous weather phenomenon that can affect aircraft and cause fatal crashes. This phenomena was first identified and named by Tetsuya Theodore Fujita after studying an accident at Kennedy Airport in 1975 [27]. Fujita acted as the project champion working to develop problem understanding and awareness even when the head of the National Oceanic and Atmospheric Administration (NOAA) was skeptical that such a phenomenon existed [100].

Microbursts are a specific type of windshear. Windshear occurs when air molecules in close proximity move in opposite directions. In a microburst, air descends rapidly from the cloud base to the ground. When the air hits the ground, it radiates outwards as shown in Figure 4-4. This air can flow at up to 45 knots, resulting in a 90 knot shear [101]. Storms, both frontal and airmass, have a downdraft component which lends itself to creating windshear and microbursts. However, microbursts can also occur without visible precipitation (virga). In fact, microbursts can be found almost anywhere there is convective activity. They typically last less than 15 minutes and are less than 2.5 miles in diameter [101].

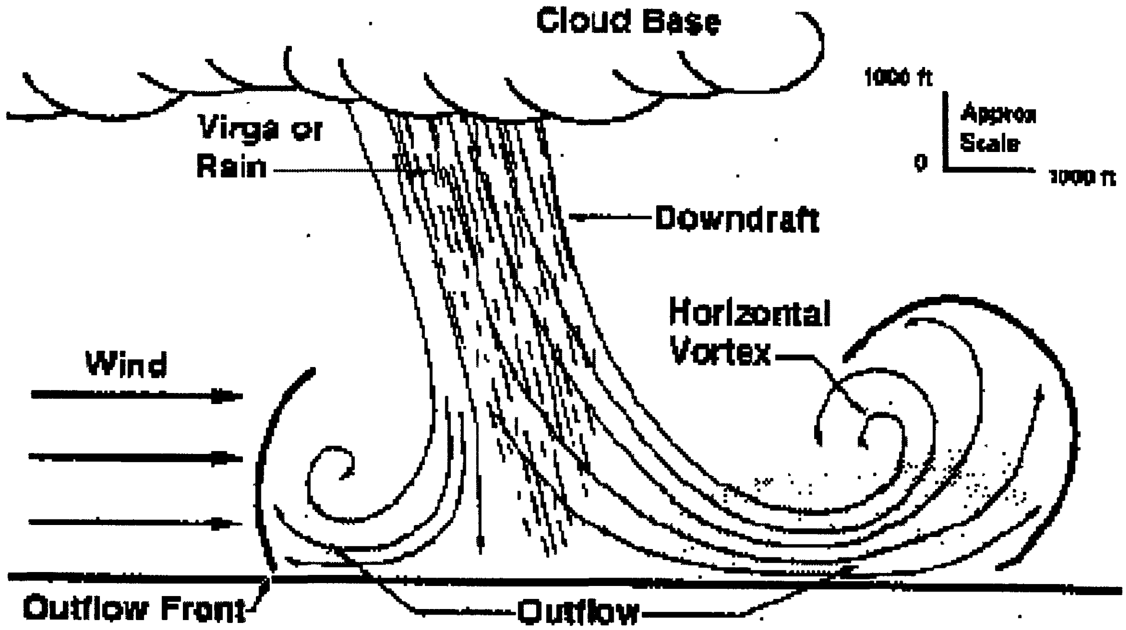


Figure 4-4: Windshear Diagram [9]

In past accidents, microbursts have posed the greatest danger to aircraft during takeoff and landing. Aircraft takeoff and land into headwinds because the wind creates increased airspeed generating more lift and allowing the aircraft to liftoff or land with a lower ground speed. Tailwinds are generally avoided during landing and take-off. However, a microburst can provide a sudden tailwind during both of these phases of flight. On takeoff this means that the aircraft loses lift and airspeed. If the aircraft is still on the runway this means it cannot takeoff in the required distance and can run off the end of the runway [57]. If the aircraft has already taken off pilots attempt to maintain the airspeed by pitching the aircraft down toward the ground. However, this causes the aircraft to lose altitude and often times when pull up maneuvers were implemented it was to late and the aircraft hit the ground. On approach an increased tailwind causes a drop in airspeed and a loss of altitude causing the aircraft to impact the ground short of the runway. [57] Microbursts during landing can be made even worse if the pilots first encounter the headwind part of the phenomenon. When this happens the pilots experience increased airspeed and lift and decrease power in response. Once they encounter the tailwind part of the microburst the aircraft loses speed and lift rapidly losing altitude and potentially crashing [102].

Many of the dynamics of a microburst that lead to crashes during takeoff and landings can be counteracted if pilots react properly. However, in order for the pilots to take proper action they need to be aware that they are encountering a microburst, how strong that burst is, and what the proper reaction is.

In order to provide pilots with the necessary information to avoid or properly react to microbursts an extensive multi agency research and development effort took place starting in the 1970s. Some of this research was conducted as part of a multi organization effort started in 1971 by the FAA to develop better methods for forecasting and detecting windshear. [27] This research ultimately culminated in the mandate and deployment of the Terminal Doppler Weather Radar (TDWR) system in the 1990s. TDWR aims to detect and display microbursts, gusts fronts, predict wind shifts and precipitation. Provides alerts in the terminal area and provides advance notice of changing conditions to permit timely redirection of air traffic [103]. TDWR is manufactured by Rayhteon and supported by Lincoln Laboratories, National Center for Atmospheric Research, and the National Severe Storms Laboratory.

In addition to research and solution development, a number of catalytic events was necessary before the microburst problem was solved. Between 1970 and 1975 17 accidents of US carriers caused by windshear occured. Many of these were not fatal and resulted only in the damage of the aircraft [27]. However, on Jan 30, 1974 a Pan American Boeing 707 crashed on approach at Pago Pago American Samoa causing 96 fatalities and 5 more injuries. The fatalities in this crashes resulted because of a fire that broke out after impact, but the crash itself was caused by windshear [27].

In addition, on June 24, 1975 an Eastern Air Lines Boeing 727 crashed, as a result of windshear during a thunderstorm, on approach at Kennedy airport in New York. As a result of the crash 113 of the 124 people on board the aircraft died. The NTSB report identified that the crew relied too much on visual cues rather than using instruments, but also stated that the windshear most likely made the accident unavoidable even if the crew had not made an error.

The NTSB also criticized controllers for continued use of the runway even after other pilots reported windshear during landings. [27]

The accident gained a significant amount of attention and resulted in a number of actions. Dr. Theodore Fujita from the University of Chicago studied the crash and concluded that several cells of downbursts occurred on the aircraft's approach path. Fujita's work became instrumental in understanding windshear and later defining the term microburst [27, 104]. In addition, the accident led the FAA to work on methods for detecting windshear both from the ground and the aircraft, and educating pilots on how to handle the weather phenomenon.

In 1976 the FAA started a six month testing program in cooperation with the National Weather Service (NWS) to identify windshear measuring devices. As a result of these tests, in 1977, the FAA began testing a ground based detection system eventually named the Low Level Windshear Alert System (LLWAS) [27]. The LLWAS was composed of instruments measuring wind velocity on the ground at the airport. The velocity measured by different instruments was compared by a computer and if a difference of more than 15 knots was reported between different sensors air traffic controllers would receive and alert and could than pass the warning to pilots. While this system was better than the previous method, where pilots would report weather that they were experiencing, it was still very limited. [27, 104]

In addition to developing the LLWAS the FAA also worked on instructions that would advise pilots how to recognize and recover from windshear when encountered. This information was distributed as an FAA Advisory Circular in 1976 and again, with upgraded information, in 1979 [104].

In September of 1978 the FAA finished installing and began full time operation of LLWAS at seven major airports in the country. In addition, 17 additional airports were to be equipped with the technology during 1979. In 1979 plans to equip additional airports were expanded to equip a total of 58 airports. The implementation of LLWAS was the first phase in addressing the microburst problem.

While progress was being made in addressing the windshear problem accidents continued.

On April 4, 1977 a crash caused by windshear during a thunderstorm in New Hope Georgia resulted in a recommendation from the NTSB to develop both an enroute and terminal area detection and warning system for windshear. The NTSB also recommended that the warnings be transmitted both to controllers and also directly to pilots though a data link. [105]. While such a system would be beneficial it did not yet exist for implementation. In order to improve the situation the FAA amended Part 121 of the FARs to require that all carriers be equipped with an approved system for receiving weather forecasts and reports of weather conditions including low altitude windshear. [104] In addition, in 1979 the FAA issued a NPRM to make air born windshear detection mandatory, potentialy with the hopes that it would spur development; however this legislature was not enacted at this time because no adequate solution to perform the task existed. [104]

At the end of 1977, the FAA also began working with the Air Force and the National Weather Service who had been developing a more advanced weather radar called NEXRAD. There was the hope that NEXRAD would be able to provide weather alerts for aviation and serve both en route and terminal detection needs. In addition, further study of the micoburst was required because relatively little was still known about the phenomenon [104].

In order to learn more about windshear the National Center for Atmospheric Research and the University of Chicago conducted experiments in the vicinity of Denver airport as part of the Joint Airport Weather Studies Project (JAWS). The experiments were conducted starting May 15, 1982 and ending in August that same year. The FAA and many other agencies participated in the effort which resulted in new understanding on the formation, duration, decay, severity, and movement of microburst [27, 104]. The research showed that some microbursts were too strong to be successfully maneuvered out of once they were encountered by an aircraft [104]. Additionally, the FAA came to the conclusion that warning and detection system separate from NEXRAD would be needed to monitor microburst activity. The NEXRAD radar were not located in appropriate places to monitor microbrusts. Further, micrbursts require a 1 minute update rate while NEXRAD used a 6 minute update rate [100].

During this time on July 9, 1982 a Pan American Boeing 727 crashed right after takeoff from

New Orleans International airport. All 145 individuals aboard the aircraft and 8 persons on the ground were killed as a result of the crash [27, 104]. As a result of the accident, Congress received numerous calls from constituents calling for action [104]. During the crash the LLWAS at the airport did trigger a windshear alarm, but that warning did not reach controllers until 2 seconds after the crash had already occurred [104].

After the investigation the NTSB recommended improvements to the LLWAS, all of which were accepted by the FAA [105]. In addition, the NTSB noted that more advanced warnings of windshear were necessary. The earlier that pilots knew about microbursts the more likely the were to avoid them. This recommendation resulted in an interest to develop forward looking sensors both for the ground as well as for aircraft.

As a result of the crash Congress passed Public Law 97369 in December of 1982 which required the FAA to contract with the National Academy of Sciences to study the state of knowledge of the problem and possible solutions for microbursts. The report was issued in September 1983 and recommended more research into detection system [27]. Specifically the report recommended that an integrated windshear program to address all aspects of the problem should be created. In the short term improvements and expansion of LLWAS was suggested since other solutions were not yet ready for implementation. As a result of this last recommendation the FAA announced plans to procure 51 more LLWAS systems in October 1983. [27]. By 1983 LLWAS was installed at 59 major airports with plans for installation at another 51. [104]

To learn more about how Doppler radar, one of the potential solutions in development, could by applied to the low-level wind shear hazard, FAA conducted Project CLAWS (for classify, locate, and avoid wind shear) in the Denver area from Jul 7 to Aug 13, 1984. FAA contracted with the National Center for Atmospheric Research to provide daily microburst forecasts, Doppler radar surveillance, and real-time advisories of microburst activities. During CLAWS, pilots gave detailed feedback on the effectiveness of the system.

On August 2, 1985 a Delta L1011 crashed during approach to Dallas-Fort Worth International

Airport. The accident was caused by windshear encountered on approach and resulted in the death of 123 of the 164 passengers on board the aircraft. The LLWAS at the airport did not detect the windshear until after the crash had already occurred, which once again demonstrated the fact that LLWS was insufficient. The NTSB recommended the development of better detection and communication systems and of specific guidelines and procedures for pilots to follow in order to avoid and escape windshear [27]. The accident caused a significant public outcry for action due to a repetition of accidents but a lack of good solutions to address the problem. Congressman George Brown from California was among the many representatives swamped by calls [104]. Following the accident he visited Langley and received a presentation on windshear and microburst as well as the state of knowledge about the phenomenon. Brown became instrumental in creating a large scale inter agency research effort to address the windshear problem [104].

In response to the NTSB recommendations, on November 27, 1985, the FAA announced a contract for the development of a windshear training program for pilots. In addition, in April 1986 the FAA announced the National Integrated Wind Shear Program. The goal of the program was to bring together a number of efforts already underway and combine them with new research to address the windshear problem. Included in the program were the development of pilot training and education materials, operational procedures, ground sensors to detect windshear (LLWAS, NEXRAD, TDWR), airborne sensors, communications systems to relay weather information, and meteorological hazard characterization [105]. Communications systems were included in the effort because controllers often had a difficult time conveying the correct information to pilots. They were already busy conducting other tasks and were not trained to interpret weather data. The program wound be housed by Langley under the direction of Dr. Bowles [104].

One of the most important results of the program was the development of the F-Factor,which tells pilots how much extra thrust they need in order to safety maneuver though an encountered windshear. The F-Factor uses the vertical and horizontal strength of a windshear to determine how much climb performance an aircraft would lose if it entered the windshear. The excess thrust needed is determined by compensating for the climb performance lost as a result of the microburst. The work showed that with 1520 seconds of warning a microburst could be averted or survived, and a 1020 seconds would be sufficient if the strength of the threat was also known. [104]

The program also investigated three alternate ways for sensing windshear. They included the Microwave Doppler Radar, Doppler Light Detecting and Ranging (Lidar), and Passive Infrared Radiometry systems. The Doppler radar proved to be the best alternative and led to the development of the Terminal Doppler Weather Radar (TDWR). The contract to develop TDWR was granted to Raytheon in 1988.

In addition, in-situ warning devices were also developed. These devices were located in the aircraft and could provide warning to pilots if they encountered windshear at an airport that did not have TDWR. However, developing this technology posed some challenges. Initial systems only provided a warning once the aircraft was inside a windshear; however, forward looking capability was desired [100]. More time and research were needed before such capability was developed. These on board warning systems also encountered some resistance from airlines that did not want to spend money on equipage, particularly if the effectiveness of the solution was questionable [100]. However, following accidents the FAA mandated airborne detection and warning system in 1988.

Once TDWR was developed the FAA planned to install it at those airports most prone to windshar. However, when doing the cost benefit analysis it was determined that windshear accidents were not frequent enough to warrant the expenditure [100]. The solution was to redefine TDWR as addressing not only a safety but also capacity problems. Airports lose capacity during adverse weather and improved monitoring allows to maintain operations longer. It was the capacity need that helped make the case for TDWR and eventually lead to the development of the Integrated Terminal Weather Information System (ITWIS) [100].

In addition, another accident helped make the decision in favor of TDWR. On July 2, 1994 a USAir DC-9 crashed while attempting to land at Charlotte-Douglas International Airport [27].

The crash killed 37 of the 57 persons aboard and showed that the windshear problem was still not solved. Following this accident, on July 10th the FAA commissioned the fist TDWR, with additional 21 units commissioned over the next two years [27]. Currently TDWR is deployed at 44 major airports. No windshear accidents have occurred at TDWR equipped airports since it was deployed.

**Conclusions**

Addressing the windshear problem can be considered a success as no significant accidents have occurred since the deployment of TDWR. In order to address this issue a number of catalytic events were required. These events drove research programs to better understand the weather phenomenon. In addition, increasingly better solutions were developed and incrementally deployed following accidents. Finally, project champions were required both the help understand the problem and the spur the development of solutions.

Tedtsuya Theodore Fujita acted as a project champion in his work to define the windshear and microburst phenomenon. His work let to a better understanding and awareness of the problem. However, because few available solutions existed when the problem was identified a substantial amount of research and development was necessary before the problem could be addressed.

Numerous programs to study microbursts and to develop potential solutions were undertaken. Many of these programs were spurred by accidents. In addition, as solutions were developed they were implemented leading to a gradual and ever improving microburst detection system. This case shows that problems can be addressed even when little understanding and no good potential solutions exist, provided that catalytic events, to maintain awareness and pressure for change, continue to occur.

This case also showed how safety and capacity divers can both be utilized in order to bring about a transition. The initial motivation for TDWR was a safety one; however, due to the relatively small number of microburst accidents it was because capacity was increased with the use of TDWR that its implementation could be financially justified.

### 4.2.3 Detailed Security Case (SC2): Need for Increased System Security Post 9/11

The effort to increase the security of the Air Transportation system, following the attacks of September 11, 2001 was chosen as a case study to better understand security drivers for change. In addition, this case provides an illustration of system changes in response to a very powerful catalytic event. The reaction following the accidents was rapid and wide ranging creating lasting changes to the system. In addition, solutions implemented span technical, policy, and procedural changes.

In addition, this case provides insight into the following aspects of system transition:

- role of catalytic events in raising awareness of a problem and generating pressure for change
- role of the executive branch when acting as project champion
- role of a law in bringing about change
- role of the state of solution when pressure for change arises
- issue displacement
- changing national values, priorities, and setting national agenda

#### 9/11 and the Security Story

On the morning of September 11, 2001 19 individuals passed through security at Boston, Dulles, and Newark airports to board aircraft that would be hijacked and used as weapons killing 256 individuals on board the aircraft [106]. The hijackers passed though security even though two were on the TIPOFF terrorist watch list (which the FAA did not use at the time) and several more were selected for additional screening [106].

Of the hijacked flights, American flight 11 from Boston to Los Angeles crashed into the North Tower of the World Trade Center in Manhattan NY at 8:46 am [61]. At 9:03 United flight 175 also from Boston and bound for Los Angeles crashed into the South Tower [61]. Both towers collapsed less than two hours later causing an estimated 2,600 deaths [106].

American flight 77 left Dulles airport bound for Los Angeles, was hijacked during the flight and crashed into the Pentagon at 9:37 am [61]. The attack resulted in 125 deaths at the Pentagon [106].

United flight 93 departed from Newark and was bound for San Francisco. It was hijacked; however, passengers learned though cell phone calls with family of the fates of the previous flights and decide to fight back. Based on black box recordings it is known that the passengers stormed the cockpit of the aircraft which crashed in a field outside Shanksville, PA at 10:02 am. At the time the aircraft was headed for Washington DC possibly with the intent of attacking the capitol or white house. [61]

The Federal Aviation Administration (FAA) and the North American Aerospace Defense Command (NORAD) were the two agencies with the responsibility to respond to the situation. Information was at first limited and uncertain; however, as the situation evolved the FAA declared a nation wide alert, grounded all local traffic, and later landed all aircraft in the country [61]. The unprecedented action of landing all aircraft occurred rapidly and without incident. NORAD also scrambled jets both in the NY and DC area which were given permission by the president and vice president to shoot down aircraft that posed a threat and were not responding to communication attempts [61].

Past terrorist attacks involving aircraft have occurred in air transportation and spurred system change. However, the magnitude of what occurred on 9/11 was unprecedented. In addition, it was the first time that aircraft had been used as a weapon to injure the non flying public. As a result, those responding to the crisis were unprepared to deal with the possibility of hijackers committing suicide:

> The threat of terrorists hijacking commercial airliners within the United States-and using them as guided missiles-was not recognized by NORAD before 9/11 [106].

The actions of the hijackers on 9/11/2001 not only highlighted failures in the US aviation security system, but also redefined the goals of aviation security from a need to protect the flying public to a need to protect the public in general.

The media response following the attacks was tremendous. On September 12th The New York Times published over 70 stories dealing with the attacks [107]. A study done by Li and Izard showed that on the 12th there were 355 newspaper stories published in the NY times, Washington Post, LA Times, Milwaukee JS, Denver Post, St. Louis PD, Huston Chronicle, and Atlanta JC and 1117 news stories on ABC, CBS, NBC, CNN, and FOX. These numbers are a conservative estimate of the coverage because newspaper stories included only fact based stories (no opinions or editorials) and the news coverage analysis only looked at the first 8 hours. [108]

The attacks of 9/11 acted as a strong catalytic event leading to pressure for change. As a result, in addition to the actions taken immediately following the attacks, a number of other changes both short and longer term were made to security procedures and practices in air transportation.

The Air Transportation System in the US was closed for 3 days: an unprecedented action. In addition emergency measures were enacted for when it did reopen. These included a ban on carry on luggage, an expanded prohibited items list including knives and other sharp objects (the hijackers used knives which were within the allowed limit [61]), locked flight deck doors, and added sky marshals [109].

Longer term actions included the passage of the US Patriot Act on October 26, 2001 and the establishment of the Transportation Security Agency (TSA) on November 19, 2001. The Patriot Act required enhanced surveillance, mandatory detention of terrorists, and asked countries to develop machine readable passports by 2003 (later extended to Oct. 26, 2004) [109]. These changes were not focused specifically on aviation, but had an impact on the screening processes that airports would need to carry out. The TSA became responsible for hiring and training personnel for security screening. In addition, it required a number of actions including [109]:

- Strengthened/ locked cockpit doors and later (April 1, 2003) hardened cockpit doors. This was adopted by ICAO as a global standard Nov. 1, 2003.
- Additional marshals on flights.
- 100% screening of all checked baggage for explosives. Adopted as a global standard by ICAO on Jan. 1 2006.
- The provision of passenger information and name records to crew
- An additional security fee for US flights ($2.50)
- The use of government information to identify dangerous passengers and deny them boarding.

The responses to 9/11 continued past 2001. On September 25, 2002 the US allowed pilots to be armed with deadly weapons. In addition, changes continued to be made to keep better track of travelers. Such changes included, the creation of a database to keep track of aliens entering and leaving the US, the creation of the US National Security Exit Entry Registration System, the gathering of biometric information, and the creation of the Advance Passenger Information System [109]. Once again these changes were not made directly to aviation and focused mostly on immigration; however, resulted in a direct impact to aviation security practices.

The changes that were implemented focused greatly on policy changes that resulted in new organizational structures and the gathering of more passenger and traveler information. In order to gather such data technologies needed to be deployed. At airports, such technologies mainly included better screening technology for bags and passengers.

In addition to the reactions to the attack of 9/11 two follow on events also received immediate and reactive responses. The first occurred on December 22, 2001 when Richard Reid attempted to blow up American flight 63 from Charles De Gaulle airport in Paris to Miami with plastic explosives hidden in his shoe [62]. He was stopped and later convicted of terrorism in the US. He is currently serving a life sentence [110].

As a result of the attempted attack travelers have to remove shoes and have them scanned as part of security measures at airports in the US.

The second event was prevented on August 10, 2006. The UK government uncovered and foiled a terror plot to blow up aircraft flying from the UK to the US. It is believed that as many as 3 US airlines and 10 flights were targeted. The terrorists planned to use liquid explosives prompting a ban of liquids, gels, and creams in carry on luggage. [63]

Both of these responses were immediate and reactive, with measures implemented directly reflecting the attempted actions.

The magnitude of the 9/11 catalytic event resulted in the president taking rapid action. He became the champion for this issue raising and maintaining awareness for a specific definition of the events [111, 112]. The rapid response taken by President Bush resulted in the highest ratings of his two terms with 92, 86, 90, and 90 percent approval reported by the ABC News/Washington post Poll, Los Angeles Times/Bloomberg Poll, Gallup Poll and USA Today/Gallup Poll, and CBS News/New York Times Poll respectively [113]. Showing that the public wanted and approved of rapid actions to alleviate pressure and the sense of insecurity that the events created [114].

The events of 9/11 provided such a large catalytic event that they became the primary driver of system change, overshadowing other significant events and displacing other issues. For example, in November 2001, just two months after the 9/11 attacks, an American Airlines plane carrying over 250 people (including 5 babies) crashed just after take-off from JFK due to wake turbulence; the most common reaction to this otherwise extremely serious accident was relief that it was not a terrorist act [115]. Delays due to congestion had also been a serious problem prior to the attacks, but little action related to capacity was taken following 9/11. Furthermore funds were diverted from capacity enhancement projects to fund security changes. This occurred during fiscal year 2002 when the FAA earmarked 17% of the AIP fund toward security upgrades, the largest allotment in the existence of the program [116]. The attacks of 9/11 show the powerful motivating effect that a catalytic event can have in terms of focusing attention and pressure for change on a specific issue. Such focus essentially guarantees that rapid changes will be made.

However, because the pressure for action was so large, the things that were implemented were things that could be done fast. As a result, readily available solutions were the ones that tended to be implemented regardless of their quality. This was the case with the CTX-9000 X-ray machines and other scanning technologies implemented at airports following 9/11. The utility of the scanners has been questioned and accusations made that they contribute to delays and long lines while only marginally increasing security [117]. In addition, Bruce Schneier, a noted security expert, believes that money is being spent too reactively and in the wrong places [118]. The dynamic of implementing an available solution when pressure arises is captured by the garbage can model of policy adaptation [36]. In addition, there often is only a single opportunity to use the attention and pressure to drive implementation [31]. Unfortunately, a solution, once implemented, may become locked-in and remain in the system for a long time [42]. Thus, the existence of a quality solution is integral to efficiently and effectively addressing an issue.

Today work is still being done to develop new methods for improving aviation security and significant research efforts have been initiated since the attacks of 9/11 [119]. In addition, the consensus seems to be that the system has becomes more secure, but that more work is needed. The GAO has conducted a number of studies to analyze the changes made to date and uncovered further need to strengthen security practices [120, 121, 122]. In addition, in 2007 GAO representatives conducted a test of airport security systems and were able to pass unstopped through security with elements necessary to create explosives [123]. Such tests show that further changes will be needed. Some of such changes are planned as part of the NextGen plan where layered security is one of the main components of planned system changes. However, more solution development is needed to make planned changes possible.

**Conclusions**

The attacks of 9/11 caused many immediate and lasting changes to the operation and management of security in the Air Transportation System. The tremendous pressure for change from the media coverage and public reaction has consistently resulted in reactive changes over the past seven years. Catalytic events create strong pressure for change that demand action. The creation of the Transportation Security Administration or the temporary ban of liquids, demonstrate the window of opportunity for change and also the need for change created by events.

However, despite many changes to passenger screening, there is still room for improvements. Passenger and baggage screening have been demonstrated to fail in capturing restricted and dangerous items. This highlights the need to create better solutions to address security problems. Such solutions should be developed, through research and development, in anticipation of pressure or change so that when such pressure arises good solutions are ready for implementation.

### 4.2.4 Detailed Capacity Case (CA7): Boston Capacity Limitations

The construction of runway 14/32 at Boston Logan International airport was chosen as a case study of using runway expansion to increase the capacity of an airport. In addition, this case also sheds insight into issues surrounding aviation noise. This case started in the 1960s and took until 2006 to come to full resolution. Bad relationships between stakeholders resulted in years of contention and litigation. This case is an extreme example of the possible barriers to airport infrastructure projects. As a result, it provides an understanding of the potential dynamics that can occur during such projects. Specifically this case provides insight into the the following aspects of system transition:

- role of stakeholder perceived costs and benefit
- role of relationships between stakeholders
- role of the environmental review process in runway expansion projects
- role of the environmental review process as mechanism for stakeholders to block transition
- role of leadership is blocking or enabling a transition
- role of diffuse vs. concentrated groups in achieving a goal
- role of problem framing and definition in raising awareness and pressure for a particular outcome

**Runway 14/32 Story**

In good weather Logan has a capacity of about 120 flight operations per hour. However, during adverse weather conditions, and northwest winds in particular, the capacity can be reduced to as few as 60 to 90 operations per hour [124]. Massport has constructed a 5,000-foot, unidirectional runway, shown in Figure 4-5, to help mitigate weather-related delays. This runway was first proposed during the 1960s and again during the 1990s. Both times a struggle between the Massachusetts Port Authority (Massport) and the communities surrounding the airport resulted.

On May 23, 1974 Massport began construction of a new runway at the Logan airport, only to be stopped the next day as the city of Boston filed a petition with the courts to stop the project [66]. These actions were both indicative of the struggle between Massport and local airport communities over airport construction.

The strife between these stakeholder groups did not start with the contention over runway

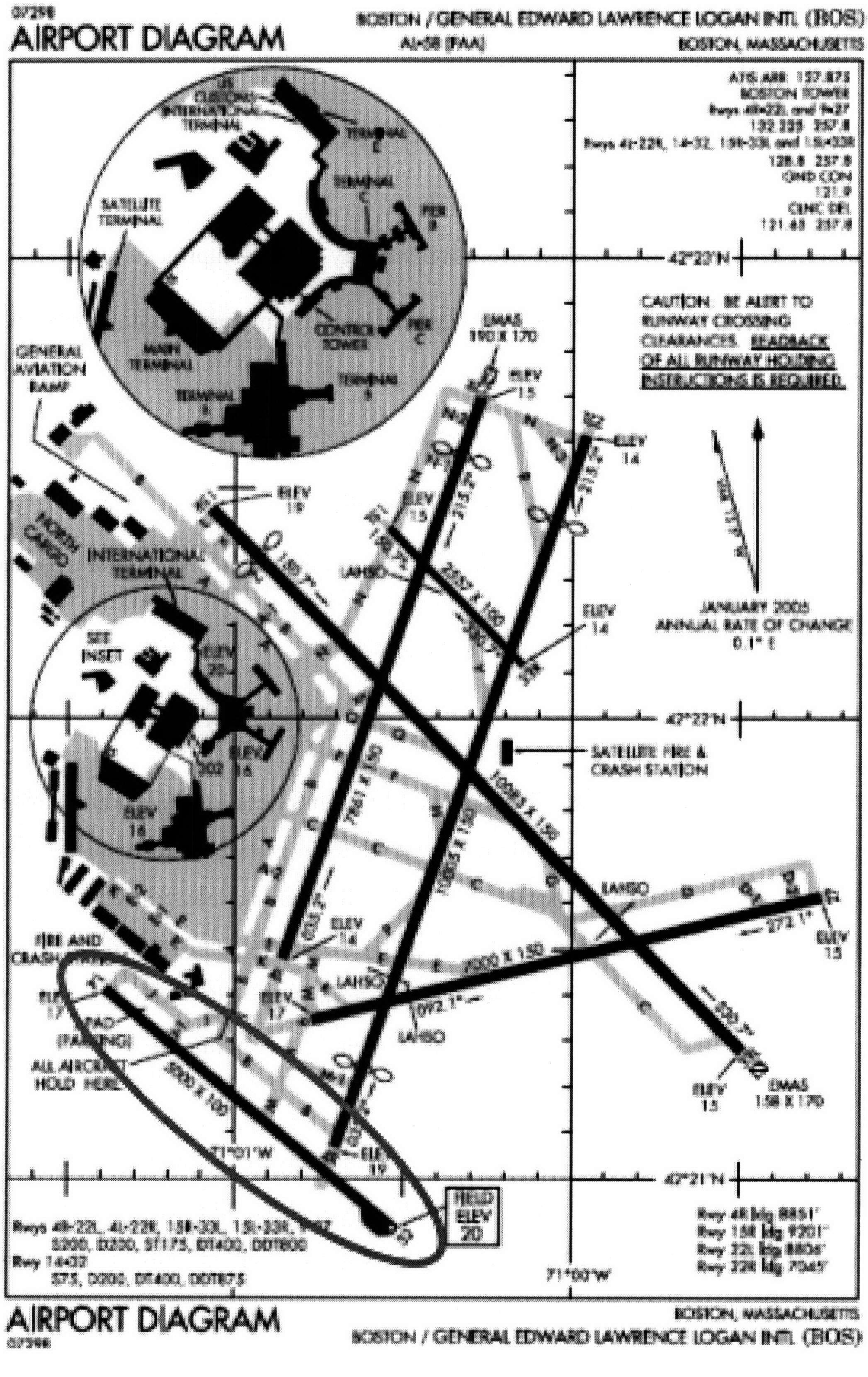


Figure 4-5: Boston Logan Surface Map with runway 14/32 circled [11]

14/32. Rather Massport had a troubled relationships with local communities, and in particular East Boston, for some time. As demand for air transportation grew Boston Logan airport expanded by taking the land it needed with the use of Eminent Domain. In particular, during the late 1960s Massport filled in the Bird Island Flats and also bulldozed Wood Island Park in order to extend runways [125]. These spaces were seen by the community as the few remaining green and recreational spaces available. It was recognized that such actions hurt communities, but it was considered the price that had to be paid for progress. As this attitude started to change local communities became more effective at opposing Massport. In addition, rallies and protests, particularly ones that blocked traffic or construction at Logan, proved an effective means for communities to be heard. The year 1970 signaled a turning point in the region: At this time the governor placed a moratorium on all highway construction and called for a $3.5 million study to prepare a coordinated transportation plan for the region. [125] Following strong opposition from communities government officials started taking notice and speaking out against projects at Logan.

In 1973 the Environmental Protection Agency was formed and NEPA came into effect on July 1, 1973. As a result of this legislature, and environment impact statement (EIS) was required for projects that would have a significant impact on the environment. When Massport announced construction projects at Logan the city requested that Massport file an Environmental Assessment Form. The form was filed on May 18, 1974 and in it Massport stated that the proposed projects would have limited impact on the environment and therefore did not require the preparation of an EIS [66]. Following this submission the FAA approved the project and Massport began construction. The next day the city began litigation to stop construction and force Massport to conduct an EIS. Massport lost the case on August 26th and an injunction against construction was issued until Massport complied with the requirements set out by NEPA [66]. In February 1975 the State Supreme Court supported the decision against Massport, which finally submitted an EIS May 30, 1975. On June 6th the Secretary of Environmental Affairs deemed the EIS not compliant. In the end Massport made compromises with the city of Boston and conducted improvements at Logan which did not include the construction of runway 14/32. The injunction against runway construction at Logan was made permanent [66].

The communities succeeded in stopping the runway in the 1970s due, in large part, to the local leadership at the time. When Massport started construction of the runway, the communities had the support of the Mayor who did not like the head of Massport [126]. As a result, the mayor supported the community and sued Massport. Massport attempted to throw money at the problem by hiring every law firm in town to create a conflict of interests and leave no firms to represent the city and communities [126]. However the city won. The political climate further turned against Massport when Dukakis became governor of Massachusetts in 1974 and began to appoint one person a year to the board of Massport. He quickly had 5 out of the 7 votes on the board against the runway [126]. This signaled a new phase in the history of Massport where emphasis was placed on ending the bad relationship with communities. In addition, Salvucci, a staunch supported of the local communities, became the sectary of transportation in Massachusetts and increased pressure to terminate the runway project [126].

The time of making amends with the communities occurred with Davis as the head of Massport and lasted between 1975 and 1990 [126]. During this time a number of actions that were strongly favored by communities was taken. First, the runway extension project was stopped. Second, a new building for the East Boston Health Center was purchased by Massport. The center was providing fist responder services to the airport, but the airport was not paying for these services in any way. When the center outgrew its current building Massport paid for a new one and Davis joined the board of directors [126]. Third, Massport sold, for $1, part of their land in Suffock Downs so that a bird sanctuary could be built [126]. Such projects helped to create a better relationship with local communities.

In addition, during this time Massport attempted to fix problems at the airport by means other than runway expansion. To this end a new terminal was constructed and Massport successfully lobbied for the construction of the Ted Williams tunnel, which improved access to the airport [126]. Davis also attempted to implement a new pricing scheme at the airport to encourage larger aircraft and discourage GA flights. However, the fee was overturned by Congress and the US Department of Transportation who were strongly influenced by the GA lobby groups [126].

When local leadership once again changed in the 1990s and Weld became governor, the runway project was resurected. In July 1995, an environmental notification form with the state, and a notice of intent to prepare an EIS with the EPA, were filed by Massport. The forms signaled Massport's re-initiation of expansion efforts at the airport. In order to receive approval for the runway project Massport needed to comply with state environmental requirements by submitting an Environmental Impact Report (EIR) and national requirements by submitting an EIS. In November 1995 both the state and EPA defined the scope of the needed EIR and EIS statements.

While the EIR and EIS statements were being prepared Massport worked to gain local support for runway 14/32. In December 1998 Massport initiated a media campaign and began lobbying businesses, political leaders, newspaper editorial boards, and frequent fliers. Massport stated that runway 14/32 was necessary to continue the economic health of the region [127]. The Boston Chamber of Commerce, the airline and hospitality industries, 19 unions form the Greater Boston Labor Council, and thousands of frequent fliers supported the plan [127]. In addition, in 1995 Massport formed the Airside Review Committee (ARC) which represented 24 local communities as well as 11 business organizations. The goal of the committee was to work toward with the communities to gain their acceptance for the runway.

The tide was again turning against local communities and in favor of a new runway. To fight back, in 1999, local communities joined together to form Communities Against Runway Expansion (CARE). This group joined together pre-existing community groups and also included new communities. The group started a website, hired a lawyer, and began an intense grass roots campaign against the runway. On March 2nd 1999, at the request of CARE the city council held a meeting about the issue. The meeting received significant media attention and CARE held the media spotlight for almost 5 hours. At the end of the meeting the city council voted unanimously to oppose the runway and passed a resolution urging the Governor to oppose it as well [127]. Before this meeting most coverage of the case portrayed communities as selfish and blocking expansion that was needed for the economic benefit of the entire region. Following the meeting the discussions turned to those about environmental justice and equity [127]. In addition, the Mayor as well as state Representatives began speaking out against the runway. The Environmental Affairs Office also received over 1000 (2nd highest number of comments in Massachusetts history) comments from the public all against runway 14/32 and instead favoring demand management [127].

Massport continued to move through the environmental review process by holding public review periods. In addition, Massport prepared a supplemental EIS which was requested by the EPA in 2000. Both the EIR and EIS were approved, but Massport could not start construction as long as the injunction at Logan was still in place. As are result, in June of 2001 Massport went to court to have the injunction lifted. Boston, Chelsea, Somerville, and Winthrop were opposing the attempt. Massport eventually won the case and the runway was opened on November 23, 2006 [128].

However, as a result of the lengthy fighting the new runway at Logan took over 30 years from proposal to completion. In addition, a number of compromises surrounding the runway were made. These include: restrictions on runway use, a required peak pricing program, and a program to limit NOx emissions. The runway restriction is currently the only implemented requirement. The restriction requires that the runway be used only during northwest wind conditions when the capacity of the airport drops. Airport authorities state that the runway has helped avoid potential weather related delays [71]. In addition, the new runway actually decreases the noise footprint of the airport when in use. However, noise patterns do shift and when the runway is in use and, as a result, complaints decrease in South Boston and Jamaica Plain, but increase in Chelsea, Somerville, and East Boston [71]. In addition, tension between Massport and the communities continue as communities sue to force Massport to speed up efforts to meet the remaining two requirements of congestion pricing and a NOx reduction program.

## Conclusions

Runway 14/32 was implemented, but only following years of conflict and litigation. As a result, while this change did address the capacity shortfall during adverse weather, it is not clear that it can be called a success. A number of factors contributed to the lengthy dispute over the project as well as to its demise in the 1970s and later success in 2006. These factors include the costs and benefits perceived by different stakeholders, the relationship between these stakeholders, the mechanisms available to block changes, as well as the role of leadership in bring about transition.

Massport believed that a new runway would help reduce delays at the airport and create a positive economic benefit for the region. However, local communities did not want the added noise associated with additional flights at the airport. In addition to the perceived discrepancy in costs and benefits, the two groups had a contentious relationship that stretched back to the 1950s. Past bad interactions led to a difficult working relationship and contention over runway 14/32.

In addition, the creation of the EPA and the passage of NEPA provided a mechanism for communities to fight projects proposed by Massport. In the past Massport could start projects without providing any warning to communities. The environmental review processes allowed communities to comment on projects and also engage in litigation with Massport in attempts to stop runway construction. To more effectively represent their interests throughout the duration of the litigation process local communities became organized and more adept at engaging the media and framing the struggle with Massport as one over environmental justice and equity.

However, it was the changes in local government that may have played the largest role in the history of the runway. When local leadership opposed the runway communities were successful at blocking its implementation and obtaining an injunction against future projects. However, when new leadership that supported the project was elected the runway eventually came into existence.

### 4.2.5 Detailed Capacity Case (CA8): LaGuardia Capacity Limitations

The implementation of slot restrictions at LaGuardia airport (LGA) was chosen as a case study of using demand management to restrict the number of operations at an airport. In most cases of capacity driven transition, adding capacity to the system is the goal. As a result, it is interesting to look at a case where adding capacity did not succeed and the use of a limited resource had to be constrained. This case provides insight into when demand management is used in the system and the difficulties that can arise during and from its implementation. Specifically this case provides insight into the the following aspects of system transition:

- role of a catalytic event in bring about rapid response
- role of removing an existing solution
- role of solution availability in addressing a problem
- role of market mechanisms in managing scarce resources
- role of stakeholder dynamics during a transition
- role of leadership in implementing change

#### The LaGuardia Story

LaGuardia airport is one of the busiest airports in the country. However, because the airport is surrounded by water and the city of New York, expansion is not possible. In the past, as demand continued to increase at the airport, eventually the airport could no longer efficiently service the number of flights requesting to operate at LGA and delays began to grow. Long term solutions were undertaken in order to increase the efficiency of the airport. Currently, more efficiency enhancements are planned and include the implementation of RNAV routes, resectorization of surrounding airspace, adding a new west bound route, and sequencing of aircraft away from the airport [129]. However, the number of flights at LGA was also capped in order to manage demand.

In the US, airlines are allowed to schedule an unlimited number of operations at most airports. However, there are four airports where the number of scheduled operations had to be limited so that the airports would not be over subscribed. LGA is one of the four slot restricted airports in the US. The restrictions were first implemented in 1968 in response to congestion problems [130]. During that time, 68 hourly slots were created at LGA. Of these 48 were allocated to air carriers, 14 to commuters, and 6 were designated as other [131]. Slots were allocated using a grandfathering method where incumbents were more likely to receive them [131]. A secondary market was also created where slots could be bought and sold.

When slot restrictions were first implemented at LGA, the goal was to restrict traffic for one year until a better solution could be identified and implemented. However, in 1969 the restrictions were extended until 1970, than again until 1973. In 1973, when a better solution was still not identified, slot resections were made permanent [67].

During the 1980s, to prevent airlines from holding onto unneeded slots, a minimum usage was added as a requirement to maintain possession of a slot. The required usage was initially 65% over a two month period and later was increased to 80% [131]. During the 1990s, some exemptions were granted at LGA in order to accommodate additional flights. These exemptions were given for international flights, new entrants that were classified as having "extraordinary" circumstances, and for flights providing essential air services to small communities [131]. Such exemptions could not be traded on the secondary market and could only be assigned by the FAA. As a result of exemptions, the total number of slots at the airport grew even though the capacity of the airport did not necessarily increase. As an example 30 new entrant exemptions were granted at the airport during the one year period between 1997 and 1998 [131].

The next major decision regarding slot restrictions at LaGuardia did not occur until the passage of the AIR-21 Act in 2000. With the goal of further deregulation and making increased competition possible, the act announced that slot restrictions would be removed at the airport in 2007 and that exemptions to current limits would be immediately granted to certain operators [67]. In particular new entrants and flights using aircraft with 70 or fewer seats and serving small or non-hub airports were eligible for exemptions [131]. Following the implementation AIR-21, the demand at LGA increased to about double the capacity of the airport as shown in Figure 4-6. The result of this increase was a rapid growth in both departure and arrival delays. Figure 4-7 shows that average delays per aircraft reached 80 to 90 minutes for both departures and arrivals. This rapid increase in delays and a 1.5 hour average delay per aircraft acted as a catalytic event requiring change. The situation appeared on national and local news and was the headline for many local newspapers [129]. This strong pressure created a need for rapid action to fix the situation. This is one of the only examples of a capacity event and provides useful insight for how such events manifest and the following reaction. However, it is important to note that this case is unique in that it was artificially caused by the decision of Congress to remove slot restrictions at LaGuardia.

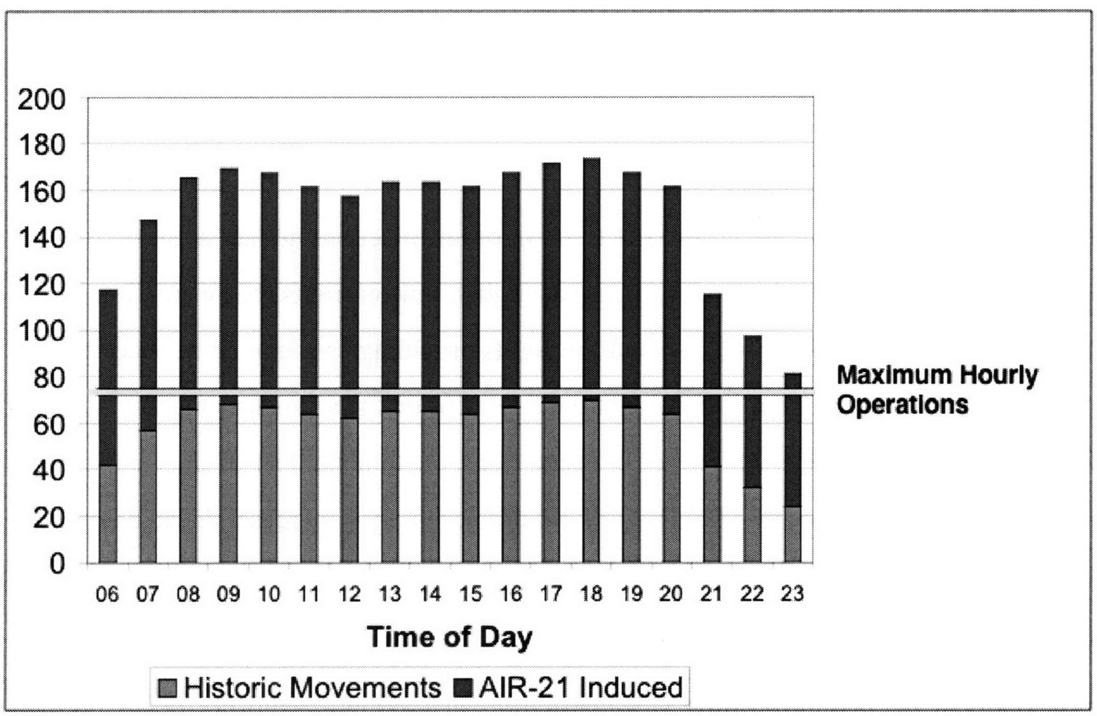


Figure 4-6: LaGuardia Scheduled Operations Following Slot Exemptions [12] (Maximum operations are approximated)

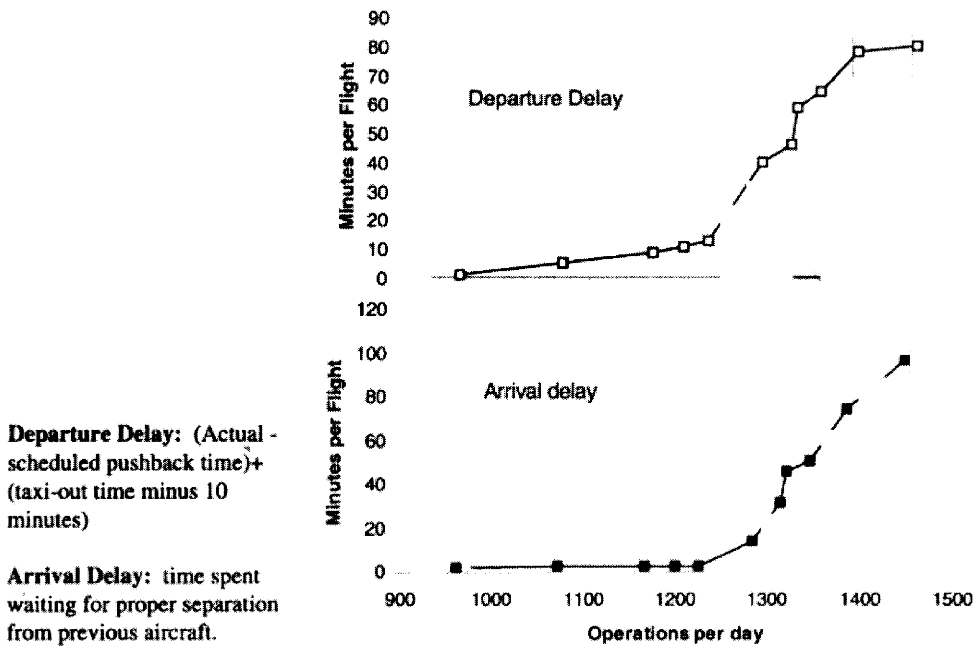


Figure 4-7: LaGuardia Delays Following Slot Exemptions [12]

In response to the rapid increase in delays, the Port Authority of New York and New Jersey, the operator of LaGuardia, quickly moved to reinstate caps on the number of flights allowed. The moratorium on additional flights was implemented on September 19, 2000. The port authority did not have the authority to impose the restriction due the the 14th amendment which prohibits states from limiting interstate commerce [129]. However, their actions was soon backed by the FAA and received support from the public and local Congressional representatives [132]. The FAA showed support and in January 2001 officially limited the number of slot exemptions offered at LGA to 159 [67]. The 159 slots were allocated using lottery with US Airways, United, and Delta gaining the highest number of slots [131].

Intervention on the part of the Port Authority and the FAA was necessary because the airlines did not have incentives to limit schedules. Following the initial passage of AIR-21, airlines wanted to take advantage of the latent (but until then unaccessible) demand for additional flights to and from LaGaurdia. However, leaving allocation of resources at the airport to the airlines resulted in a commons problem where each airline stood to benefit by adding flights, even if it was ultimately to everyone's detriment. In addition, even once it became clear that action to reduce the number of flights would have to be taken, airlines had the incentive to continue adding flights in anticipation of slots being reinstated and assigned, at least in part, based on who already held them.

The capping of traffic was followed by a string of actions similar to those taken in the 1960s and 1970s. When the FAA approved the NY Port Authority's moratorium on additional flights, the cap was to be temporary and last about 9 months. However, it was subsequently extended 4 times until a new cap of 75 scheduled flights and 6 non-scheduled flights per hour was announced in August 2006 and went into effect January 1, 2007. The August announcement by the FAA proposed a Congestion Management Rule for the airport where flights would be capped during the week between 6:30am and 9:59pm and on Saturdays between 12pm and 9:59pm. Slots would be allocated in 15 minute increments for scheduled flights and in 30 minute increments for non-scheduled flights. In addition, allocation would be done based on historic usage of slots. Airlines would have to meet a usage requirement in order to maintain possession of a slot. Furthermore, in oder to encourage the usage of larger aircraft at the airport, airlines would have to meet an annual airport wide aircraft size requirement. However, aircraft serving small and non-hub airports would be exempt from the aircraft size requirement. Finally, the ownership of slots would expire between 2010 and 2019. The slots would then be reassigned in 10 year increments. [133]

The rule proposed by the FAA in August 2006 did not complete the rule making process by January 1, 2007. As a result, the temporary restrictions at LGA were extended [134] because, without the availability of alternate solutions to rapidly increase the capacity at LGA, it was not possible to remove the restrictions without once again increasing delays to an unmanageable level. As of 2008 the rule making process remains pending.

Unfortunately, the implementation of slot restrictions is not a solution where all stakeholders impacted can walk away with a benefit. Who benefits and loses depends on a number of factors. The following is a list of some of the questions that must be addressed in implementing slot restrictions [131]. These questions engender strong disagreements between stakeholders.

- How should a slot be defined? Is it the right to land and takeoff or should access to ramps, gates and other facilities be included?
- Who owns the slot? The FAA, airlines, airports, or should a new entity be created?
- Should there be distinctions between different categories of flights, such as domestic and international?
- Who can exchange slots and how? Swap, lease, sale between airlines or also between other parties.
- How long should a slot be available once assigned?
- How should slots be initially allocated? Grandfathering, lottery, other.
- How should new capacity be allocated when it becomes available?

As part of the rule making process the FAA received and reviewed comments form interested stakeholders. During this time, stakeholders continued to dispute how slot restrictions should be implemented and positioned themselves to lobby leadership in order to influence the final rule. Airlines who currently have adequate slots at LGA want to maintain the status quo where they are allowed to keep these slots and at the same time limit slots available to new competitors. New airlines want access to LGA, and as a result, are unhappy with the status quo. Airlines who have slots claim that the situation is fair to new entrants since they can purchase slots using the secondary market. However, new carriers claim that few or no appealing slots are available for sale. In addition, government entities such as the DOT and DOJ want to maintain competition at the airport. The FAA is in the difficult position of attempting to appease different stakeholders while solving the congestion problem.

### Conclusions

The implementation of slot restrictions at LGA is one of the few existing examples of catalytic events driving system transition in response to capacity needs. The case shows that when the capacity problem becomes severe, and no solution that can rapidly increase the capacity exist, demand management becomes a necessary alternative. The case also illustrates that a number of stakeholders in the system value increasing capacity and do not want to restrict demand. However, for an airport like LGA, which is surrounded by a city and water, there are no expansion opportunities. While efficiency improvement can increase the capacity of the airport, the benefits from these do not necessarily match the pace of growing demand. As a result, as demand continues to increase, more demand management can be expected at other airports with similar qualities to LGA.

The implementation of demand management is not without difficulty. It is a solution where it is not possible to deliver benefits to all stakeholders involved. As a result, strong stakeholder disagreements can be expected. Action on the part of an authority figure will be needed to move past stakeholder differences and implement a change. Such an action is easier to take if delays reach the point where they constitute a catalytic event, due the strong pressure for change that is created.

## 4.2.6 Detailed Capacity Case (CA14): Outdated ATC Surveillance System

The planned implementation of the Automatic Dependent Surveillance Broadcast System ADS-B was chosen as a case study because of the significant role ASD-B plays in planned system changes. ADS-B allows for the exploration of multi-stakeholder dynamics and dependencies and the role they play in transition. It also provides an example of safety certifying a new and complex technology and the barriers that can arise. Specifically this case provides insight into the following aspects of system transition:

- role of stakeholder perceived costs and benefit
- role of relationships and dynamics between stakeholders
- role of safety and approval processes in transition
- role of incentives and structuring a change to ensure benefits

**The ADS-B story**

As mentioned in the introduction, the US Air Transportation System is facing a number of challenges, in particular a need to accommodate more demand, that require transition. In order to address these challenges the JPDO has prepared the NextGen plan to update the current system. ADS-B is a pathfinding technology for the modernization of Air Traffic Management and the Next Generation Air Transportation System. Many of the changes planned in NextGen depend on the implementation of ADS-B [21].

ADS-B is an integrated set of airborne components (avionics) and ground components (ground stations) that provide the position of aircraft and can be used as a replacement or complement to radar-based surveillance, as well as enable other applications. ADS-B avionics broadcast GPS-based position from aircraft to ground-based receivers and other aircraft. The information transmitted includes 3-D position, 3-D velocity, and other data fields. This datalink enables a variety of capabilities on the aircraft and in air traffic control, as shown in Figure 4-8. Broadcast to other aircraft and the ground is named ADS-B-in. Because of the presence of a datalink, aircraft can also receive ADS-B information from other aircraft and receive information from the ground. This functionality is known as ADS-B-out.

The development of ADS-B started in the early 1990s with a desire to take advantage of opportunities presented by the availability of the Global Positioning System (GPS). In particular, in the late 1980s and early 1990s there were a number of airport surface accidents that occurred in Los Angeles, Detroit, and St, Louis. These accidents acted as catalytic events and created pressure on the FAA to provide better surface monitoring. At that time many

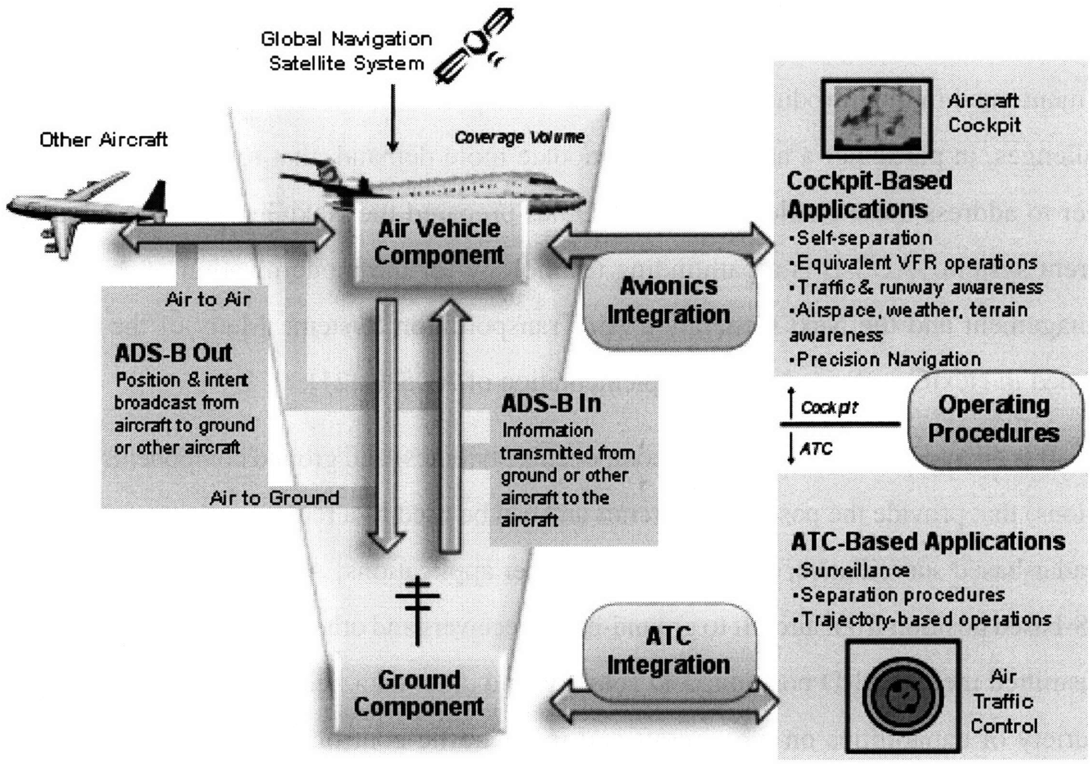


Figure 4-8: Automatic Dependent Surveillance - Broadcast System and Applications [13]

locations could only use primary radar to manage surface operations. Such radar created a lot of false targets and false alerts. Once work was started by the FAA to address the issue, ADS-B was one of the concepts that emerged. In addition to the FAA, The Cargo Airlines Association became interested in the technology as they came to realize that a number of other promising uses existed for it. The growing interest resulted in additional funding being directed toward the development of ADS-B and eventually lead to the adoption of ADS-B as a major component of NextGen. [135]

ADS-B alone does not provide any new capability in the system. Rather it enables applications that then provide new capabilities and potential benefits to stakeholders. A list of potential applications was compiled by Ted Lester and is shown below in Figure 4-9 [14]. The applications are divided into 4 categories. Non-Radar ADS-B-out applications would allow for radar like coverage and procedures in areas where radar coverage currently does not exist enabling better use of that airspace. Radar airspace ADS-B-out applications would improve on current radar based operations because ADS-B provides a higher update rate of displayed information (1 sec as compared to 4.2 sec for terminal radar and 12 sec for en route radar), more reliable information that does not degrade with distance, and additional information not currently available (for example heading and airspeed, altitude). ADS-B-in traffic display applications would allow for Cockpit display of traffic information (CDTI) that would provide pilots with more information about the traffic around them increasing situational awareness and safety. Finally, ADS-B-in datalink applications allow for providing weather and other information in the cockpit. However, this would not be available for all versions of ADS-B and is already available through commercial vendors through other means. [14]

Through the enabled applications, ADS-B has the potential to allow the system to handle a higher number of operations and as a result provide a way to deal with the projected growth of demand [136]. In addition, there are potential safety benefits associated with implementing ADS-B. For example, the NTSB encourages ADS-B as a way to reduce runway incursions [58]. The additional awareness provided to pilots about other aircraft around them can help reduce accidents [14]. Providing radar like coverage in currently uncovered areas

| Application | Application Category |
|---|---|
| *Non-Radar "ADS-B Out" Applications* | |
| Non-Radar Operation Center/Company/Online Flight Tracking | User/Ground |
| Non-Radar Radar-like IFR Enroute Separation | Full Population |
| Non-Radar Increased IFR Airport Acceptance Rate | Full Population |
| Non-Radar Increased VFR Flight Following Coverage | User/Ground |
| Non-Radar ATC Tower Airport Surface Surveillance | Full Population |
| Non-Radar ATC Tower Final Approach and Runway Occupancy Awareness | Full Population |
| *Radar Airspace "ADS-B Out" Applications* | |
| Radar Airspace Improved ATC Traffic Flow Management | Full Population |
| Radar Airspace Increased Enroute Capacity | Full Population |
| Radar Airspace Improved Operation Center/Company/Online Flight Tracking | User/Ground |
| Radar Airspace Monitoring of Parallel Approaches | Full Population |
| Radar Airspace Reduced Separation Standards | Full Population |
| Radar Airspace More Accurate Search and Rescue Response | User/Ground |
| *"ADS-B In" Traffic Display Applications* | |
| CDTI Enhanced Visual Acquisition | Pair-Wise |
| CDTI Cockpit Airport Surface Surveillance | Pair-Wise |
| CDTI Cockpit Final Approach and Runway Occupancy Awareness | Pair-Wise |
| CDTI Assisted Visual Separation (CAVS) | Pair-Wise |
| CDTI Merging and Spacing to a Final Approach Fix | Pair-Wise |
| CDTI Continuous Descent Approach | Pair-Wise |
| CDTI VFR-like Separation in All Weather Conditions | Pair-Wise |
| CDTI Self-separation or Station Keeping | Pair-Wise |
| CDTI In-trail Climbs and Descents | Pair-Wise |
| *"ADS-B In" Datalink Applications* | |
| Datalink Cockpit Weather Information | User/Ground |
| Datalink Cockpit Airspace Information | User/Ground |

Figure 4-9: ADS-B Applications [14]

would also help increase awareness and safety [136]. ADS-B could also potentially provide cost savings to the FAA by allowing them to consolidate or eliminate radar [136].

However, in order to gain these benefits operators must equip with ADS-B avionics, the FAA must install ground stations, and grant safety certification and approval for hardware, software, and specific applications.

Before operators equip with ADS-B, they need to see a sufficient expected benefit from the transition. However, the benefits delivered to airlines and other operators can vary and depend on the specific applications of ADS-B that will be supported. In addition, a critical mass of equipage by operators is required before any operator will see benefits. This means that each stakeholder depends on others to fulfill their part of the transition before benefits can be realized. Such dependencies appear as uncertainties in the cost benefit analysis conducted by stakeholders and impact their objectives. Worse, it creates an incentive for each operator to wait until others equip to reduce their own uncertainty and the time between equipage and delivery of benefits. Since every operator has the same incentive to wait, it is difficult to convince any one stakeholder to act.

Providing incentives for equipage is a potential leverage strategy that can be used to overcome this barrier. However, if sufficient incentives don't exist to generate the needed equipage threshold for system wide benefits it may become necessary to mandate equipage to gain full benefits. A mandate would indicate that those without equipage will not have access to airspace, adding significant costs to those who do not equip. In current plans, the FAA is seeking to encourage early voluntary equipage, but recognizes the need for an ADS-B mandate which is expected in 2020 [137].

To encourage equipage, the FAA is seeking to understand which ADS-B applications deliver the most benefit to operators. By understanding this and providing these applications first, operators can be incentivized to equip with the technology. Working with the FAA, Hansman and Lester conducted a survey to understand which applications of ADS-B are viewed by operators as providing the highest benefits. A detailed description of the methodology and results is reported by Lester and Hansman [14]. Based on the survey results, Lester determined that the strongest leverage mechanisms to accelerate implementation of ADS-B-out are the provision of radar-like separation services in areas where radar coverage is currently lacking. Therefore, adding ADS-B coverage volumes where current use of procedural separation limits access to airspace and airports would encourage operators toward voluntary equipage. For equipage of ADS-B-in, the highest benefits rated by users relate to traffic separation in Visual Flight Rules (VFR) and Marginal Visual Flight Rules (MVFR) conditions, requiring development of procedures and avionics to utilize cockpit-based CDTI.

In addition to convincing users to equip with ADS-B, the FAA must ensure the availability of ground infrastructure, stable technology and procedure requirements, and certified technology for operators to equip with. As a result, the certification and approval process can be a key barrier to implementation if there are difficulties carrying out this process. Due to the innovative nature of some of the ADS-B applications, carrying out the needed approval processes will pose a challenge [16].

The FAA has been and is working on ensuring that this transition occurs successfully. Currently the FAA plans to implement ADS-B nationwide by 2014 [138] and mandate equipage by 2020 [137]. In order to reach this goal, the FAA has taken a phased approach to implementing ADS-B. Early initial trials were performed in Alaska and the Ohio River Valley as operational demonstration programs, which proved initial feasibility of the technology [14]. The main nationwide deployment of ADS-B is divided into segments. Segment one deploys ADS-B to limited key sites, including the Gulf of Mexico, Louisville, Philadelphia [139]. Service is also continued along the East Coast, Alaska, and other areas with legacy ADS-B equipment [139]. Segment two of the program extends ADS-B ground infrastructure nationwide [139]. A mandate is expected requiring ADS-B out equipage to access high density airspace by 2020. This phased approach allows focused cost-benefits delivered in each phase, and facilitates early adoption by specific users or geographic areas.

Segments one and two of the ADS-B program will enable capabilities in the cockpit and in air traffic control surveillance. In the cockpit, applications primarily augment pilot situational awareness. ADS-B-in applications include enhanced visual acquisition (of traffic), enhanced visual approaches, final approach and runway occupancy awareness, and airport surface situational awareness [140]. Broadcast of weather and other aeronautical information also provides additional situation awareness. On the ground, ADS-B-out will be incorporated as a surveillance source for air traffic control services, and to support separation of aircraft on the surface and in the enroute and terminal environment [140].

In the future, more accurate position information, available as a result of ADS-B, offers the opportunity to reduce separation standards. Cockpit-based traffic also provides the potential to delegate separation responsibility from air traffic control to the cockpit under certain conditions. However, these applications are not being implemented in the initial phases of ADS-B deployment.

In addition to plans for implantation and test deployments the technical development of ADS-B has also been proceeding. Specifically, a number of technical decisions regarding communication protocols and requirements for ADS-B have been made. Most notably, a standard protocol for encoding and decoding data has been selected. Three candidate technologies were initially considered to provide transmission and reception of ADS data: Voice Data Link Mode 4 (VDL Mode-4), 1090 Extended Squitter (1090ES), and the Universal Access Transceiver (UAT). After a cost-benefit analysis, VDL Mode 4 was ruled out in cost and benefits, UAT was shown to be less expensive for GA operations and offer a higher bandwidth for uplink of graphical weather information, and 1090ES was shown to be roughly equivalent in performance but less expensive for air carriers because they are already equipped with 1090-Mhz capable Mode S transponder [141, 142]. The final decision in the US was to support ADS-B through both UAT and 1090ES [141]. The decision to support both protocols required the addition of a "MultiLink Gateway" to all ground stations so that UAT traffic information is uplinked to 1090ES equipped aircraft and 1090ES traffic information is uplinked to UAT equipped aircraft, eliminating the ability to perform air to air separation applications without working through ground stations [141]. In this way stakeholder considerations have impacted the architecture of the broadcast communication standard.

In addition to choosing the link technology, choosing a standard protocol on that link has been problematic for stakeholders. The initial ADS-B system performance standards (MASPS) were developed by RTCA, a federal advisory committee, as DO-242. However, limitations and issues with this protocol were discovered. In particular, the way in which GPS integrity and accuracy is characterized proved to be an issue [143]. This led to DO-242A, a newer protocol that resolves many of the problems found with the original standard. However, avionics manufactures and operators have been hesitant to implement the DO-242A standard in equipment because of uncertainty in which standard the FAA will support, or if stakeholders will revise the ADS-B MASPS again in the future. As a result, work to iron out the technical details of ADS-B continues.

### Conclusions

ADS-B represents the potential for significant improvements in the infrastructure and capabilities of the Air Transportation System. However, implementation of this technology will require careful navigation of difficult stakeholder differences. The selection of technical standards has already demonstrated the potential for stakeholder preferences to affect the decision making process. As the FAA moves towards wider deployment, stakeholder issues, such as the resistance to equipage caused by the need for critical mass, will play a larger role. Development and evaluation of viable incentive measures, based on desired applications may serve to mediate this problem. However, dealing with stakeholder differences over technical standards and approval processes may take more effort. Whether the FAA can achieve successful completion of ADS-B deployment will depend in large part on how well they can manage these important issues.

### 4.2.7 Detailed Environment Case (EN3): International Aviation Emissions

The attempt by the EU to gain ICAO agreement to incorporate international carriers into their cap and trade program was chosen as a case study because it is one of the few examples of an attempt to address aviation emissions on a global scale. While many countries have taken measures to limit $CO_2$ emissions, the nature of the problem is global and understanding how the dynamics of a global change occur is needed. The case provides insight into international stakeholder dynamics and the role of authority in bringing about change. Specifically this case provides insight into the following aspects of system transition:

- role of stakeholder dynamics during a transition
- role of leadership in implementing change
- role of solution availability in addressing a problem
- role of market mechanisms in managing scarce resources
- role of existing legal framework as a potential barrier to transition

**The EU/ICAO cap and trade program**

The International Civil Aviation Organization (ICAO) is an international body made up of representative countries which deals with international aviation issues. As part of these issues ICAO is tasked with reducing international aviation emissions. In December 1997 the United Nations Framework Convention on Climate Change (UNFCCC) adopted the Kyoto Protocol which was to be enacted in February 2005. As part of this decision, responsibility for reducing national aviation emissions fell to independent states, however, recognizing the international nature or air travel ICAO received responsibility for coordinating and heading efforts to reduce international aviation emission. As part of this work ICAO undertook studies to better understand the role of emissions as well as to devise better methods of monitoring and gathering emissions data. [144]

In addition, ICAO worked on conducting studies to determine how aviation emissions would best be addressed. Voluntary measures, charges or fees, and emissions trading were considered. Voluntary measures were hard to study, but were encouraged and ICAO provided guidelines to anyone interested in adopting them. Studies between fees and emissions trading showed that trading was the cost effective alternative to reaching emissions targets sets by Kyoto. [145] The determination to pursue emissions trading was made in 2001 and subsequent work focused on understanding how a trading program should be structured [146].

Emissions trading is also known as a cap and trade program and is a market mechanism to limit aviation or other emissions. In such a scheme a cap on the total emissions is placed. Companies are granted permits or allowances for a certain level of emissions, further permits can be traded or purchased from others who do not use them. In this way companies who pollute more than the allotted amount pay companies who pollute less than that amount keeping the cap fixed and creating a market for emissions. [147]

In 2004, during the 6th meeting of the Committee on Aviation Environmental Protection member states agreed that that ICAO should not run whatever cap and trade scheme was devised. Instead the committee passed resolution A3 5-5 urging individual states to develop trading schemes [146]. ICAO again took the role of providing guidelines to countries who were interested in developing emissions trading schemes. This development occurred between 2004 and 2007 [145], with draft guidelines published in February 2007 [146].

While member states did not want ICAO to oversee a cap and trade program the airline industry did. The airlines, as represented by IATA, felt that a world wide open cap and trade program administered by ICAO would create one system rather than forcing the airlines to deal with multiple systems governed by different countries. [148]

During the time that ICAO was working on providing guidelines for a cap and trade program, the EU established a cap and trade program for $CO_2$ emissions called the Emissions Trading System (ETS). The ETS came into effect on January 1st 2005 and is targeted mostly at stationary point sources in the EU. [147]

On December 20, 2006 the EU proposed to extend the ETS to aviation. Initially, in 2011, only flights within the EU would be required to comply. However, starting in 2012 any flights using an EU airport would have to participate. Aircraft operators would have to comply with the ETS in order to continue flying to the EU. With exemptions granted for state aircraft, small private aircraft, and VFR aircraft. [146]

In September 2007, at an ICAO meeting the EU presented its plans for reducing aviation emissions and asked for international support for including non EU airlines in the trading scheme. However, the EU encountered strong opposition from international airlines, represented by the International Airlines and Transport Association (IATA), as well as from the US, China, Brazil, Saudi Arabia and others [84].

The disagreement over the EU proposal is about geographic scope and the power of one state over another. The disagreements are not about the science and understanding about climate change or the utility of using market mechanisms. Rather the disagreements encountered by the EU at ICAO focus around who has the authority to impose what on whom. Europe feels that they can impose their scheme on anyone who flies in the EU, while other countries disagree and hold that mutual consent between participating states is required. [145]

While European airlines have expressed support for the ETS, US airlines feel that a cap and trade program should not be applied to aviation. In their view aviation already has an incentive to reduce carbon emissions because such emissions are tied to fuel use and the cost of fuel has been increasing. Any additional need to spend money would only divert resources from being able to invest in more fuel efficient aircraft and other technologies. In addition, the US airlines worry about the impact of how ETS would be administered. The current plan is for each international airline to have the ETS overseen by the EU country to which they fly the most. This means that different airlines would have to follow rules set out by different states, potentially creating significant differences and a competition imbalance. The European commission is aware of the potential for problems, but it is not clear what the plan to address these issues is. European airlines don't have the same potential for negative impacts because the European Commission will oversee ETS for intra Europe flights and because they have lobbying power in their home countries. [148]

Part of Europe's motivation for attempting to take unilateral action at ICAO may be the strong pressure it is facing to address aviation emissions. The aviation industry in Europe has faced significant negative press and growing pressure to reduce their green house gas contributions [149]. As a result of this backlash against aviation the EU is pressured to act to address the issue. However, the US who strongly opposes the EU proposal, faces different political pressures that drive decision making. During the last few years Europe has seen a 30% increase in fuel use by the aviation sector. At the same time the US has seen a 4% decrease [150] and as a result faces less pressure to address aviation emissions. In the US, noise rather than aviation emissions are still the main focus of political pressure [145]. As a result, the US does not feel pressure to act immediately and has a number of longer term plans to address the problem. These plans focus on technology development, as well as increasing the efficiency of operations [150].

Despite the support of environmental groups and EU's strong pressure for implementation the UN did not back the EU. Because ICAO is made up of representatives from participating countries the strong opposition of these countries was sufficient to overrule the EU. In addition to not supporting the EU, the IACO assembly passed a resolution that its members should sign individual agreements with third parties before applying emissions trading schemes to foreign airlines flying in their territory [151]. As a result of its decision, ICAO has been criticized by some as having abdicated its leadership role in limiting aviation emissions [23, 83]. If accepted by the EU such a resolution would prevent it from including non EU airlines in the ETS. However, the EU filed a formal reservation indicating that it would not follow this resolution [83].

The US and other countries are questioning the legality of the EU decision to continue with their plans to include international carriers in the ETS. In this case there is general consensus on the science behind and understanding of the problem, and there is even agreement that a cap and trade program offers a potential solution. These are issues that stakeholders often use to derail a change when it is perceived to not be beneficial. Rather, the mechanism for blocking action appears to be a legal one. The EU believes that they can legally impose their scheme on international carries, while the US and other countries believe that such an act violates the Chicago convention and numerous bilateral agreements [149]. In addition, such a move also potentially violates the Kyoto protocol which specifically gives jurisdiction over international aviation emissions to ICAO [148]. The result of this difference is likely to be legal action initiated by the US and other states if EU imposes ETS on their carriers; this is likely to be lengthy and stall progress on addressing aviation emissions.

**Conclusions**

As in other cases, stakeholder differences are the dominant factor in how quickly a problem can be addressed. When stakeholders are countries, the process can be exceedingly slow. However, the case demonstrates that, even at this scale, political pressure drives the values and goals of each state. Unlike other cases, the disagreement is not over the science or benefits of the approach; however, economic differences mean that some stakeholders are not interested in adopting the approach. This has resulted in resistance to implementation, likely to be expressed formally as legal action.

Environmental diplomacy is particularly difficult because it is consensus-based. The ICAO does not have strong power over stakeholders or mandate authority to force an action. The fact that the EU can choose not to agree with an ICAO decision demonstrates the limited power of the organization. This decision can only be challenged by other states through litigation. The EU is trying to take action but unless the world buys-in, it becomes difficult to adopt a solution. Without leadership and mandate power it is difficult to carry out transitions that may have short term negative impacts on stakeholders, but provide long term system benefits.

# Chapter 5

# Awareness Building Process

In this and subsequent chapters, the observations from case studies are integrated with literature and the basic feedback framework, presented in Chapter 2 and shown below in Figure 5-1. Each of the subsequent four chapter focuses on a specific process within the model and develops it further by incorporating lessons from specific cases.

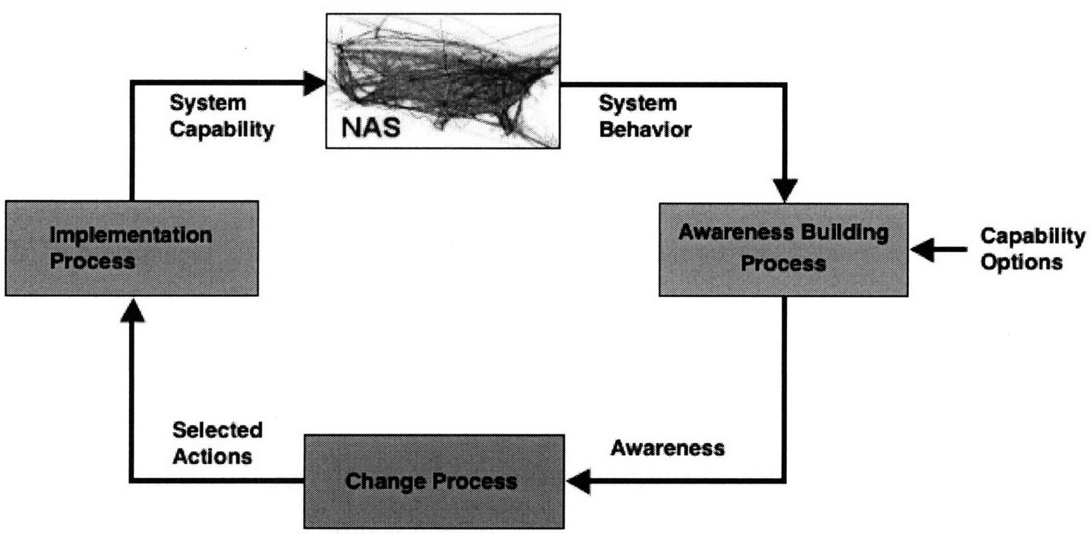


Figure 5-1: Feedback Model Framework

The first process in the transition model captures the building of problem awareness. In problem driven transition, stakeholders must first become aware that a problem exists. Because the US Air Transportation System is a multi-stakeholder system, different stakeholders can become aware of problems and communicate that knowledge to a broader audience. Specifically from this point forward this thesis will refer to stakeholders as those individuals or groups who work within the air transportation system or are directly impacted by a problem. In addition, the media and general public will be discussed as two other groups of interest. The process of problem identification and the building of awareness by different stakeholders and the public is captured by the awareness building process section of the model framework. This chapter uses case studies to explore the process of awareness building in more detail including how problems are identified and how that information is spread to a broader audience.

A detailed model of the awareness building process, shown in Figure 5-2, was constructed based on the dynamics and patterns observed in the early phases of case studies and from the literature. The development of awareness can be broken into three component processes: problem identification, communication, and mental model formation. The input into the awareness process is system behavior, of which catalytic events are a subset. Catalytic events are highly visible events that draw a significant amount of attention and raise awareness of a specific problem or issue. Such events were found to play a key role in addressing past problems in the system and will be discussed further in this chapter.

When deviations from expected or desired system behavior are observed stakeholders may begin work to identify the cause of that behavior leading to problem identification. This dynamic is captured by the problem identification process which is further broken down into system monitoring and analysis capturing the separate actions of monitoring system behavior and conducting analysis to understand the cause and dynamics of a problem. The resulting problem understanding is then communicated with the public and other stakeholders who together with the media engage to frame the issue and generate a definition of the problem. This corresponds to the agenda setting process in the policy literature and is captured by the communication process in the model. In addition to generating problem definitions, each stakeholder in the system will also form an independent belief, or mental model, of how they understand the problem and expect it to evolve. This representation of the situation is later

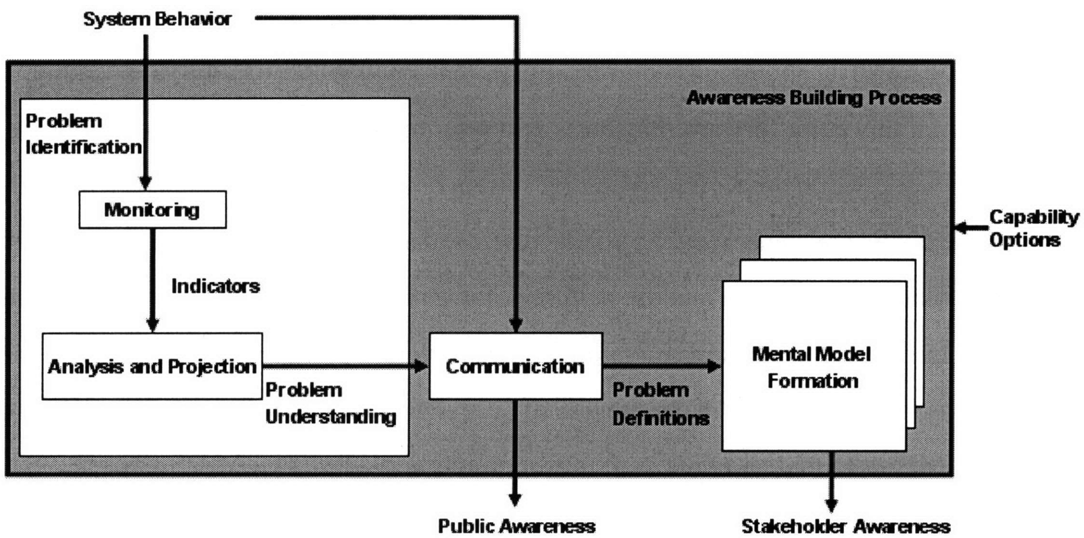


Figure 5-2: Detailed view of Awareness Building process

used by stakeholders to identify what actions they would like to see taken in response to the problem. As a result, capability options are also an input to the awareness building process, since stakeholders must become aware of potential actions that can be taken to address a problem. The awareness building process has two outputs: stakeholder awareness and public awareness. These two categories of awareness are represented separately to capture the fact that when the public becomes engaged it creates higher pressure for change and helps bring about transition.

Figure 5-3 expands the model framework shown in Figure 5-1 to include the key dynamics of the awareness building process. In particular the model captures the role of catalytic events and the resulting public and stakeholder awareness. The remainder of this chapter explores awareness building in more detail.

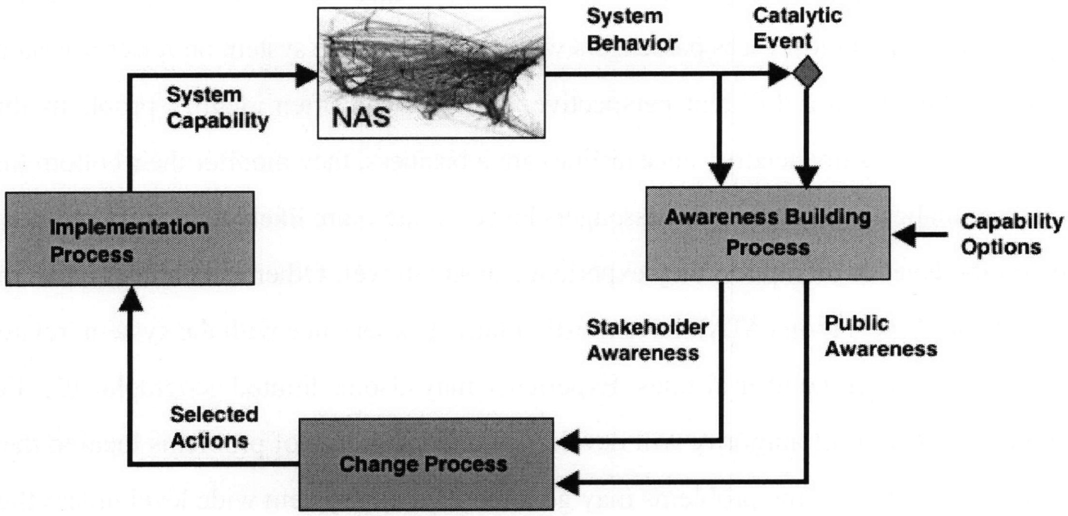


Figure 5-3: Transition Model Including the Awareness Building Process

## 5.1 Identifying the Need for Transition

According to Cobb problem identification is carried out by the identification group and spread to other interested parties [30]. In the Air Transportation System there are two main mechanisms that were observed to contribute to the identification of a problem or need for transition. The simplest mechanism happens when stakeholders who work in and with the system experience inconveniences or system disruptions and in this way observe system behavior. Such mounting experience can lead to a stakeholder identifying these anecdotes as a problem and begin the process of understanding their underlying cause. This leads to the second and more formal identification mechanism—in this mechanism, systematic efforts are taken by a stakeholder or stakeholder group to collect data and process it with the aim of identifying a root cause for observed system behavior.

Stakeholder experience with the system can lead to anecdotal evidence that a problem may exist. However, this mechanism is not sufficient for to create awareness among all stakeholders or for all problems because stakeholders have different and often limited experiences within the Air Transportation System. For example, an operational problem such as delays is experienced directly by airlines and controllers. Passengers have direct experience with delays as well, but in most cases passengers will interact with the system on fewer occasions and view delays from a different perspective. Airlines can often identify problems that manifest themselves financially: since airlines are a business, they monitor their bottom line and any anomalies will be tracked. Passengers however, are more likely to identify problems based on the level of disruption they experience during travel. Other stakeholders, like the Air Transport Association (ATA), have mostly indirect experience with the system, related to them through their member airlines. Experience may also be limited geographically. For example, a local airport authority will develop an understanding of problems local to their jurisdiction, but these same problems may go unnoticed at a system wide level unless they begin to impact other locations. As a result, anecdotal problem identification may lead to different levels of awareness and problem understanding in different stakeholders.

Once experience suggests to a stakeholder that a problem exists, a typical reaction may be to go look at data to learn more about what they are experiencing. Don Bateman and Ted Fujita both conducted research to further investigate their observations. Bateman doing work on understanding controlled flight into terrain (SA1) and Fujita working to understand microbursts (SA2). This begins a more formal version of problem identification where stakeholders look for systematic rather than random errors in the system because systematic errors are likely to be predictable and preventable. Stakeholders may need to gather data (or access routinely gathered data) and perform some analysis to understand if there is a problem and what exactly is happening.

When data is available time trends and patterns in system behavior can be tracked so that deviations from the norm can be noticed. However, in order for such data to exist stakeholders had to decide, a priori, what should be measured. Such metrics are used as indicators of system health and potential problems and are factors that have been determined to signal a particular aspect of system state. For example accidents and incidents are indicators of safety, delays are indicators of system capacity, and the level of $CO_2$ is used as an indicator for climate change.

Data on state of the systems exists because the daily operation of the Air Transportation System, which results in system outputs, is monitored by a number of stakeholders. Over time, various agencies have been formed to monitor system outputs regularly and identify potential problems. For example, the US Department of Transportation's Bureau of Transportation Statistics collects numerous statistics about the regular operation of the system. These include information on accidents, operations, and delays. The NTSB investigates and compiles information on accidents, and financial reports result in economic information about stakeholders, such as airlines, in the system. Monitoring is done in order to build public trust in the system, for system management purposes, and in response to past problems.

The monitoring process produces indicators or metrics used to understand the health and state of the system. Deviations and unexpected trends in this data are investigated and can lead to problem identification. In the case of air transportation safety there is an existing infrastructure for collecting and storing data and for identifying the root cause of accidents. The National Transportation and Safety Board conducts investigations of every accident that occurs. In addition, the Aviation Safety Reporting System (ASRS), and Flight Operational Quality Assurance (FOQA) exist so that accidents and incidents can be tracked and recorded when they occur. These systems came into existence as problems were discovered and the need to monitor system state recognized. New states that need to be monitored can also be introduced as part of a transition in order to monitor how successful that change was. For example monitoring microburst and other weather phenomenon began when their effect on aviation became known. Such monitoring can lead to adaptations in implemented solutions if it is discovered that they do not adequately address the problem they were implemented to solve. Solutions to the microburst problem were implemented until a sufficient one was found. The implementation of GPWS was followed by EGPWS to further reduce the number and risk of accidents.

While initial problem identification is typically done through observation or data collection, subsequent work involves data analysis, modeling, and experimentation in order to determine the underlying causes of indicators, the mechanism of problem behavior and evolution, as well as the implications of the problem. An example is detecting that microbursts exist, but the next step was to understand how they work, where they can be expected, and how to detect them so that pilots could be warned. Similarly for capacity problems observing growing delays is only part of understanding the problem. Knowing how these delays propagate through the system and how to best mitigate them is the next step. Understanding such causes and mechanisms allows stakeholders to address the cause of the problem rather than the symptoms. Problem understanding can be developed based on historical data and trends, but can extend into prediction. Data and the results of data analysis can also be used to model the situation and make predictions. In cases such as understanding the result of growing demand or carbon emissions, models are necessary to predict possible consequences. Such predictions help stakeholders understand how a problem will evolve and therefore how significant it may become. Models often include a number of future scenarios that depend on how the problem will evolve and the possible solutions that can be used to address them.

Abnormalities in data, anecdotal experience, accidents and others visible system malfunctions can all result in a closer analysis of the situation to determine its underlying cause and identify a problem. However, not all problems are easy to detect. Indicators of a problem have to become sufficiently visible for detection to occur. CFIT accidents occurred for a long time before Don Bateman detected and defined them. Similarly, security vulnerabilities were present in the system, but were not highlighted and detected until hijackings and attacks occurred. Furthermore due to limited resources not all anomalies can be investigated in depth. In such cases project champions who have a strong interest in an issue can play a large role in bringing attention to it.

The role of project champions is widely recognized in organizational theory and product development literature. While stakeholders are likely to pay attention to problems because they feel the effects of decreased performance, in some cases a project champion may be necessary to bring awareness to others. A project champion is an individual who has strong dedication to addressing a particular problem or class of problems. Such a person spends a significant amount of time and possibly other resources to spread awareness and generate momentum for change. Project champions are necessary because every problem competes with others for resources and without an advocate a problem may continue to lose in lieu of addressing others.

In the case of Controlled Flight into Terrain (CFIT) Don Bateman acted as a project champion. Bateman worked at Sundstrand (later Honeywell) and is responsible for identifying CIFT as a category of accidents. Bateman began analyzing National Transportation Safety Board (NTSB) accident reports identifying a series of accidents in which an aircraft malfunction did not lead to the accident [88]. In many cases, such accidents were attributed to pilot error and according to Bateman the predominant attitude was that they had not been fit to fly. However he showed that most of these accidents had a set of common features and began to work on raising awareness of this problem as well as on developing a solution. His worked showed that over a 20 year period about 300 CFIT crashes occurred leading to over 4000 lives lost and more than $400 million of financial losses [87]. His efforts and work on this problem contributed to a mandated solution and significant decreases in CFIT accidents.

CFIT is not the only problem addressed with the help of a project champion. TCAS (SA3), TDWR (SA2), in-situ radar (SA2), and other examples were all implemented due to the dedication of a champion. In some cases more than one champion can exist. For example in addressing microbursts Bowles is cited as a champion of in-situ detection [104], while Jim Evans helped develop and implemented TDWR.

Finally, problem analysis is often done building on existing knowledge. Such knowledge plays a role in defining new problems in that it provides monitoring and measurement capabilities, analysis capabilities, and previous understanding of the system. As the analysis process is undertaken and problem understanding begins to take shape the metrics used to monitor the system can be updated to gain more information and better insight into the problem. In addition, new methods of data gathering or analysis may be developed as part of understanding a new problem.

## 5.2 Communication and Dissemination of Awareness to a Broader Audience

Detecting and understanding a problem is not always sufficient in order to address it. Because problems compete with others for attention and resources engaging a broader audience is needed to bring focus and resources to bear on an issue. The broader the audience that is aware, with awareness among the general public being the goal, the more likely it is that an issue will gain agenda space and be addressed [30]. Once initial understanding of a problem exists, stakeholders engage in a process of problem definition and redefinition to engage a broader audience and control how a problem is understood and perceived. The result of this process is a problem definition, which is a specific framing of the problem. It includes the aspects of problem understanding that are shared with others as well as imagery and specific language that becomes associated with the problem [30].

Stakeholders have a vested interest in the outcome of the communication process and as a result work to shape problem definitions to their advantage. This vested interest comes from the fact that how a problem is defined often includes what solutions are deemed acceptable to address it [30]. Multiple definitions of a problem can emerge as a result of different stakeholder views. Alternatively, those involved can converge to one definition that is influenced by the interaction of stakeholders with different beliefs.

In the case of runway 14/32 at Boston Logan airport (CA7), stakeholders favoring the project framed it as economically beneficial to the region. As a result, those opposing the project were seen as selfish and favoring their own interests over those of the region as a whole. However, the formation of Communities Against Runway Expansion (CARE) and their work against the runway helped reframe the issue as one of environmental justice and equity [152]. The issue of carbon emissions and their connection to global warming provides another interesting example of problem definition. Arguments still exist on whether global climate change (which is global warming reframed and renamed) is man made or natural and for many years prior argument existed about whether the phenomenon was taking place at all [153].

There may also be instances where it is in the best interest of a stakeholder to suppress rather than disseminate knowledge of a problem or to fight hard for alternative definitions. If they would lose by the fact that an action to correct the issue would be required a stakeholder may try to suppress awareness. Those who wish to suppress a problem may be at conflict with those who wish to see it addressed. As a result, fights over what data means, how bad a problem actually is, how modeling should occur and what uncertainties mean can occur. In cases where prediction of problems play a large role arguments about how such predictions are done can take a significant amount of time and delay or stall transition. Runway expansion cases show that litigation over runway expansion often take the form of arguments about models predicting the resulting noise contours and other effects on the local environment. Having credible sources of information and prediction can help to create trust in the results. In addition, stakeholders can work to shape public perception about causality and blame striving to assign blame for a problem to a specific stakeholder [154]. This can be particularly important if there are penalties for the party at fault. Following aircraft accidents lawsuits and insurance increases can occur if an airline is deemed responsible.

Methods used to spread awareness during the communication process include publication, presentations, meetings, public and Congressional hearings, as well as the engagement of the media. The interaction and competition between stakeholders for problem definition results in an emergent shared pool of knowledge and information about a particular problem. Depending on how successful the process is more of the general public may be engaged and become interested in the issue and aware of the resulting problem definition [30].

Media, in particular, can play an important role is spreading awareness of an issue to the general public. Cobb and Elder conducted research on the role of awareness in bringing about change [30]. They divided the stakeholders into 4 groups: identification groups, attention groups, the attentive public, and the general public. They discuss how a problem is identified by the identification group and is redefined and reshaped to appeal to a broader audience. If the redefinition process is successful, awareness of the problem may spread from the identification group to the attention group and further with the general public being the most broad audience possible. They showed that the further awareness of an issue spreads the more likely it is to gain space on the national agenda and be addressed. The media can report on what the scientific community and aviation stakeholders have learned about an issue, but they can also directly report on system behavior. In particular catalytic events tend to generate media, and as a result public, attention.

## 5.3 Mental Model Formation

Cognitive science literature states that individuals form internal models, called mental models, of situations as a way to understand them [155]. As a result, the formation of a mental model occurs for stakeholders gaining familiarity with a problem in the Air Transportation System. This mental model formation occurs during the awareness building process. Stakeholders assimilate information from scientific literature, media, and interactions with others to form their own understanding of the issue, which is updated and expanded as new information is learned. Such understanding progresses through perception, comprehension, and projection [156]. Perception is when stakeholders are aware of important information relevant to the problem. Comprehension occurs when they have the ability to combine, interpret, store and retain that information. Finally projection is the ability to use available information to forecast the situation into the future.

The process of mental model formation is influenced by the data and information that becomes available during the communication process as well as the emergent problem definitions that arise. Stakeholders make a judgment about the available information. This judgment is influenced by the values and context of a stakeholders as well as by the credibility of those engaging in the communication process. Stakeholders are also influenced by their own experiences and interactions with the system: The system outputs visible or felt to the stakeholder.

While every stakeholder forms their own mental model, the awareness resulting from the awareness building process has two dimensions. The first is the independent mental model of every stakeholder and the second and the second is the emergent problem definition that becomes accepted by a winder audience and becomes widely known. For the purpose of this thesis the first will be called stakeholder awareness, where stakeholders are those individuals or groups who interact with the system on a regular basis. The second will be called public awareness and refers to the general US public that is not necessarily regularly involved with the Air Transportation System. The distinction between the two groups is important because as pointed out by Elder and Cobb when a broader audience is engaged a problem has more chance of being addressed [30]. As a result, when the public becomes aware of an issue that issue is more likely to gain attention and result in transition. Catalytic events are a key dynamic observed in past cases because they engage the public and help facilitate transition.

## 5.4 The Role of Catalytic Events

Occasionally, highly visible events occur that draw significant amounts of awareness to an issue. Acting as catalysts for change, these events gain media attention which also stimulates the attention of the general public. The result is that pressure on authority figures to act increases making change inevitable if pressure reaches a sufficiently high level. This dynamic was observed to be a key mechanism in bringing about safety driven transitions in the US Air Transportation System.

The existence of such events for safety problems—namely, accidents—has led to many past transitions and safety improvements, including the introduction of positive radar control (SA3) and the ground proximity warning system (SA1). In addition to safety driver, security concerns can also be highlighted by catalytic events: from the earliest hijackings to the attacks of September 11, 2001 (SC2), security failures clearly demonstrate the ability of Congress and the White House to respond quickly to public pressure. However, the role that catalytic events play in bring about change in response to capacity and environmental drivers are less clear, though cases indicate what a capacity event may be.

This section first demonstrates the effectiveness that catalytic events have had in causing transitions in response to safety and security drivers. Through an analysis of news paper articles over the history of the Air Transportation System, the precise kinds of accidents that generate media coverage (and thus awareness) are discussed. The potential for anticipating catalytic events is also addressed. In addition, the state of awareness of capacity and environmental drivers is discussed and the role that catalytic events may play in these cases.

### 5.4.1 Safety Drivers

In the US Air Transportation System, past changes were implemented predominantly in response to safety concerns. In addressing CFIT (SA1), microbursts (SA2), and mid-air collisions (SA3) all the changes were implemented as a result of the awareness and pressure generated by accidents. Every aircraft that departs has an expectation of safely landing at its destination. When this does not occur it is a problem. As a result, detecting and knowing when a safety problem exists is relatively simple and building awareness for safety problems is easier than for other issues. The detection of indicators and identification of a root cause is also enabled by the existing infrastructure for investigating accidents and recording both accident and incident data. In addition, determining a root cause of a given safety failure often occurs rapidly: this short time constant reduces uncertainty and makes it easier to garner support for action. It also means that when a problem is addressed it can be rapidly evident if a solution has been successful and what its effect has been. When the problem is not eliminated following an action it can be seen and sends a clear signal to stakeholders that either the problem understanding or the solution were inadequate.

Finally, because the indicator of safety problems are aviation accidents, the media and general public become involved in the transition process and play a large role in generating pressure for change. Such catalytic events are the dominant reason for the success of safety driven system transition. Table 5-1 shows examples of changes implemented in the US Air Transportation System following accidents that resulted in significant media attention.

| Catalytic Event | Casualties | New System Capability |
|---|---|---|
| *Grand Canyon, AZ (June 30, 1956)* Midair collision between two commercial aircraft in uncontrolled airspace over the Grand Canyon. | 120 | Positive Radar Control was implemented for all flight levels above 18,000, designating them as controlled airspace. (SA3) |
| *Los Cerritos, CA (August 31, 1986)* Midair collision between a commercial and general aviation (GA) aircraft occurred above a residential neighborhood. | 82 | The Traffic Alert and Collision Avoidance System (TCAS) was developed and mandated by the FAA. (SA3) |
| *Dulles, VA (December 1, 1974)* A Controlled Flight into Terrain (CFIT) accident of a Trans World Airlines jet occurred near Berryvilla VA while on approach to Dulles International Airport. | 92 | The Ground Proximity Warning System (GPWS) was mandated for use in all aircraft with more than 10 seats.(SA1) |
| *Cali, Colombia (December 20, 1995)* A CFIT crash of an American Airlines jet near Buga Columbia while on approach to an airport in Cali Columbia. | 159 | Enhanced Ground Proximity Warning System (EGWPS) was mandated. (SA1) |
| *New York, NY (June 24, 1975)* A rapidly evolving weather phenomenon called a microburst caused an Eastern Airlines jet to crash during a thunderstorm while on approach to John F. Kennedy International airport. | 113 | Low Level Windshear Alert System (LLWAS) was implemented at airports in regions with convective weather. (SA2) |
| *Charlotte, NC (July 2, 1994)* A USAir jet crashed after encountering a microburst while attempting to land at Charlotte-Douglas International Airport. | 37 | Terminal Doppler Weather Radar (TDWR) was installed at airports with microburst activity. The system provided significant improvement over LLWAS because it could detect the speed and direction of wind in a volume rather than just along the ground. (SA2) |

Table 5-1: Example Catalytic Events and the Resulting Changes

The implementation of positive radar control shaped the current paradigm of air traffic control. Early controllers managed flights by talking on the phone with airline dispatchers, airway radio operators, and airport traffic controllers. In June 1956, however, a midair collision made it clear that this system was not scaling to safely keep pace with the growth of traffic. Two commercial aircraft requested, and were granted, a scenic detour into uncontrolled airspace over the Grand Canyon. Unfortunately, they did not see one another; the collision resulted into 120 deaths. The resulting outcry led to the hiring of 1400 new controllers, and the deployment of additional towers and navigational aids. Most notably, this led to the implementation of positive radar control. As part of this change radar were installed and all flight levels above 180 (18,000 feet) were designated as controlled airspace where aircraft would be monitored by air traffic controllers.

Although the implementation of radar increased safety, it did not entirely eliminate midair collisions. In 1986, a general aviation (GA) aircraft inadvertently strayed into the controlled airspace around Los Angeles International Airport (LAX); it collided with a commercial aircraft, resulting in 82 casualties, including 15 on the ground. Following this incident, the Traffic Collision Avoidance System (TCAS) was mandated. TCAS provides warnings to pilots of possible midair collisions. Today, TCAS also provides a back-up system for controllers during radar outages, allowing operations to safely continue rather than restricting flights in parts of the system while radars are fixed [157]

Controlled Flight into Terrain (CFIT) accidents were also addressed following large and visible crashes. On December 1st, 1974 on approach to Dulles International Airport a Trans World Airlines Boeing 727 crashed killing 92 passengers. At the time of the accident, the ground proximity warning system (GPWS) was developed and certified for use. Following the accident the FAA mandated equipage with GPWS that same month.

Although the frequency of CFIT accidents decreased significantly after the implementation of GPWS, CFIT was still a major safety threat. The solution to the CFIT problem was updated in the 1990s following an accident at Cali, Colombia. The accident occurred because pilots entered incorrect data into the flight management computer and due to a miscommunication between pilots and controllers about which navigational aid was to be used. At this time progress in technology allowed for an Enhanced GPWS (EGPWS) which contained a database of terrain maps and could warn of potential CFIT crashes with terrain ahead of the aircraft and not only below.

A rapidly evolving weather phenomenon called a microburst can pose a large threat to arriving and departing aircraft. However, when accidents involving microbursts were first detected, there was a poor understanding of the phenomenon. Thus, an understanding of the weather pattern first needed to be developed. In this case both research programs as well as incremental implementations of increasingly better solutions were spurred by multiple accidents. The first of these solutions was the Low Level Windshear Alert System (LLWAS), implemented soon after a microburst crash in June 1975. Research programs and technical improvements continued through the 1980s. The crash of a US Air Jet in 1994 led to the installation of the Terminal Doppler Weather Radar (TDWR) at airports with common microburst activity. Since the implementation of TDWR, there have been no fatal accidents caused my microbursts at airports equipped with the technology. Figure 5-4 shows the pattern of accident and implementation that occurred for this case. Each new accident spurred a new round of research as well as implementation of available solutions.

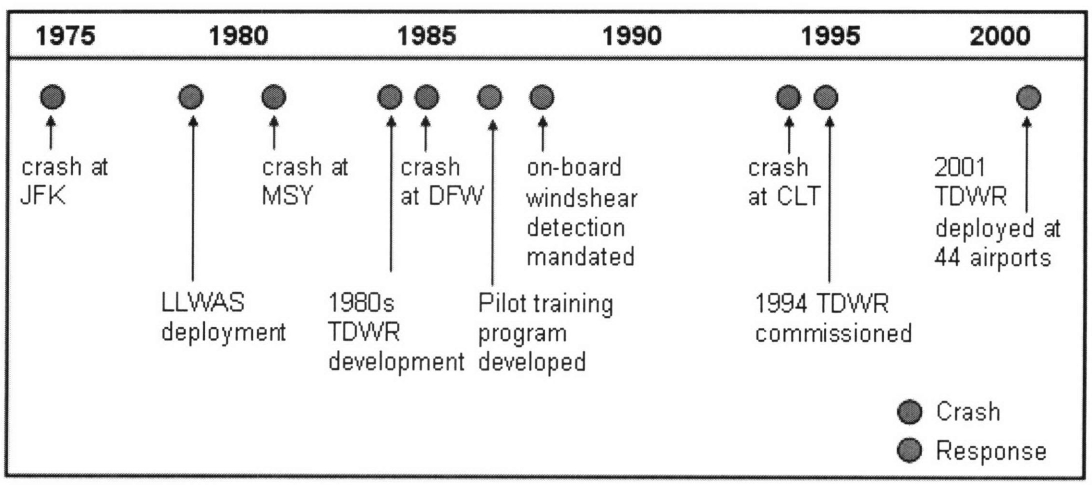


Figure 5-4: Time Line of Events for Addressing Microburst Problem

These examples of past problems highlight a pattern of how changes are introduced into the US Air Transportation System. Problems in the system are defined by stakeholders and the first step to defining something as a problem is to know that it exists. Accidents provide a clear indication that something is amiss. In addition, accidents receive a significant amount of media attention spreading awareness of the event and potential system problems to the public. Such awareness causes pressure for change to occur. This reactive and catalytically driven transition mechanism has been the dominant patten of addressing safety problems in the system.

### Safety Catalytic Events and the Media

While knowing that change occurs in response to events increases understanding of transition processes, predicting which events will result in a strong reaction could be a useful way to anticipate windows of opportunity for change [31] created by catalytic events. This and the following sections strive to better understand what aspects of accidents or the general setting of a transition are likely to result in a catalytic event for safety drivers.

When accidents receive a significant amount of media attention they also raise public awanress. Previous work has indicated that airline accidents receive significant media attention: disproportionate to the their risk of mortality [154]. Risk perception literature postulates that situations which are uncontrollable, potentially catastrophic, and involuntary are perceived as more risky [158]. Cobb and Primo summarize the explanation for our fear of aviation accidents by saying "Once the cabin door closes, passengers are at the mercy of the crew and the equipment. By nature, humans are loath to relinquish control over their fate." [154]

While media does pay attention to accidents, not all accidents receive the same amount of attention. Understanding what accidents gain significant media attention is one way to predict when an accident is likely to be a catalyst for change. In order to understand which accidents drew more attention a content analysis of the front page of The New York Times was conducted. The Pro quest archive was used to search the front page of the New York Times for articles about aviation accidents occurring between 1940 and 2003. The title and first paragraph of each front page story was searched looking for variations of the following key words: airplane, aircraft, airlines, plane, or air travel in combination with safety, crash, accident, or collision. The resulting articles were coded and classified based on the type of article (accident announcement or follow up), the type of accident or incident, the type of aircraft, the location of the crash, the ownership of the aircraft (US or foreign), and whether or not any persons aboard were singled out by name.

Figures 5-5 show the types of articles that appeared on the front page. It can be seen that the majority of articles appearing on the front page of the NY times reported the occurrence of an accident. Followed by mid-air collisions, ground accidents, and near misses. Very few front page articles reported follow up information on a crash. This shows that the initial occurrence of a catalytic event is likely to receive the most visible coverage. In addition Figure 5-6 and Figure 5-7 show the amount of reporting dedicated to accidents by type of operation and location. It can be seen that commercial accidents and accidents where the accident occurred in the US and the aircraft was US owned received the most attention. Finally, the analysis showed that accidents with famous or known persons on board were more likely to become front page news. As a result, accidents that occur in the US, for US carriers, and tend to have high loss of life and known individuals aboard are more likely to be catalytic events. This corresponds to criteria developed by Cobb and Elder who state that media pays attention when accidents have a high number of causalities, have proximity (occur close to major metropolitan areas and readers), have a high causal uncertainty, and have the presence of a political entrepreneur (the equivalent of a project champion in this thesis) [154].

The attention created by accidents creates pressure for change, but is also short lived. In his work, Kingdon asserts that certain circumstances create windows of opportunity during which change can occur [31]. Accidents create such an opportunity for change, but the response must be rapid. Table 5-2 shows the progression of New York Times articles following the Trans World Airlines CFIT crash on December 1, 1974. It can be seen that most of the articles occur on December 2nd and 3rd. After this immediate attention to the issue, the number of articles decreases and none appear on the front page. This indicates that there was awareness of the problem and pressure for change immediately following the crash, but it did not last very long. Accidents create a short window of opportunity during which change can occur and in the case of strong pressure, during which change must occur. Because of the need for rapid response in the face of strong pressure for change, solutions must be developed ahead of time and ready to implement.

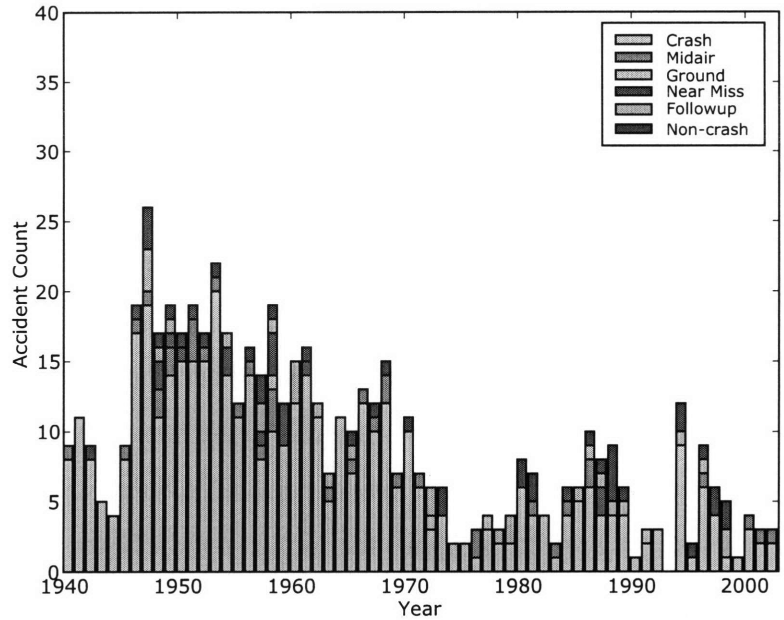


Figure 5-5: Types of Articles Included on the NY Times front Page

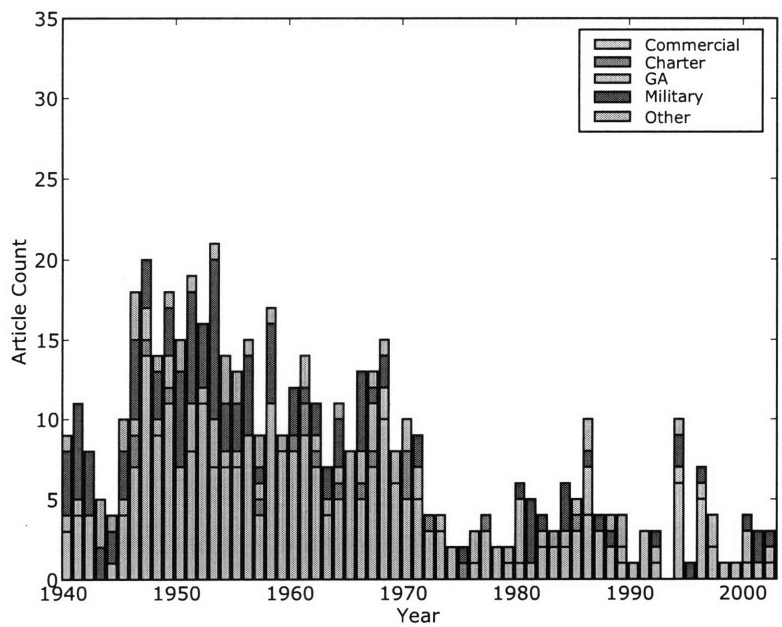


Figure 5-6: Accidents by Aircraft Category

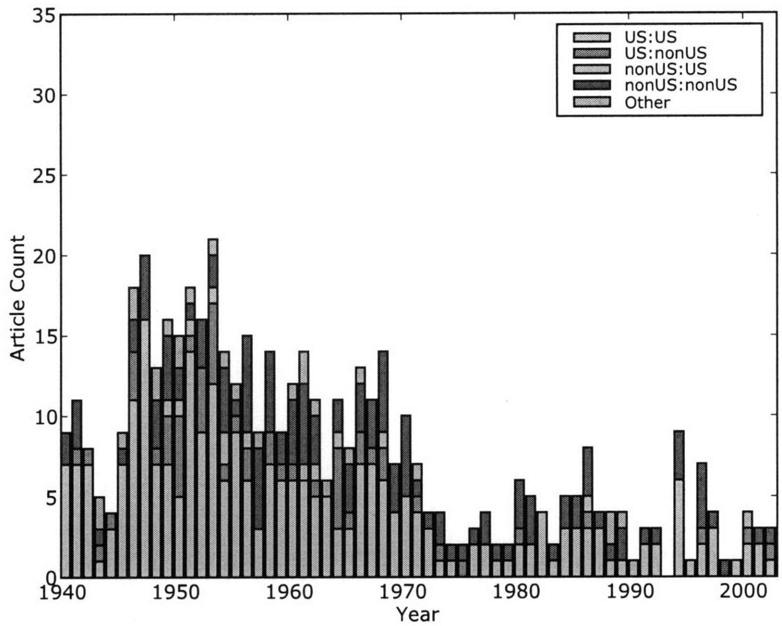


Figure 5-7: Distribution of Accidents by Aircraft Owner and Accident Location

**Mounting Pressure for Change**

A single accident does not necessarily mean that an issue will be addressed or that that event will be catalytic. For some cases, pressure from multiple accidents as well as other mounting factors can contribute to a mounting pressure for change. This pressure reaches a tipping point with an accident that becomes catalytic. The implementation of GPWS (SA1), EGPWS (SA1), TDWR (SA2), Radar (SA3), and other technologies all followed such a pattern.

The adoption of GPWS in response to CFIT is an example of where pressure mounted incrementally until a system transition became inevitable. Figure 5-8 shows the progression of events that led to addressing the CFIT problem. Research and development of CFIT accidents lead to the creation of a new category of accidents and defined them as a problem. Each CFIT accident that occurred following the development of this accident category increased the pressure for change. The NTSB investigated these accidents and recommended that actions, in the form of pilot training and a warning system, be taken. These recommendations created

| Article Date | Article Page Number |
|---|---|
| Dec. 2, 1974 | 1 |
| Dec. 2, 1974 | 21 |
| Dec. 2, 1974 | 21 |
| Dec. 3, 1974 | 81 |
| Dec. 3, 1974 | 81 |
| Dec. 14, 1974 | 21 |
| Dec. 16, 1974 | 32 |
| Nov. 23, 1975 | 22 |
| Jan. 22, 1976 | 39 |

Table 5-2: Example Window of Opportunity Created by the Trans World Airlines CFIT Accident

political pressure for change.

The development of GPWS as a solution for CFIT also resulted in pressure for transition. The solution was developed, certified and approved, and adopted by a number of airlines. These early adopters helped prove that the solution was viable and priced at a rate that was affordable. In addition, the existence of a solution allowed insurance companies to increase insurance rates for aircraft unequipped with GPWS. This increase created further incentive for airlines to equip.

In contrast to groups creating pressure for the FAA to act, the Air Transport Association (ATA) was lobbying the FAA against a mandate for GPWS equipage. This group was representing those airlines that were not interested in equipage with the technology.

Finally, visible accidents and the resulting media and public attention tipped pressure in favor of system transition. Following the accident at Dulles on Dec. 1, 1974, the FAA also experienced pressure from Congress in part because members of the Hill were involved in the accident. In addition, during previous Congressional hearings it was recommended that the FAA mandate GPWS. The combination of past accidents, and existing solution, and pressure from multiple groups for addressing the issue focused strong criticism and pressure on the FAA for not acting sooner. Following the accident and resulting outcry, the FAA rapidly mandated equipage with GPWS.

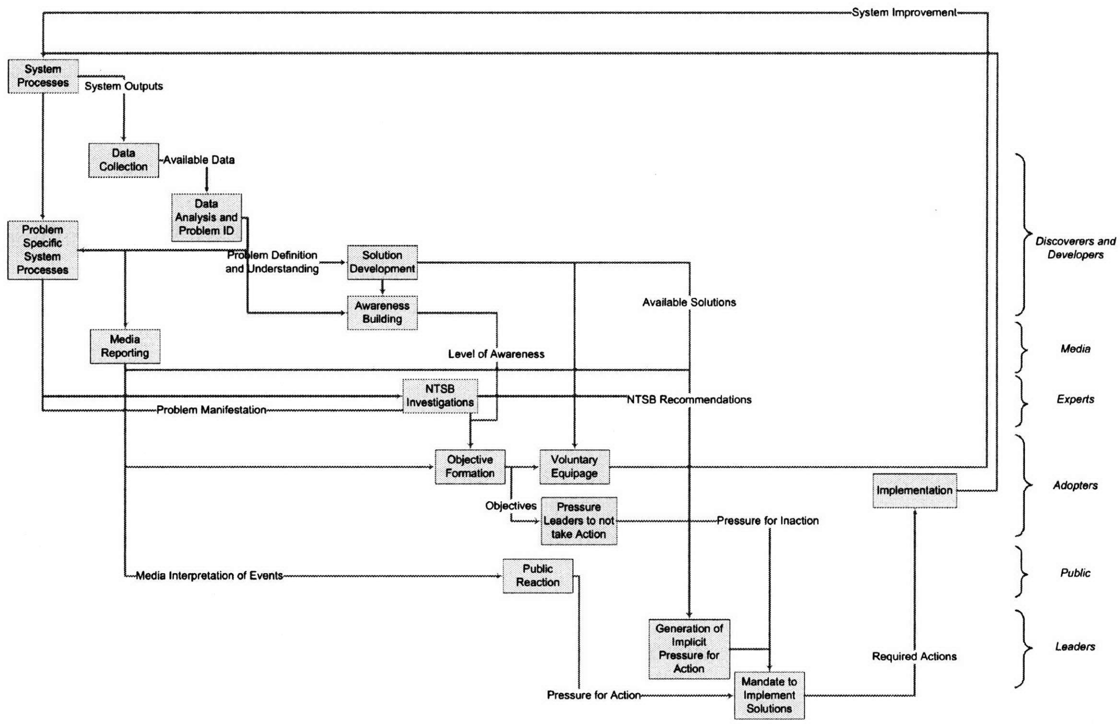


Figure 5-8: GPWS Events Leading to System Transition

### 5.4.2 Security Drivers

The history of the Air Transportation System has demonstrated that security is also a reactive process. Changes have generally been implemented in response to specific security failures in the form of terrorist attacks or attempted terrorist attacks. Like aircraft accidents, hijackings and other terrorist attacks on air transportation create broad public awareness and cause pressure on governments to make changes to prevent future attacks.

Airplane hijackings (or air piracy) began sporadically, mostly being motivated by eastern Europeans seeking asylum in the west. After Fidel Castro came to power in 1959, a wave of hijackings from people seeking to leave or go to Cuba (SC1) led to the government to post armed guards on flights when requested by airlines [27]. By 1961, the problem was bad enough that President Kennedy asked Congress to pass a law making air piracy punishable by death [27].

Kennedy's intervention was the start of a trend of similar responses to air piracy. The FAA formed a Task Force on the Deterrence of Air Piracy that developed a "profile" of potential hijackers and encouraged the deployment of metal detectors. When this was insufficient to deter a series of hijackings in the early 1970s, President Nixon proposed a comprehensive new air security program and push the FAA to complete some rulemaking actions quickly [159].

The most recent and significant example of security being motivated by catalytic events were the attacks of September 11, 2001 (SC2). In addition to the immediate response to shut down the Air Transportation System for two days, the media attention paid to the attack and its aftermath meant that little else was on the national agenda. Security became the primary driver of system change, overshadowing other significant events and displacing other issues. For example, in November 2001, two months after the 9/11 attacks, an American Airlines plane carrying over 250 people (including 5 babies) crashed just after take-off from JFK due to wake turbulence; the most common reaction to this otherwise extremely serious accident was relief that it was not a terrorist act [115]. Delays due to congestion had also been a serious problem prior to the attacks, but little action related to capacity was taken following 9/11. Rather, in aviation, the Bush administration focused on improving baggage screening, cockpit security and deploying additional air marshals. The attacks of 9/11 show the motivating effect that a catalytic event can have in terms of focusing attention and pressure for change on a specific issue. Such focus essentially guarantees that rapid changes will be made.

### 5.4.3 Predictive vs. Reactive Transition

Safety and security driven transitions have led to implemented changes in the system in part because these problems have been addressed reactively. Reactive transition occurs when the change is initiated in response to a problem whose consequences are visible. For example, in the case of safety changes are implemented after accidents have already occurred.

However, as system safety improved, engineers began looking for indicators of problems that have not yet resulted in consequences. In terms of safety, instead of looking at accidents, incidents and near misses are being tracked as indicators of potentially dangerous situations that may lead to accidents. Changing the system in response to precursors of a problem is a predictive transition. For example, adding capacity in anticipation of demand growth or stemming carbon emissions in anticipation of climate change would both be predictive changes. Such changes require modeling to understand and anticipate a problem and usually have a greater level of uncertainty making them more difficult to bring about. In particular, defining the problem and understanding its dynamics is more difficult without clear manifestations of the issue. In addition, moving past stakeholder differences is hard when no clear problem definition, and therefore need for change, exists.

In cases of capacity and environmental transition advocates for predictive change have existed. However, in many cases it is difficult to generate sufficient awareness for change before catalytic events occur. Unfortunately, with issues such as global warming changes can take hundreds of years to reverse and waiting for catalytic events to occur before change is implemented may mean that it is too late to adequately prevent severe and adverse consequences.

## 5.5 When Catalytic Events are Unclear

While addressing safety problems has led to many system changes, not all drivers of transition exhibit clear catalytic events that stimulate change. In the case of both capacity and environment drivers catalytic events are less clear. Without such events it is difficult to generate public awareness of an issue and the resulting pressure for change. Awareness often exists among aviation stakeholders, those who deal with and interact with the system on a daily basis, but without strong pressure for change it difficult to overcome stakeholder interests and differences during the change process (discussed in Chapter 6).

### 5.5.1 Capacity Drivers

Case studied of system transitions show that addressing capacity has not always been as successful. Table 5-3 shows a number of implemented or attempted capacity changes. It can be seen from the figure that cases can fail or succeed only after a significant amount of time. It can be seen that AAS and MLS both failed. The following two planed changes were implemented, but took a very long time. The slot restrictions at LaGuardia were implemented, but fights continue and the final form of the solution is still not definite. Finally the last one is pending, but encountering barriers which will be discussed in later chapters. Not all capacity changes have encountered such problems, but the lack of catalytic events can result in longer stakeholder disputes and barriers during implementation both of which add to the overall time it takes to enact change.

| System Capability | Description | Status |
|---|---|---|
| Advanced Automation System (AAS) (CA1) | Projected increases in demand required an upgrade in controller support tools to allow increased automation. | Failed (1994) |
| Microwave Landing System (MLS) (CA3) | Plans to update ILS with a new technology. | Failed (1994) |
| Reduced Vertical Separation Minima (CA11) | Need for added enroute capacity and international standardization led to RVSM. | Implemented (2005) after 23 years of delay. |
| Runway 14/32 at Boston Logan International Airport (CA7) | Flight delays at Boston Logan Airport, particularly during north west winds, caused the Port Authority to seek another runway. | Implemented (2006) after over 30 years of delay. |
| Slot restrictions at LaGuardia Airport (CA8). | Attempt to remove slot restrictions at La Guardia airport caused sharp increases in delays resulting in an updated slot restriction plan. | Implemented (2000) and updated in (2007) as interim measures. |
| Automatic Dependant Surveillance-Broadcast (ADS-B) (CA14) | Projected increases in demand require a change in the current paradigm of air traffic management. | Pending. |

Table 5-3: Case Studies of Attempted Capacity Driven System Changes

One of the reasons for the difficulties in addressing capacity problems is that capacity problems are difficult to isolate and correct. Accidents and near-accidents are definitive indicators of a safety problem. However, while delays can indicate a capacity problem, they can occur when there is sufficient capacity but, for example, a severe thunderstorm passes near an airport. Further, unlike safety problems, which generally manifest in response to local conditions, delays can have network-wide impacts. As aircraft fly their series of routes during the day, each delay accumulates, affecting the on-time arrival and departure of later flights. Delays can also affect gate availability at airports: a late departure may mean that an incoming aircraft does not have a gate available to disembark its passengers. Weather events can inject delays into many flights simultaneously by closing entire airports or regions of the country. Thus the threshold of delays that signals a system problem is not clear.

As a result, the presence of a delay is not always an indication of a problem: while it is clear that insufficient capacity manifests as delays, there is nothing in capacity that corresponds to the expectation that a plane always lands safely. In fact, the expectation is that some delays will occur and this expectation is built into the schedules of airlines as well as the perceptions of the public [160]. In addition, since delays mount slowly, public expectations can adjust to accommodate these delays without creating strong awareness that a problem exists. Lacking a clear definition of a problem, it can be difficult to generate awareness and override stakeholder barriers that may be preventing capacity improvements.

Aviation stakeholders are aware of capacity problems and see addressing them as an important goal; however, they do not necessarily agree on what the best way to address them is. National plans for developing the Air Transportation System, such as NextGen and the OEP, pay close attention to increasing system capacity in order to handle predicted increases in demand. However, public awareness and pressure is not obvious. Without public awareness stakeholders differences on what changes should be implemented and how are difficult to overcome. In addition, capacity problems often manifest in specific locations and gain awareness in those places, but must become very severe before a more national audience is engaged.

In certain instances, passengers and the public do decide that certain delay related conditions are unacceptable. Extreme delays and poor passenger treatment result in media attention and public outcry that raises awareness and leads to pressure for change. In the winter of 1999, thousands of passengers were stranded at the Detroit Metro airport due to a snow storm. Some passengers were kept aboard aircraft, that never took off, for over 8 hours without adequate food, water, and toilet facilities [161] (CA18). As a result of this incident, the Airline Passenger Rights Act bill was introduced in the House of Representatives [78]. As more incidents of passengers stranded on aircraft occurred subsequent bills were proposed either in the House of Representatives or the Senate; these bills are S 2891, HR 1734, and S 678 [162, 163, 164]. None of these bills have been passed because airlines have successfully lobbied for permission to handle the problems themselves. However, with every incident awareness and pressure for change mounts and will potentially result in a tipping point in the future.

Excessive delays at LaGuardia in 2001 (CA8) also generated significant awareness and pressure for change. In response caps on the number of allowed flights were implemented at the airport. This example is discussed more extensively in Chapter 8. Such cases indicate that catalysts and potentially catalytic events are possible in the case of capacity drivers for change, however, to date only a small number of them has occurred.

As demand continues to increase, the system will reach capacity limits in more places. This will lead to less tolerance for failure and the system will become brittle: smaller and smaller disturbances will propagate non-linearly causing system wide effects. As a result, it can be expected that a major delay event, and possibly a catalytic event, will occur as the system becomes increasingly taxed creating growing awareness and pressure to address this problem.

### 5.5.2 Environmental Drivers

Addressing the problems of $CO_2$ emissions is likely to be one of the most difficult aviation problems to tackle. Aviation emissions are defined as a problem in the context of the general issue of emissions and global climate change. Global warming and environmental damage are problems that exhibit extremely long time constants both for their manifestation and the impact of any changes to address them. This leads to significant uncertainty between cause and effect. Long-term historical data often must be inferred, and projections for the future are necessarily made based on models and predictions. This leads to significant uncertainty in the accuracy of the results. In addition, the impacts of potential solutions are also uncertain. As a result, many political debates are ongoing and use uncertainty very effectively to defer action in favor of continued study or even inaction.

Given the arguments over general human impact on climate and the fact that aviation only contributes 2-3% of carbon dioxide emissions, the awareness and pressure on the air transportation sector to make changes to address the environment is understandably low. However, as general awareness of global warming has been growing, as shown by Figure 5-9, aviation's contribution to this problem is also coming under increased scrutiny. The figure shows the number of New York Times articles dealing with emissions and global warming. It can be seen that interest in and awareness of the issue is growing.

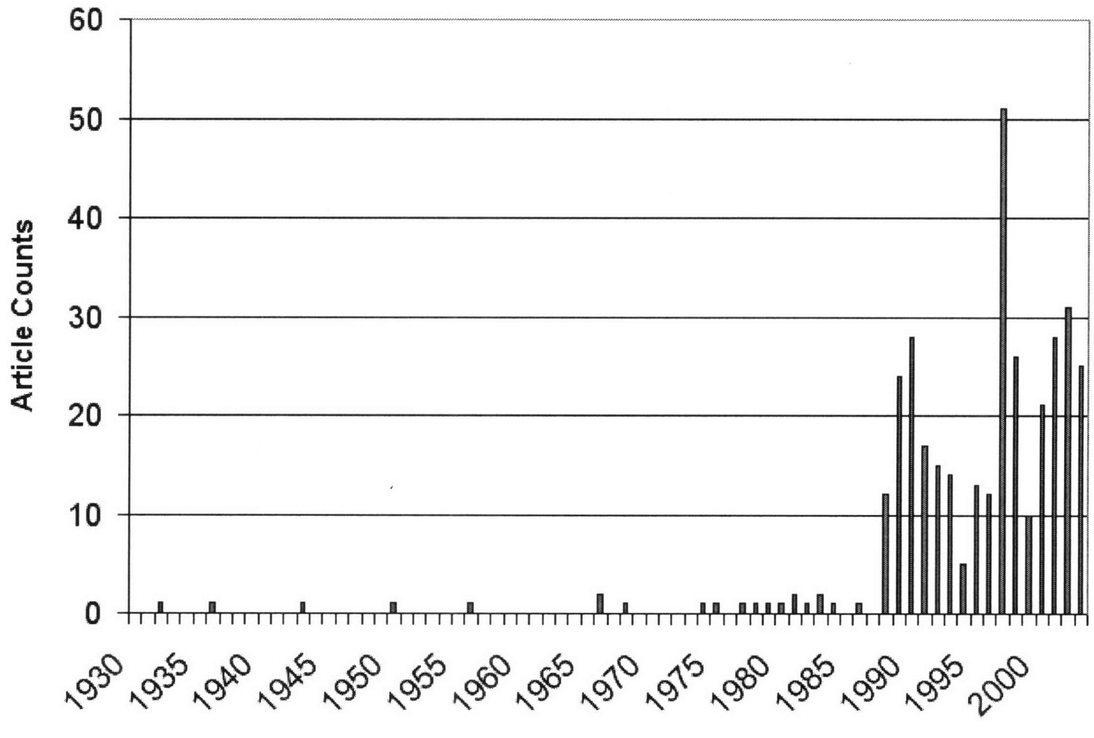


Figure 5-9: Trend in the Number of New York Times Articles dealing with Emissions and Global Climate Change

In the US pressures to address $CO_2$ emissions is growing and the Lieberman Warner bill introduced in Congress in 2007 proposes to create a cap and trade program to limit emissions from major industries including aviation [148]. In Europe the aviation sector is also coming under increasing pressure to reduce or control emissions [165]. It can expected that as pressure to address global emissions increases, the pressure on the US aviation sector to make environmental improvements will continue to grow. As a result, preparations should be made now to develop solutions that can be ready when pressure reaches a critical level.

## 5.6 Implications

As capacity and environmental issues become the dominant drivers for change in the Air Transportation System, waiting for catalytic events may not be a successful transition dynamic. Rather, alternate means of generating awareness and pressure for change may be needed to create the necessary pressure for change.

In addition, when catalytic events do occur they are likely to create strong pressure for change that will need to be rapidly addressed. Developing solutions in anticipation of change would allow for a better use of the windows of opportunity for change created by catalytic events.

# Chapter 6

# Change Process

Once awareness of a problem exists, stakeholders must next decide how to address it. Such decisions are captured in the change process section of the model framework, shown below in Figure 6-1. During this process, stakeholders select actions to address the problem identified and defined during the awareness building process. Selected actions can be chosen from a pool of available existing capability options. However, in some cases, no viable alternatives to address an issue exist. In such cases, the selected action may be to study a problem more closely and work on developing solutions. Whether stakeholders are choosing an existing capability or deciding to develop solutions, in order to select an action stakeholders must decide what it is that they want to occur, resolve potentially divergent objectives of other stakeholders, and commit resources to implementing change.

These processes are represented by two sub-processes: the objective formation process captures how stakeholders forming objectives and the action selection process captures how divergent objectives are resolved and ultimately resources are allocated for carrying out the selected action. The resulting structure is shown in Figure 6-2.

The inputs to the change process are stakeholder and public awareness, as discussed in Chapter 5. Objective formation takes stakeholder awareness and stakeholder values and context as inputs and outputs stakeholder objectives. This process is conducted independently

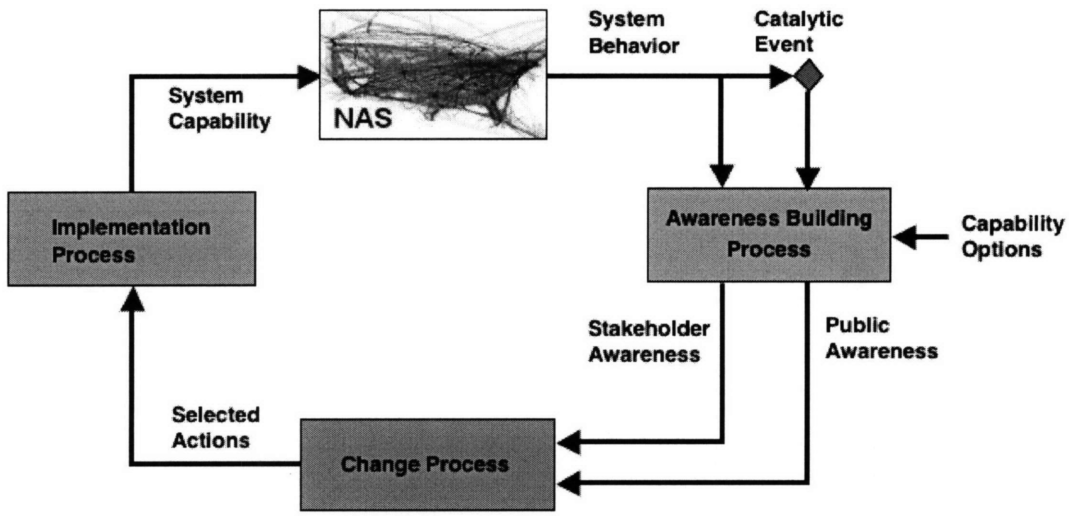


Figure 6-1: Feedback Model Framework

by each stakeholder or stakeholder group as represented by the stacked boxes in the figure. In this step each stakeholder evaluates the potential projections formed during the awareness building process to form objectives for potential actions to implement. In addition to evaluating options stakeholders also form a position as to what action they want to see taken given the range of possibilities.

Examples discussed in this chapter show that, in multi-stakeholder situations, stakeholders must interact and engage to resolve possibly conflicting objectives and choose a collective action. The cases demonstrate that stakeholders take a set of potential actions and select a subset to implement. The interaction that occurs between stakeholders to select a collective action is captured by the decision refinement loop where potential options for compromise feed back to the objective formation process. The decision refinement loop can be a delay loop in the change process. When stakeholders are unable to resolve their differences on problem understanding, the correct action to address the problem, or the details of how a selected action should be implemented delays to transition are created. In addition, to collective actions individual stakeholder actions can also be taken. As a result the action selection process can capture both collective and independent stakeholder actions.

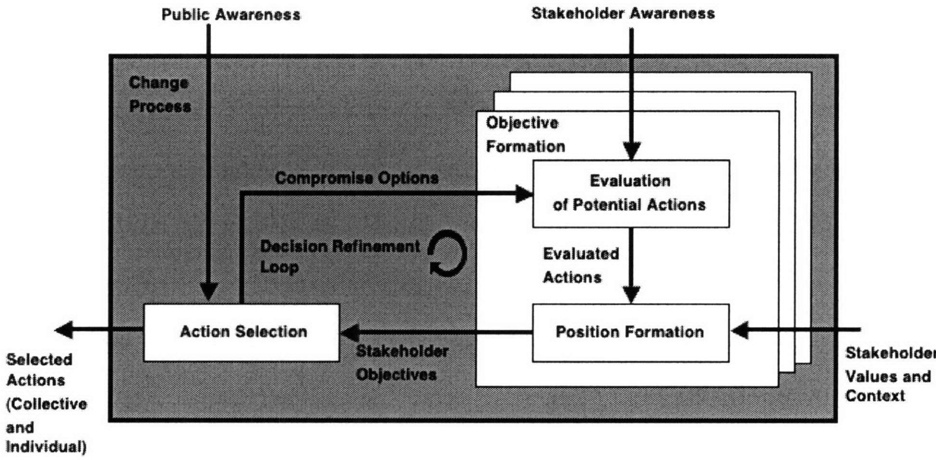


Figure 6-2: Change Process

Figure 6-3 shows a modified version of the transition model that includes the awareness and change processes with the key feedback loops and subprocesses of each included.

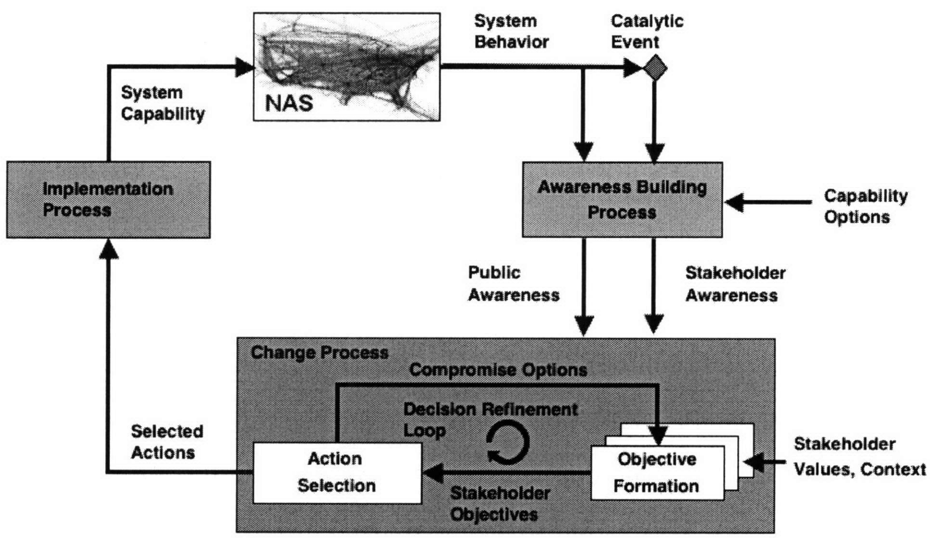


Figure 6-3: Transition Model including Change Process

## 6.1 Objective Formation—Costs and Benefits

In order to implement a change in the air transportation system, the FAA is required to conduct a cost benefit analysis and have it approved by the Office of Management and Budget (OMB) under OMB300 [166]. Airlines and other companies usually calculate an expected return on investment before funds are allocated for the implementation of a change. As a result, the estimation of costs and benefits of a proposed system change play a large role in what objectives stakeholders form.

Marais and Weigel [39] developed a framework for analyzing cost benefit dynamics of stakeholders and showed that while the overall cost benefit analysis for a transition may be favorable, there is no guarantee that individual stakeholders will derive value from the transition. Some stakeholders may reap a disproportionate share of the benefits, while others may incur a disproportionate share of the costs. Stakeholders who are asked to bear a disproportionate share of costs while reaping little benefit can to be reluctant or unwilling to cooperate with a transition effort. As a result, ensuring a successful transition requires looking at the cost and benefit distribution between stakeholders.

In order to understand stakeholder dynamics during the change process, this thesis frames stakeholder objectives in terms of the value distribution provided to each stakeholder by a system transition, where value is the difference between benefits and costs. In addition, a stakeholder's objectives are influenced by their context and values. For example the FAA may favor overall system efficiency while an airline might prefer to maximize their individual profits. Influenced by values and context stakeholders evaluate the costs and benefits of potential actions to address a problem and determine individual objectives. It is important to point out that stakeholders have optimized their operations for the current state of the system and, as a result, can be hesitant to make changes. This hesitancy comes from the uncertainty associated with both the costs and the benefits of potential system changes. Understanding the perceived distribution of costs and benefits between stakeholders can provide insight as to why come changes proceed and others stall.

Individual stakeholders examine the perceived value that a change can provide to determine if it is of positive value. To understand stakeholder cost and benefit dynamics, a simple framework was utilized to describe value delivery and is shown in Figure 6-4. Distinct categories of benefits, such as fuel savings through more efficient operations or reduced out-of-service costs due to increased utilization could be provided by a system change. In this framework, a transition delivers multiple benefits, indexed by $i$, to multiple stakeholders, indexed by $k$. The benefit magnitudes are then considered for each combination, $b_{i,j}$. Changes also come at a cost, which is represented as $c_{j,k}$ where $j$ is the cost category and $k$ represents the stakeholder.

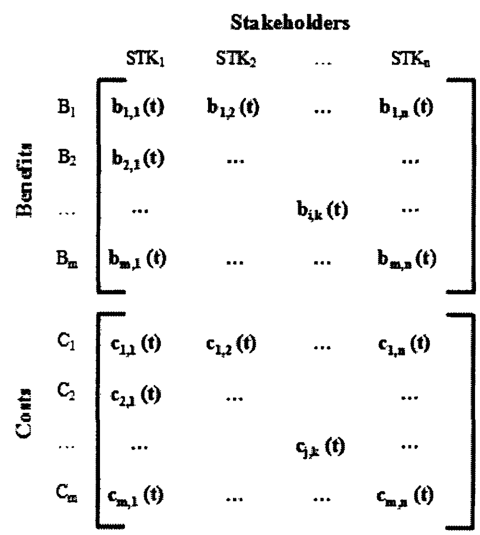


Figure 6-4: Distribution of Costs and Benefits between Stakeholders

Individual stakeholders derive a level of benefit from the implementation of a transition. This benefit is the sum across all benefit categories, as shown in Equation (6.1). The aggregate cost paid for a technology is the sum across cost categories, as shown by Equation (6.2).

$$B_j(t) = \sum_{i=1}^{m} b_{i,j} \tag{6.1}$$

$$C_j(t) = \sum_{i=1}^{m} c_{i,j} \tag{6.2}$$

When examining value distributions for stakeholders in the system, it is important to point out that stakeholders evaluate positions based on perceived costs and benefits, which may differ from the actual costs and benefits delivered. This occurs because perfect information and models to predict costs and benefits do not exist. As a result, the benefit of a change may be discounted by stakeholders if they perceive that is not easily achievable or easily implemented.

Based on the conducted case studies it was found that four different and notable cost benefit dynamics occur and shape the formation of stakeholder objectives. These are:

- single stakeholder cost and benefits (cases: insufficient airport capacity resulting in schedule depeaking (CA4) and secondary airports (CA5))
- multi-stakeholder symmetrical cost and benefits (cases: schedule disruptions due to weather resulting in CDM (CA16) and runway incursions resulting in runway status lights (SA4))
- multi-stakeholder asymmetrical cost and benefits (cases: controlled flight into terrain (SA1) and microbursts (SA2) resulting in the implementation of avionics, all insufficient airport capacity cases resulting in runway construction (CA7, CA6, CA10), growing aircraft emissions resulting in the proposed cap and trade program (EN3), and others)
- multi-stakeholder dependencies (cases: outdated ATC surveillance system resulting in ADS-B (CA14))

Single stakeholder cost and benefit means that a stakeholder is independently impacted by a problem and any action that stakeholder takes will not effect others. Multi-stakeholder symmetrical cost and benefit occurs when all parties that are impacted by a potential change see benefit or all parties see a disbenefit. In both of these cases changing the system is fairly easy; however, they do not occur often. Rather most system changes involve multiple stakeholders and asymmetrical costs and benefits. In the case of multi-stakeholder asymmetrical costs and benefits different stakeholders see different levels of costs and benefits and overall value delivered by a change is positive for some and negative for others. A majority of the case studies examined falls in this category. The case of multi-stakeholder dependencies is one where the level of benefits delivered to each stakeholder depends on the actions of others. ADS-B is the only case studied that exhibits this dynamic. These different dynamics of objective formation impact how action selection is carried out. In the first two cases a stakeholder can either act independently or form consensus. However, in the second two cases stakeholder disagreements can be expected and must be resolved before a change can be implemented.

In addition to a distribution of value between stakeholders, the temporal distribution of costs and benefits needs to be considered since stakeholders must see a return on investment in a reasonable time frame in order to support a transition. Figure 6-5 shows a notional example of costs and benefits distributed over time. Stakeholder objectives will be formulated not only on based on whether a change results in a net benefit, but also on the timing of that benefit. When the levels and distributions of both costs and benefits are certain the net-present value (NPV) can be calculated and used to determine if a transition makes financial sense. Investments in transition are more attractive if benefits are rapidly realized. That is, in addition to a total positive NPV, a positive NPV over the short term is preferable, especially when initial costs are high.

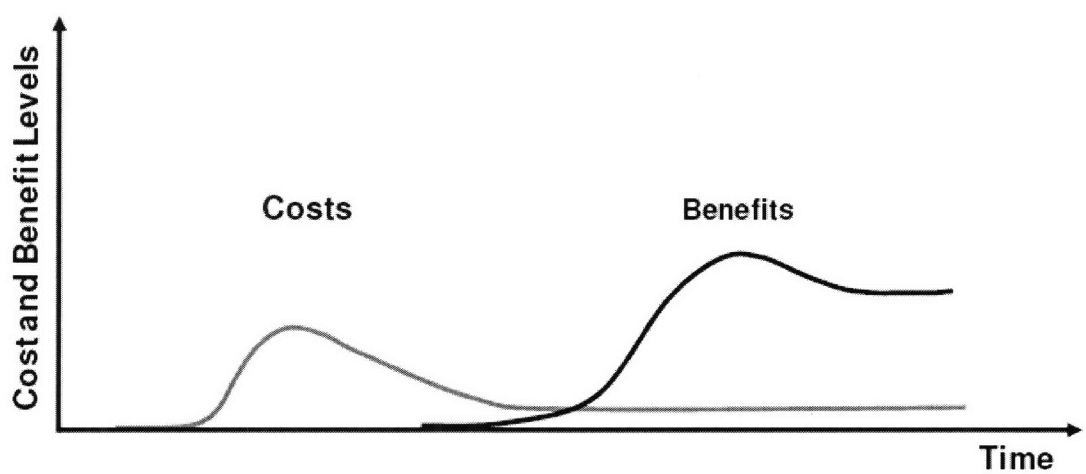


Figure 6-5: Temporal Distribution of Costs and Benefits

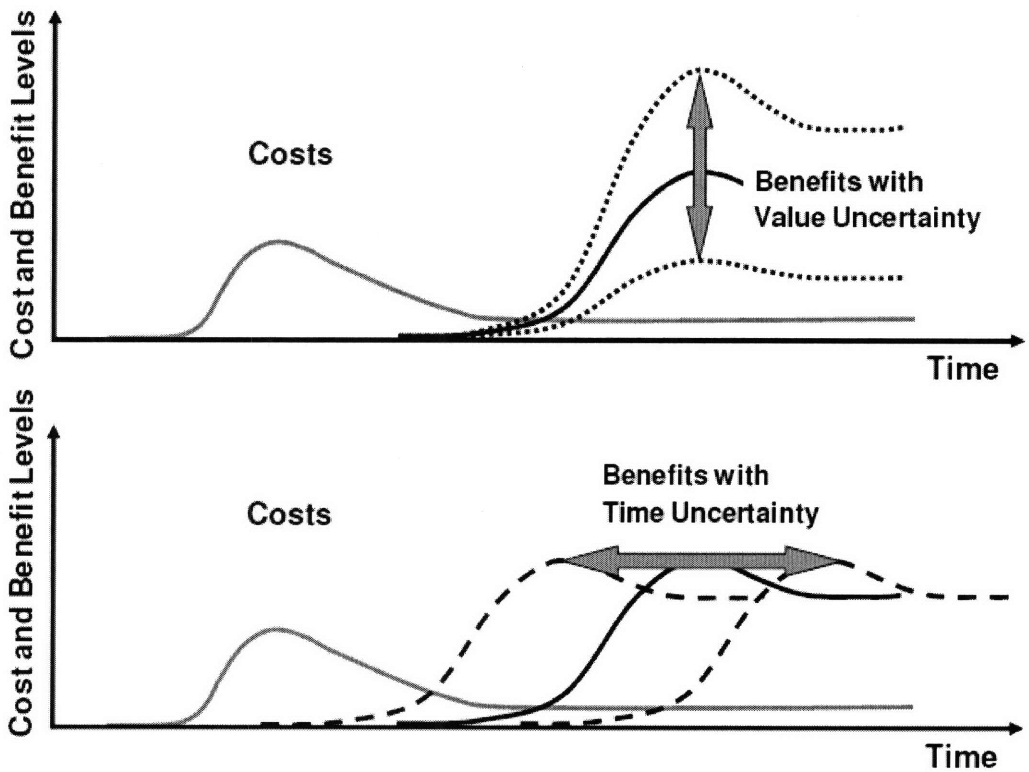


Figure 6-6: Uncertainty in Value and Time of Benefits Delivery

Figure 6-6 shows the effect of both value and time uncertainty on the level of benefits. If value increases or time to realization of benefits decreases, transition becomes more favorable. However, if the level of benefits decreases and time to realize these benefits increases the risk adjusted NPV begins to look less favorable. In most cases estimates of costs and benefits contain uncertainty due to risks associated with system transition. Adjusting for risks in level and time of benefit delivery can change the resulting NPV and potentially reduce the attractiveness of a transition.

The following two sections provide examples of cases where asymmetrical costs and benefits, as well as, multi-stakeholder dependencies and the distribution of costs and benefits over time play a significant role in the transition.

### 6.1.1 Example of Asymmetrical Cost and Benefit Distribution in Cases of Runway Construction

An example where differences in stakeholder objectives clash and impede change occurs during airport expansion. Many airports are currently facing capacity constraints as well as increasing demand, resulting in increased delays. As part of the FAA Operational Evaluation Plan a number of these airports are attempting to expand runway capacity by extending or adding runways. However in many cases these projects have been met with strong community opposition.

The reason for community opposition is apparent from the cost-benefit distributions shown in Figure 6-7. Relevant stakeholders included in the figure are the airlines which operate at an airport in question, the local airport authority, the flying public (specifically those who use the airport), commerce groups, local communities living around the airport and the groups representing them, and the FAA. The local government also plays a role, but is not included in the cost benefit matrix because it is not directly impacted by the construction of the runway, but acts indirectly in the process. Local governments are lobbied by local communities, commerce groups, as well as port authorities and airport users. They are also elected by members of all or some of these groups and have a responsibility to represent their interests.

As can be seen from the figure, local communities perceive themselves as paying most of the non financial costs of the runway, such as increased noise and pollution, while the benefits extend mostly to other groups. Benefits to communities that result from airport expansion are less clear. Strong air transportation is tied to the economic health of regions and can induce economic growth and development, but the effects are difficult to measure and therefore are not apparent to communities as a tangible benefit.

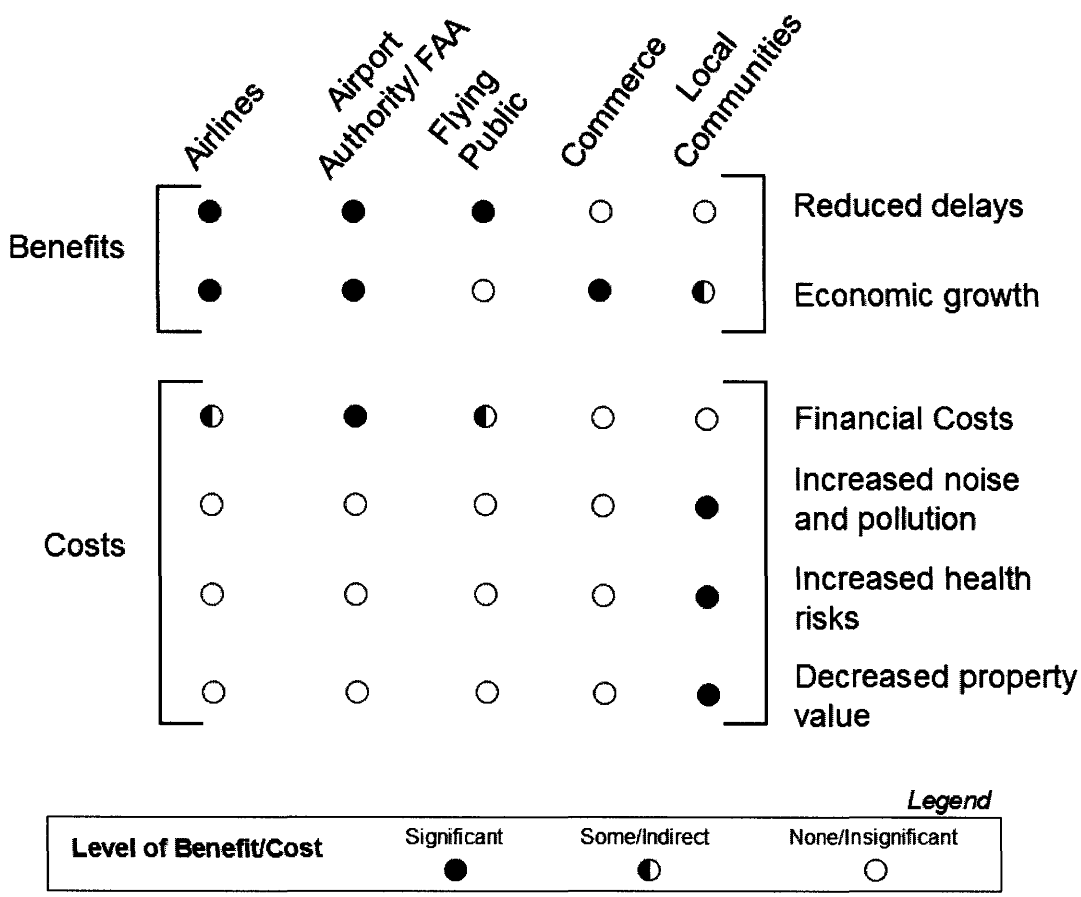


Figure 6-7: Perceived Aggregate Cost Benefit Matrices for Airport Runway Expansion Projects

Because local communities perceive themselves as gaining little benefit from a new runway, but paying substantial cots they invest time and effort into preventing such changes from occuring. There have been successful and rapid (on the order of 10 years) cases of airport expansion projects such as construction of a new runway at ATL (CA6). In these cases the communities are often more removed from the airport. In addition, interested parties anticipate potential stakeholder opposition and mitigate the adverse effects to communities. However, there are also cases such as Boston and Seattle where community opposition is very difficult to overcome and expansion projects can stall for as much as 30 years even when mitigation measures such as sound proofing are implemented and compromises on runway usage are made [128, 167].

### 6.1.2 Example of Multi-Stakeholder Dependencies in Airline Equipage Decisions

An example of multi-stakeholder dependencies occurs when objectives are disparate and the benefits received by each stakeholder depend on the actions taken by others. Such examples occur when airlines need to invest in aircraft equipage, but when benefits from that equipage are delivered only if other airlines chose to equip as well, or if the FAA must provide the necessary infrastructure and approval to make the new equipment usable. In such cases, stakeholders may have an incentive to delay equipage in order to ensure that others act and the transition will definitely take place. Also, stakeholders may want to delay cost so that they occur closer to the realization of benefits. However, this creates a cycle where each stakeholder waits for another to act and as a result the entire transition is delayed.

The case of ADS-B (CA14) is the one example that was studied as part of this thesis where multi-stakeholder dependencies play a significant role. There are three major sources of risk associated with ADS-B implementation. The first is that a critical mass of equipage needs to be reached before stakeholders can begin to receive benefits of implementation. As a result, stakeholders are dependent on the actions of others for ADS-B to be successful. Because there is no guarantee that other operators will equip, there is an incentive for operators to postpone implementation and be the last to equip. In this way they can minimize uncertainty about the actions of others.

Providing incentives for equipage is a potential leverage strategy that can be used to overcome this barrier. However, when insufficient individual equipage for delivery of benefits does not occur it may become necessary to mandate equipage to gain full benefits. A mandate indicates that those without equipage will not have access to airspace adding significant costs to those who do not equip. In current plans, the FAA is seeking to encourage early voluntary equipage, but recognizes the need for an ADS-B mandate in 2020 [168].

The second risk deals with which applications of ADS-B will be supported and when. ADS-B is an enabling technology. This means it does not provide benefits in and of itself, but rather enables the development of applications which deliver benefits. Both the level and timing of benefits will be impacted by the selected applications and their timing. As a result, choosing which applications of ADS-B to support influences the total costs and benefits seen by stakeholders.

The third source of risk deals with the ability and timing of the FAA's infrastructure deployment and completion of safety and certification processes. In order for operators to gain benefits from ADS-B equipage the FAA has to ensure the availability of ground infrastructure, stable technology and procedure requirements, and certified technology for operators to equip with. As a result, the certification and approval process can be a key barrier to implementation if there are difficulties carrying out this process. If these processes are delayed the benefits will be delayed as well. In addition, if some of the processes fail the level of benefits will be significantly decreased.

The uncertainties listed above impact the NPV calculated by stakeholders as part of their cost benefit analysis. Higher levels of uncertainty and delay in the delivery of benefits result in a lower NPV and make a potential transition less attractive to stakeholders thereby creating a barrier to transition.

**Simple Model of Investment Decisions for Airline Equipage** Although ADS-B is the only case studied where the level of airline equipage as well as the timing of benefits played a large role in impacting stakeholder objectives the case can be generalized to better understand operator equipage decisions. Since many changes in the air transportation system require that airlines equip with a new technology, it is important to understand what impacts their decision to do so. To better illustrate the issues in temporal delivery of costs and benefits, the following presents a simple parametric model used to evaluate a hypothetical equipage decision by stakeholders and the impact that delay has on the resulting NPV, as developed in collaboration with Roland Weibel [13].

In this example, investment decisions are made by operators to equip a fleet of aircraft, $n_{\text{fleet}}$, with a technology that will require payment of costs and receipt of benefits as a function of time in operation. Costs are decomposed into two factors: acquisition costs and operational costs. Installing the equipment then results in operational benefits.

As an example, equipage is evaluated for an individual stakeholder's aircraft fleet that requires payment of acquisition and operational cost and delivers operational benefits. The proportion of aircraft equipped, $n_{\text{equip}}/n_{\text{fleet}}$, is modeled as the integral of a normal distribution centered around a mean time, $T_{\text{mean}}$ and with standard deviation $\sigma$ shown in Equation (6.3).

$$n_{\text{equip}}(t) = n_{\text{fleet}} \frac{1}{\sigma\sqrt{2\pi}} e^{\frac{-(t-T_{\text{mean}})^2}{2\sigma^2}} \qquad (6.3)$$

Expanding the model in Equation (6.4), acquisition costs are assumed to be proportional to the number of aircraft equipped in an operators fleet $n_{\text{equip}}$ at a unit acquisition cost per aircraft of $C_{\text{unitacq}}$. The acquisition cost function accounts for costs such as the purchase and installation of equipment, aircraft out-of-service costs during installation, and crew training, and certification costs.

$$\begin{aligned} C_{\text{acq}}(t) &= C_{\text{unitacq}} n_{\text{equip}}(t) \\ &= C_{\text{unitacq}} n_{\text{fleet}} \frac{1}{\sigma\sqrt{2\pi}} e^{\frac{-(t-T_{\text{mean}})^2}{2\sigma^2}} \end{aligned} \tag{6.4}$$

Total acquisition is calculated from the integral of incremental acquisition cost over time, as shown in Equation 6.5.

$$C_{\text{totacq}} = C_{\text{unitacq}} n_{\text{fleet}} \int_0^{\infty} \frac{1}{\sigma\sqrt{2\pi}} e^{\frac{-(t-T_{\text{mean}})^2}{2\sigma^2}} dt \tag{6.5}$$

As modeled in Equation 6.6, operating costs include recurring maintenance on the equipment, potential subscription or service rates, or depreciation of equipment. Operating costs are modeled as proportional to the total number of aircraft equipped from Equation (6.3) by the unit cost of operation per piece of equipment, $C_{\text{unitop}}$. The total number of aircraft equipped at a given time is given by the cumulative distribution function of equipage, $\Phi_{\text{equip}}(t)$.

$$\begin{aligned} C_{\text{op}}(t) &= C_{\text{unitop}} \int_0^{t} n_{\text{fleet}} \frac{1}{\sigma\sqrt{2\pi}} e^{\frac{-(x-T_{\text{mean}})^2}{2\sigma^2}} dx \\ &= C_{\text{unitop}} n_{\text{fleet}} \Phi_{\text{equip}}(t) \end{aligned} \tag{6.6}$$

In this example, operational benefits can include multiple categories of benefits, such as operational efficiency savings, cost avoidance, or prioritized access to resources, depending on the structure of the program. Operational benefits are modeled proportional to the number of aircraft equipped at a unit benefit of $B_{\text{unitop}}$, similar to operational costs. Delivery of operational benefits is assumed to require the implementation of supporting infrastructure and operational approval to utilize the technology and infrastructure. Therefore, benefits can be delayed relative to equipage.

To model the effect of delay in the delivery of benefits, benefits are assumed to begin at a time, $T_{\text{delay}}$, when a given percentage of the fleet has already been equipped. Thus, the benefits function is defined piecewise, as shown in Equation (7). No benefits are delivered before $T_{\text{delay}}$. After $T_{\text{delay}}$, benefits are proportional to the cumulative fleet equipage.

$$B_{\text{op}}(t) = \begin{cases} 0 & \text{for } t < T_{\text{delay}} \\ B_{\text{unitop}} \int_0^t n_{\text{fleet}} \frac{1}{\sigma\sqrt{2\pi}} e^{\frac{-(x-T_{\text{mean}})^2}{2\sigma^2}} dx & \text{for } t \geq T_{\text{delay}} \end{cases}$$
$$= \begin{cases} 0 & \text{for } t < T_{\text{delay}} \\ B_{\text{unitop}} n_{\text{fleet}} \Phi_{\text{equip}}(t) & \text{for } t \geq T_{\text{delay}} \end{cases} \tag{6.7}$$

Equations (6.3) through (6.7) describe a simple model of acquisition costs, operating costs, and operating benefits. These factors are summarized in Figure 6-8 which shows the distribution of costs and benefits as a function of time.

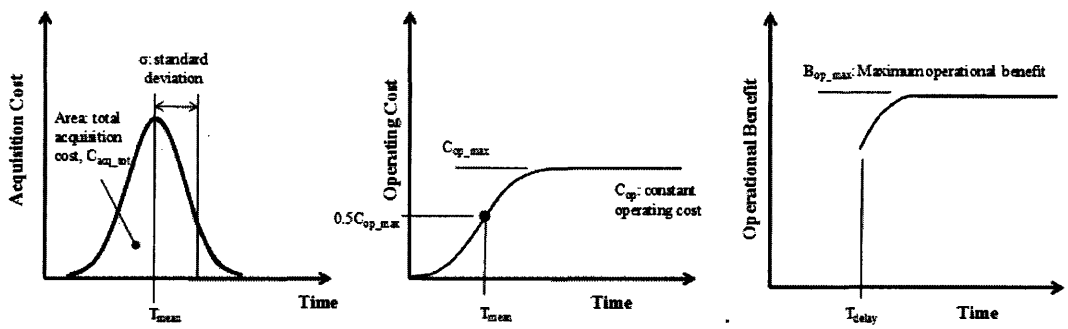


Figure 6-8: Temporal Distribution of Costs and Benefits

Representing the technology or change adoption decision using investment analysis, the net present value (NPV) of a given combination of costs and benefits is indicative of the attractiveness of investment. The net present value is calculated by discretizing costs and benefits to annual net cash flows. Future cash flows are discounted a rate $\gamma$. The resultng NPV is shown in Equation (6.8).

$$\text{NPV} = \sum_{t=0}^{t=T} \frac{B_{\text{op}}(t) - \lfloor C_{\text{acq}}(t) + C_{\text{op}}(t) \rfloor}{(1+\gamma)^t} \tag{6.8}$$

**Equipage Evaluation** To illustrate issues in temporal aspects of value delivery, the simple model introduced in Equations (6.3) through (6.8) is used to describe the influence of several equipage parameters. For the analysis, several assumptions were made. In the absence of specific cost and benefit data, the total acquisition cost, $C_{\text{acqtot}}$ was normalized to 1. Additional trades are presented as multiples of total acquisition cost or unit operating cost. For example, a displayed NPV/$C_{\text{acqtot}}$ of 1.5 indicates a present value of 1.5 times the total acquisition cost. Additionally, a standard discount rate, $\gamma$, of 7% was applied to future benefits, and a unit operational to acquisition cost ratio $(C_{\text{unitop}}/C_{\text{unitacq}})$ of 10% was assumed. Acquisition costs were distributed around a mean time of 5 years, with a standard deviation of 2 years, indicative of 95% equipage within an 8 year time span. The magnitude of benefits was varied as a ratio to operating costs, essentially varying net benefits. A Net Present Value over 25 years of operation is indicative of the attractiveness of equipage over an approximate system's life cycle, although in business decisions financial return would certainly be required sooner. The effect of delaying the implementation of benefits on Net Present value under these assumptions is shown in Figure 6-9. The benefit/cost ratio required for a break-even NPV for different delay times can also be determined, and is shown in Figure 6-10.

Because of up-front acquisition costs, early cash flows are strongly negative. Therefore, large net operational benefits are required to pay off the initial investment. The NPV is negative for any implementation time when the magnitude of operational benefits is just under twice the operational cost. Even when benefits are high, delaying implementation significantly reduces the net present value of equipment, especially beyond the acquisition time period (approximately 8 years). If benefits are delayed significantly, levels of operational benefits have a weaker influence. The net present value becomes negative regardless of the magnitude of benefits within the range shown after 15 years.

Time delays in benefits delivery occur due to a mismatch between acquisition times and delivery of operational benefits. Causes of this mismatch can include dependency on other stakeholders to equip with similar technology, or requirements for certification before using the technology. Perception of delays is also a strong disincentive for equipage. If stakeholders

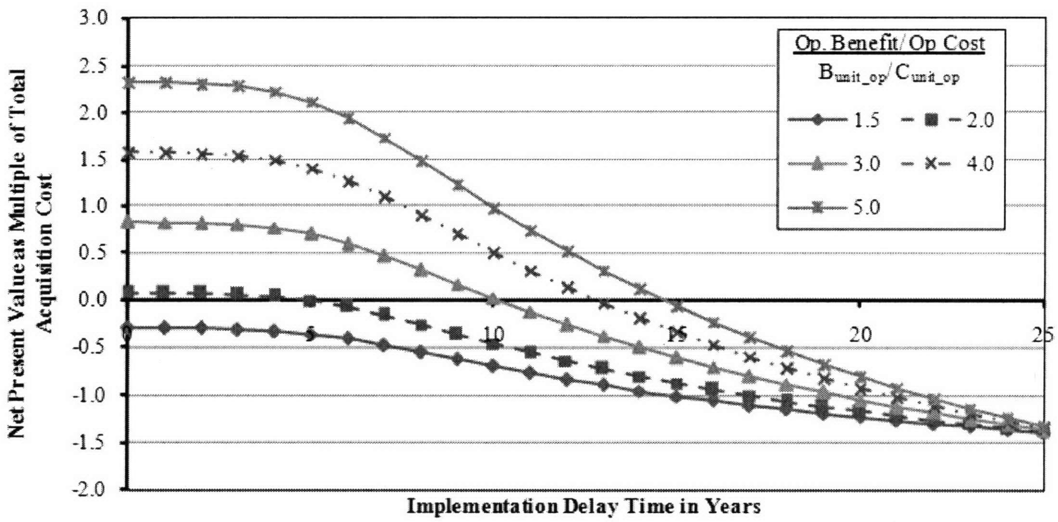


Figure 6-9: Influence of Implementation Delay on Net Present Value (assumed 7% discount rate, 10% operational to acquisition cost, normally distributed equipage with mean of 5 years and standard deviation of 3 years)

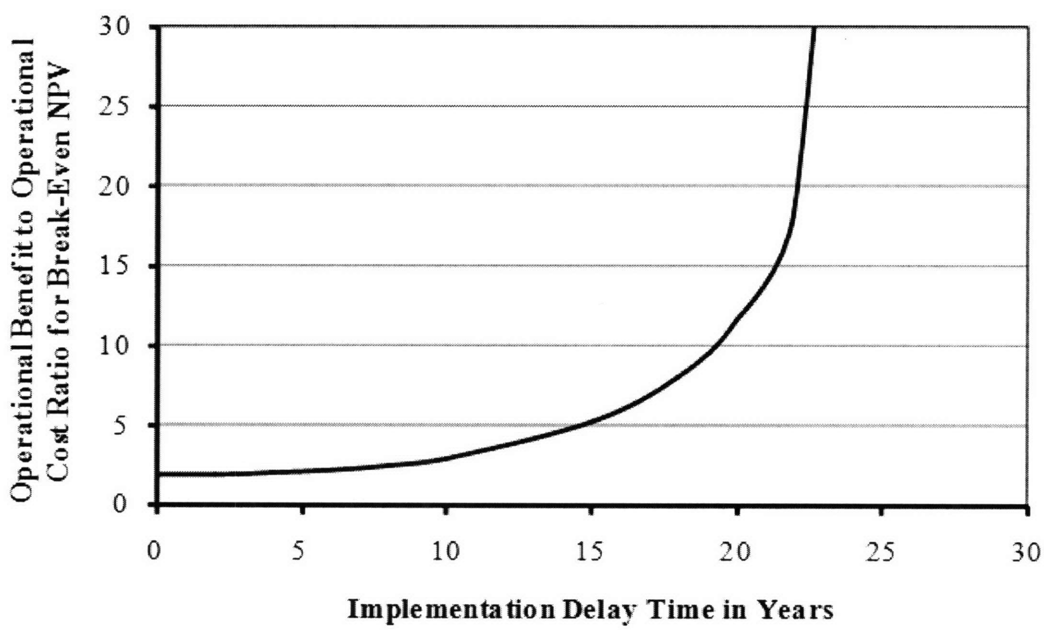


Figure 6-10: Benefit Magnitude Required for Break-Even NPV

incorporate uncertainty into their estimate of benefit delivery time or magnitude due to risks of benefit delivery, technology value is reduced. As a result, to structure successful technology adoption, it is useful to reduce the delay of benefits delivery as much as possible.

## 6.2 Action Selection and Decision Refinement

Once stakeholder objectives have been established a action must still be selected. However, formed objectives do not guarantee an action, in particular when multi-stakeholders with different objectives exist. In such cases differences between stakeholders must be resolved to collectively select and action. This process is captured in the model through the action selection process and decision refinement loop as shown in Figure 6-11.

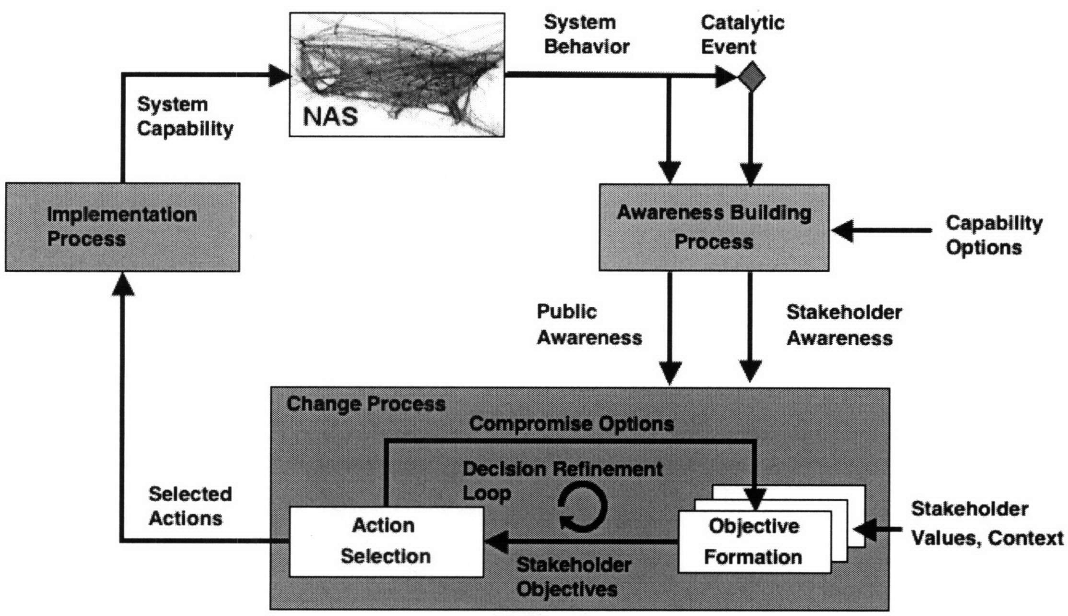


Figure 6-11: Feedback Model Framework

Based on case studies four important types of action selection were identified and include:

- Independent Action: when as single stakeholder can make a decision and enact change without affecting others
  - Example Cases: insufficient airport capacity resulting in schedule depeaking (CA4) and secondary airports (CA5)
- Consensus: when stakeholders must work together to resolve differences to select an action
  - Example Cases: schedule disruptions due to weather resulting in CDM (CA16) and runway incursions resulting in runway status lights (SA4)
- Authority: when stakeholders work to educate and influence and authority figure who has the power to make a decision
  - Example Cases: controlled flight (SA1) into terrain and microbursts (SA2) resulting in the implementation of avionics, insufficient airport capacity resulting in slot restrictions (CA8, CA9), aviation noise resulting in stage 2 and 3 aircraft engines (EN2), and others
- Stagnation: when no resolution can be found between stakeholders and transition is not enacted
  - Example Cases: growing aircraft emissions resulting in the proposed cap and trade program (EN3)

**Independent Action** Independent action can occur when a system change requires that only a single stakeholder act, and that action does not have an adverse affect on anyone else. In such a case, the stakeholder objectives and action selection are one and the same. The stakeholder has the power to independently chose an action and implement it. This is mostly likely to occur in cases of single stakeholder cost and benefit objective formation. An example of such a single stakeholder independent action change is the depeaking of schedules by airlines at airports and the movement of operations to secondary airports. Airlines can make these decisions without needed agreement from other stakeholders.

**Consensus** In some cases of transition stakeholders with divergent objectives can interact and refine an action until consensus is reached. This is simplest to achieve in cases of symmetrical benefits where all stakeholders receive benefits that outweigh costs. Such changes include the implementation of Collaborative Decision Making (CDM) as well as the implementation of runway status lights. CDM was implemented to allow airlines, in collaboration with the FAA, to share data in order to better make decisions about canceling and reschedule flights when resources become strained. By taking part in CDM airlines have access to data that allows them to make better decision in cases where system capacity is constrained do to weather or other circumstances. As a result, delays and disruptions can be better managed. The case of addressing runway incursions with runway status light provides another example where stakeholders received clear benefits. Status lights provide a warning if a potential runway incursion conflict exists. It provides an extra safety measure while not requiring training or equipage by airlines. As a result, safety is increased while airlines do not bear any cost for the added benefit.

Consensus can also be built in situations where multiple stakeholders exist and have asymmetrical costs and benefits. In these cases mitigation, incentives, and other measures can be used to shift stakeholder objectives. However, building consensus when not every stakeholder benefits is challenging and often an authority figure is needed to bring about transition.

**Authority** Of the 7 detailed cases studied, 6 involved the use of authority in the form of a mandate, law, or the involvement of courts. Such actions are imposed by an authority figure, who has the power to impose a decision on other stakeholders and is often necessary to bring about change in multi-stakeholder situations where asymmetrical costs and benefits exist. The intervention of an authority figure is different than independent action in that the authority figure is influenced by the other stakeholders and cannot make a unilateral decision that is not supported by anyone else. For example the FAA is lobbied by other stakeholder attempting to influence decisions.

Public awareness can also play s significant role during collective action selection. Such awareness can impact the decision made by an authority figure by creating pressure for action. In addition, stakeholder objectives can change when public awareness exists. For example, if it becomes clear to stakeholder that leadership will act in response to public awareness and pressure they may begin supporting an action rather than blocking a transition.

In cases of asymmetrical costs and benefit and multi-stakeholder dependencies where an authority does not exist and consensus it the only means for selecting an action, implementing transition can be very difficult and lead to stagnation and lack of transition.

**Stagnation** In cases where multiple stakeholders must interact to bring about a system transition and the distribution of costs and benefits is asymmetrical it is possible that stakeholder differences are never resolved. This can occur because consensus cannot be reached or because no stakeholder is in a position of authority to impose a decision. In such cases stagnation occurs. Transition stalls and no decisions to implement system change are reached. The most effective means to prevent stagnation is through the use of power, leadership, and authority as discussed in the following section.

### 6.2.1 Stakeholder Power and the Role of Leadership

The difficulty of reaching a consensus or authority decision in a multi-stakeholder setting varies based on how mis-aligned the goals of stakeholders are and also the relative power between them. Few cases exist where decision refinement, during which stakeholders attempt to reach compromises, results in a situation that is to everyone's benefit. Rather some stakeholders can be overpowered by others, leading to change. Stakeholder power is an indication of how much influence a stakeholder has over others in the action selection process. Power can be defined as the ability to make someone else do something they otherwise wouldn't, to exercise authority or control. Stakeholders can have different amounts of power within the group and also for different problems. How much resources a stakeholder is willing to use can also determine their power and stakeholders may have to chose between committing their resources between competing problems and other system needs.

Transition attempts where stakeholder interests are misaligned and where no significant power disparity between stakeholder exists often result in stagnation where airport runway construction projects are a prime example. Stakeholders can gain political power by capturing the interest and support of the general public. This can be done with the use of awareness building and framing as mentioned in Chapter 5. In addition, stakeholder can band together to form a concentrated rather than diffuse group [169]. Often such groups can wield more influence. This was exhibited in the Boston Logan case when local communities banded together to form Communities Against Runway Expansion (CARE) (CA7).

A single individual or stakeholder can also wield significant influence during action selection. Such project champions were already mentioned in the discussion of awareness building, but they can also play a role during the change process. These individuals assume leadership roles and work to develop agreement between stakeholders to push though barriers and facilitate change. Don Bateman played an important role in brining about the adoption of GPWS. He worked with airlines who equipped with the technology prior to an FAA mandate and also worked to improve the quality of that solution. In addition, he worked with the FAA and Congress to increase their understanding of the problem and of GPWS.

Any stakeholder can assume a leadership role. However, when that stakeholder also has a position of authority in the system, such as the FAA or Congress, they are most likely to be successful in enacting change. The FAA, for example, is a powerful stakeholder in the Air Transportation System and possesses the authority to regulate the system, issue mandates, make system level decisions, and allocate funding to different problems and changes. A leader who is also an authority figure must work to balance the different problems faced by the system as well as the different objectives of stakeholders. Not all problems can be addressed given the existence of limited resources, and not all stakeholder objectives can be satisfied by a selected action. As a result, when the FAA acts as a leader and authority in a transition other stakeholders position themselves to influence and pressure the FAA by educating them about particular problems and solutions as well as lobbying for the support of specific actions.

Figure 6-12 below captures the notion of multiple problems and consequently multiple pressures acting on an authority figure attempting to influence their decision. The figure shows and expanded view of the action selection process, which takes place within the change process, and the influence of other system problems and obligations. As can be seen, stakeholders can pressure an authority figure to act on a particular system problem and also in a particular way. Since any problem requires resources in order to be addressed and since the amount of available resources is finite the stakeholder who is in the position of leadership and authority makes the decision about whether a problem should be addressed and how much resources it should receive. A commitment of funds to one problem means that addressing that issue becomes a system obligation and, as a result, leaves fewer resources available to address other problems. Public awareness is also included in this figure since increased awareness and pressure for addressing a particular problem can lead to resources being redirected from other efforts to that issue. The result of such a decision is a selected action.

In the ideal case, in order to exercise leadership the authority figure looks at the different problems facing the system and the interests of all stakeholders to make a decision that takes these factors into account, but ultimately results in the best choice for the system as a whole. However, such a figure can also be influenced by powerful stakeholders and has its own self interests: for example, the FAA must maintain credibility as an organization capable of fulfilling their mission.

In addition to the FAA, Congress and the President can also be significant power figures in the Air Transportation System; however, they engage on fewer occasions than the FAA. Stakeholder actions and events, such as accidents, which create public awareness can put pressure on the FAA, Congress, and the President to act. The attacks of 9/11 were such a significant event that the President was heavily involved in addressing the issue. Congress is also involved in determining the FAA budget as well as authorizing the FAA. Reauthorization occurs every 5 years and certain things about the system can only be changed at that

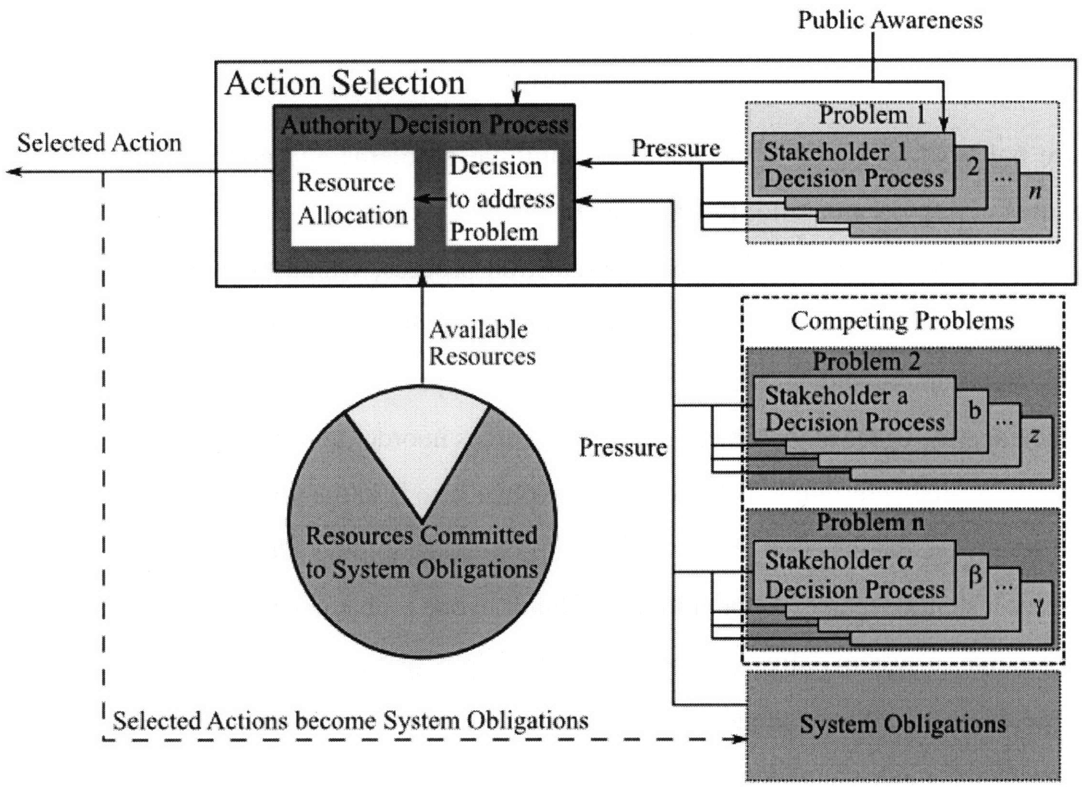


Figure 6-12: Authority Figures are Pressured by Stakeholders to Allocate Resources between Competing System Problems and Obligations

time.

Both the FAA and Congress can act as a leader and authority to decide if a transition will occur. In cases where stakeholders cannot resolve differences such an authority figure is often needed to move past barriers. An FAA mandate or a decision made by Congress can eliminate stagnation and move a transition forward. Many cases of past system transitions have included an FAA mandate.

**Example of Limited Authority and the Impact on Transition Dynamics** The lack of an authority figure can mean that stakeholders cannot agree on a change and stagnation results. The case of addressing aircraft emissions through a cap and trade program proposed at ICAO by the EU (EN3), provides an example of a case where no strong authority existed. While this is the only detailed case studied that exhibits this dynamic, it is expected that many international cases, which require cooperation from numerous countries, could exhibit similar behavior.

Addressing the issue of aircraft emissions can occur at a local level, but also requires international cooperations and measures to be successful. The European Union (EU) is currently leading the world by planning the most aggressive plans to limit the growth of $CO_2$. The EU is planning on incorporating air transportation into the existing Emissions Trading Schemes (ETS) [170]. Under the program airlines would be issued emissions permits and additional emissions would require the purchase of either additional permits or offsets. Such programs set a cap on emissions and allow for the trade of addition permits and as a result are called cap and trade programs. The goal of these actions is to establish a market for carbon trading which in turn would help to reduce carbon emissions [165]. In addition to adding European airlines into the ETS the EU also plans to require international carriers operating in any of the EU member countries to participate.

The International Civil Aviation Organization (ICAO) is a part of the United Nations (UN) and governs international air transportation. In addition, ICAO is tasked, with the responsibility of limiting aviation emissions [23]. In September of 2007 at an ICAO meeting the EU presented its plans for reducing aviation emissions and wanted international support for including non EU airlines in the trading scheme. However, the EU encountered strong opposition from international airlines, represented by the International Airlines and Transport Association (IATA), as well as from the US, China, Brazil, Saudi Arabia and others [84]. Despite the support of environmental groups and EU's strong pressure for implementation the UN did not back the EU. Because ICAO is made up of representatives from participating countries the strong opposition of these countries was sufficient to overrule the EU. As a result of its decision, ICAO has been criticized as having abdicated its leadership role in limiting aviation emissions [23, 83].

In addition to not supporting the EU, the IACO assembly passed a resolution that its members should sign individual agreements with third parties before applying emissions trading schemes to foreign airlines flying in their territory [151]. If accepted by the EU such a resolution would prevent it from including non EU airlines in the ETS. However, the EU filed a formal reservation indicating that it would not follow this resolution [83].

Due to the strong differences in stakeholder objectives it is likely that this case will have to be settled in international courts. The EU believes they have the power and legal right to impose ETS on any airlines flying in their territory, while other countries perceive a strong financial interest in avoiding the cap and trade scheme. These countries may question EU's authority though litigation once aviation is incorporated into the ETS.

In applying the transition model to this case it can be seen that during the change process international stakeholder relations play a large role. In addition, ICAO does not have strong power over stakeholders or mandate authority to force an action. The fact that the EU can chose not to agree with an ICAO decision demonstrates the limited power of the organization. ICAO can do very little to enforce its decision, rather the matter will most likely have to be settled through litigation. However, the EU also has limited power to act unilaterally. Without the agreement of other states an attempt to apply ETS to international flights will likely result in litigation. This case illustrates the difficulty of implementing a change when different stakeholder views cannot be resolved by an authority figure. Litigation is likely to add a significant amount of time to the transition process and postpone addressing an important issue.

### 6.2.2 Changing Stakeholder Preferences

Stakeholder objectives are not fixed throughout the change process. Rather as a change proceeds, decisions are refined as a result of adaptive transitions undertaken by individual stakeholders, compromises between stakeholders, agreed on mitigation and incentive measures, decisions made by leadership, and the occurrence of catalytic events. Such actions can shift the context in which other stakeholders evaluate their own objectives and result in changes to those objectives.

Actions taken by one stakeholder can change the cost benefit for others. If stakeholder benefits increase as operators equip, with every stakeholder who equips, the cost benefit ratio of those who have not yet decided to accept the transition changes and becomes more favorable toward equipage. Equipage by airlines with ADS-B exhibits this behavior (CA14). Another example can occur in the case of safety changes where insurance rates can increase thereby changing the cost benefit structure for deciding to implement a potential solution. An increase in insurance rates occurred during the implementation of GPWS (SA1). As the solution became developed and available, insurance companies increased rates for unequipped aircraft prompting some airlines to equip. Many such actions and events can be taken leading to a tipping point when transition becomes more cost effective than opposition.

Not all cases of successful transition rely on stakeholders actions or context to change in a way to encourage transition. Rather transition can be facilitated, by an authority figure, through the use of incentives and mitigation measures that better distribute stakeholder benefits and costs. In the case of safety accidents and incidents, reporting systems were implemented in order to better understand and address safety problems. However, it wasn't until such systems stopped holding those reporting an error liable that pilots and controllers began to report errors. Not holding individuals liable provided an incentive for sharing information.

Incentives can also take the form of delivering benefits to stakeholders that participate in a change, or by offering to cover the cost of that participation. In addition, the FAA can use mandates as a way to incentivise participation in a transition. Reimbursement of acquisition costs reduces the initial up-front payout for technology, accelerating benefits delivery. Such an action was taken by the FAA during the Alaska Capstone trial program for ADS-B. A mandate often requires participation in a transition in order to access parts of the Air Transportation System. As a result, a mandate means that a stakeholder's cost benefit analysis must now include the costs of not complying and losing access to system resources. A mandate can therefore significantly alter the NPV of a proposed change and force stakeholders to participate in transition.

Finally, a catalytic event can occur anytime during the process of transition and create additional awareness and pressure for change. Such an event can make it clear that an action must and will be taken. When it becomes certain that an action will be taken stakeholder objectives can shift to accommodate this certainty. This mechanism is what allows for safety and security driven changes to quickly move through the change process.

### 6.2.3 Adaptive vs. Transformative Change

The different change dynamics explored in this section can be broadly classified based on the degree to which they change the system and the ease with which change happens. As this section has shown, the degree of change and the ease of change tend to be correlated. Cases of single stakeholder (individual action) or multi-stakeholder symmetrical costs and benefits mean that transition can be brought about more easily. However, such changes are often small incremental system changes that stakeholders use to rapidly adapt to new system behavior. This thesis refers to such changes as adaptive changes. Examples of adaptive change include the implementation of schedule depeaking and the movement of operations to secondary airports. Unfortunately, due to their limited extent, adaptive changes can not deal with all problems.

Large scale changes that affect the entire system will have a significant and lasting effect on system operation. These changes can be classified as transformative change. The scale and scope of a transformative change, such as ADS-B, means that many stakeholders will be involved. As shown above, the difficulty of a transition increases when multiple stakeholders with varying interests are involved. In particular, when costs and benefits are asymmetrically distributed between different stakeholders it can create a situation where stakeholders have directly competing interests. In some cases such as ADS-B, another layer of difficulty is added by the fact that not only do stakeholder differences to be resolved, but cooperation between stakeholders is required for the transition to be successful. Stakeholders depend on others to fulfill their part of the transition process before their benefits can be realized. Due to the multi-stakeholder nature of transformative system changes such transitions are more difficult to enact.

Not all changes can be classified cleanly in this way—runway construction, for example, is a relatively localized change that may or may not have a major impact on the system as a whole. In this sense, a new runway can be seen as an adaptation that attempts to increase capacity locally. On the other hand, runways tend to involve many stakeholders in a region, with disparate goals, that can take significant effort to resolve. Operations in the vicinity of the airport will be permanently altered by the new runway, and, if the airport is a major hub, can affect delays systemwide. From this point of view, runway construction appears to be a transformative change. The utility of the adaptive/transformative distinction lies in realizing that many changes that are needed are in fact transformative, but those are the most difficult changes to achieve. By classifying a proposed change as adaptive or transformative, one can immediately gain some intuition for the level of difficulty of the transition.

## 6.3 Resource Allocation

Choosing an action in the change process often means allocating resources to carrying it out. Resources often take the form of funds, but can also include human capital, time, and other forms. For airlines and operators carrying out a transition often means that funds must be allocated to buy aircraft equipment, avionics, as well as to cover the installation costs and out of service costs for aircraft. In addition, pilot training may need to be developed and carried out. For developers of a solution funds for the development, testing, and refinement needs to be allocated. In addition, funds for certification and approval processes that occur during the implementation process are also needed. Airports and port authorities may also need to allocate funds to expansion of infrastructure or implementation of ground based technologies. As mentioned in previous sections, authority figures often have to make decisions about the allocation of resources and in doing so chose between addressing different problems that the system is facing. In the case of the air transportation system, the FAA often makes decisions about investment in system transition.

In many large transitions, the FAA must allocate funding for system modernization. However, such funding comes from a finite budget that must be split between system operations, sustaining the existing infrastructure, and system modernization. The FAA also administers funding in the Airport Improvement Program, but these are earmarked for airport projects only. Figure 6-13 shows the breakdown of a $14,310 million budget in 2006 and a $14,537 million budget in 2007 [15]. It can be seen from the figure that over 50% of the budget is used for operating the system, about 18% is used for facilities and equipment wich can include new technologies. Finally, only about 1% of the budget is reserved for research that may lead to transitions in the system.

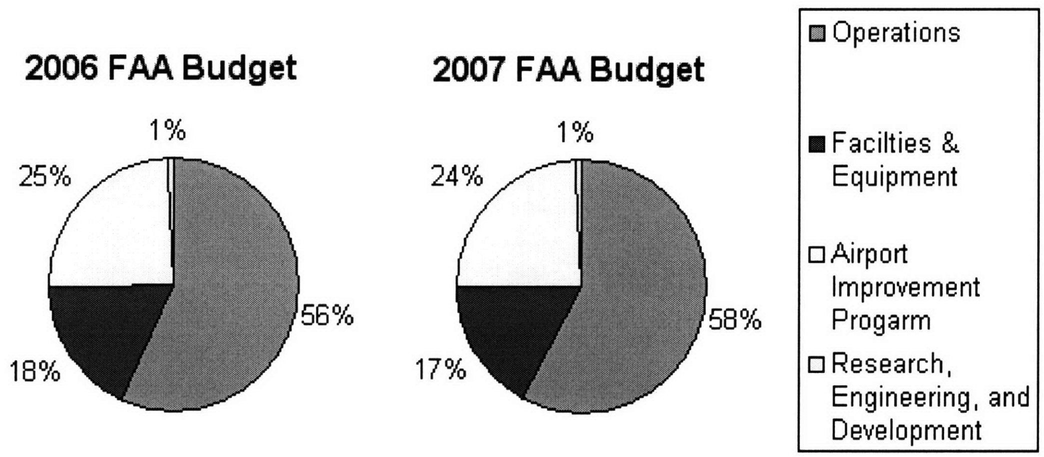


Figure 6-13: FAA Budget Breakdown [15]

In addition to there being limited funds for system transition, the FAA is not necessarily free to spend these funds as they like. Rather the FAA budget is viewed aa having political importance because it allocates resources between different problems and between different system stakeholders. The FAA budget also includes earmarks for specific projects. These earmarks amount to about $312 million a year [171]. Because FAA resources allocation decisions guide which transitions will be implemented, stakeholders lobby and attempt to influence how FAA resources are spent. This dynamic of the FAA acting as a leader with authority was discussed in Section 6.2.1.

In the case studies conducted for this thesis, all implemented change involved or required the allocation of resources. Some pending cases such as ADS-B have had commitment in the form of resources allocation form some stakeholders, but not from others. Because transition requires resources, stakeholders must decide if a system change is worth the investment, or put another way if benefits outweigh the costs. Because the amount of resources is finite, any stakeholder contemplating a change need to allocate those resources between competing problems and between problems and continuing their existing activities. As a result, addressing a particular problem competes with the cost of existing system obligations and with the investment in addressing other problems or opportunities. This competition for resources is shown in Figure 6-14.

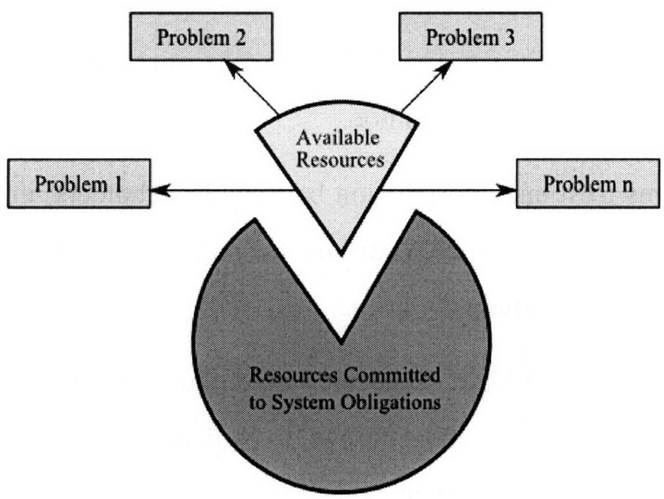


Figure 6-14: Different Problems Compete for Resources

In addition to specific problems competing for resources, drivers of transition may also compete, especially if they are in conflict. For example, it would be impossible or very difficult to enact a capacity change that reduced the safety of the system. Addressing capacity and environmental issues can also be at odds since allowing for more flights also results in increased emissions. However, while in some cases drivers and problems compete in others they may complement each other. For example TDWR increased both the safety and capacity of the system. Being able to point out the benefits in addressing both drivers for change helped in making the business case for this technology. Such interactions between different drivers and problems add a layer of complexity in the change process. Stakeholder objectives need to be resolved not only for each particular potential system transition, but also among all the different problems that are vying for attention and resources.

## 6.4 Implications

In order to overcome stakeholder barriers to system transition the distribution of costs and benefits between stakeholders must be understood. Understanding this distribution will make it clear which stakeholders are likely to support a proposed change and which are likely to oppose it. In addition, understanding what aspects of a change can help better deliver benefits to stakeholders is important. Structuring changes to maximize the benefits to stakeholders will encourage their participation in transition.

If a transition requires trust and coordination between stakeholders, measures should be taken to ensure that trust exists. The FAA can also use incentives and mitigation measures to encourage stakeholder participation.

Finally, it must be recognized that a decision by an authority figure, such as the use of a mandate, if often necessary to bring about change. In particular, in cases where no possibility exists for all stakeholders to receive a benefit, legislative and mandate power may be needed to bring about system change.

# Chapter 7

# Solution Development Process

In order for stakeholders to select an action during the change process, capability options from which solutions can be chosen must either exist or the selected action during the change process has to be to develop them. The model constructed so far and shown below in Figure 7-1 presumes the existence of capability options but does not capture their development. As a result, a solution development process is missing from this framework and must be added to the representation of transition processes. This addition is shown in Figure 7-2. The input to the solution development process is selected actions in the form of a decision to engage in solution development. The outputs of the process are capability options which feed into the awareness building process and provide potential solutions to identified problems.

## 7.1 Research and Development

While solution development is represented as a separate process in the transition model it is part the broader category of research and development, which plays an important role throughout each of the transition processes. During the awareness building process research and development are used to develop understanding of problem dynamics including root cause and potential impacts of the problem. In addition, research and development, as well as

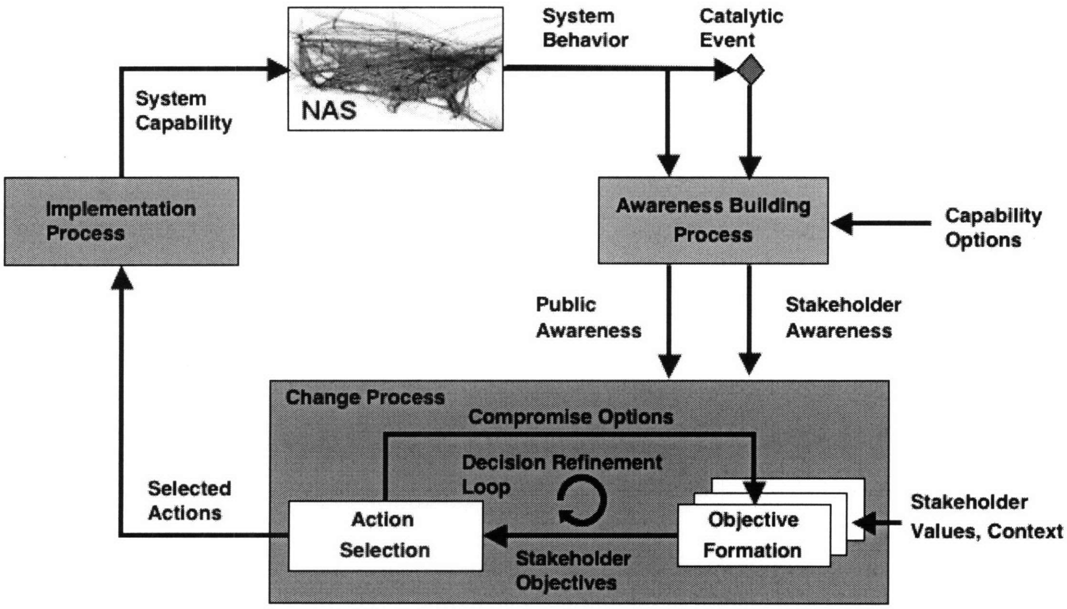


Figure 7-1: Feedback Model Framework

expert opinions, can be used during this process to build credibility for a specific problem definition. During the change process, research and development can be used to engage stakeholders together to plan a response to a problem. In addition, an action to study a problem or develop capability options can be used politically in response to pressure when no adequate solution exist or when a stakeholder group is attempting to delay action while still creating the appearance of response. The role of research in the awareness building and change process are incorporated into the discussion of those process in Chapter 5 and Chapter 6. During the implementation process, research and development are used to refine a selected solution and to prove that it meeds requirements necessary for approval. This process will be discussed further in Chapter 8.

This remainder of this chapter discusses the process of solution development in more detail and its role in bringing about system change. Information on the types of solutions and actions typically employed to address safety, security, capacity, and environmental drivers for change is provided. The importance of solution availability and viability is also discussed.

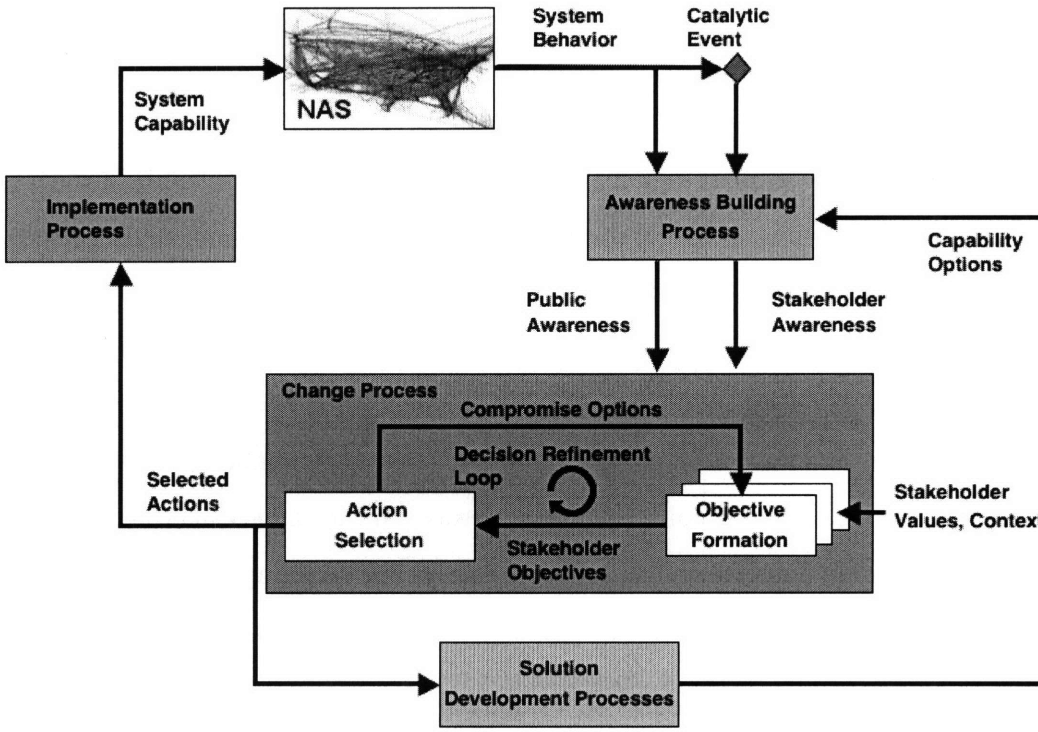


Figure 7-2: Transition Model Including Solution Development

## 7.2 Solutions

### 7.2.1 Safety Solutions

As mentioned in earlier chapters, safety drivers have historically led to a significant number of changes in the US Air Transportation System. Many of the solutions implemented to address these issues included technology implemented into aircraft (avionics). Examples of avionics include GPWS (SA1), EGPWS (SA1), and TCAS (SA3). Other problems, such as accidents caused by microbursts (SA2), were addressed using both avionics as well as technologies on the ground. Microbursts are detected using ground based radar, TDWR, as well as on board warning and radar systems in aircraft. Runway status lights use only ground based warning lights to prevent ground incursions. In order to implement new avionics and ground technologies and use them effectively, the development of procedures is often required as well. Finally, many safety changes also include pilot training. In some cases, such as CFIT (SA1) and microbursts, training was seen as one of the most vital components of addressing the issue [90].

In the case of microbursts pilot training played a significant role in preventing accidents. In particular microbursts pose a danger during landing when pilots first encounter a headwind and later a tailwind. When the headwind is encountered pilots experience increased airspeed and lift. Since they are attempting to land, in order to continue descending a natural reaction is to decrease power. However, when the aircraft encounters the tailwind part of the microburst it loses speed, lift, and as a result altitude. In these cases pilots cannot always pull up with sufficient speed to recover, and collide with the runway. This dynamic can be avoided if pilots know that they are in a microburst and react properly. Pilot training along with microburst detection capabilities helped pilots react properly when faced with a microburst.

Some safety changes also resulted in the establishment of methods for problem detection, measurement, and data gathering. For example the Aviation Safety Reporting System (ASRS), where pilots can voluntarily and without fear of punishment report any unsafe occurrences and hazardous situations [172], was implemented following the 1974 TWA accident near Dulles Virginia (SA1). These changes provide methods to better identify and address future safety concerns.

Addressing safety concerns often results in the implementation of technology as the primary action. In addition, policy and procedural changes have been built up over time to improve safety and also to create a system where safety is continuously studied and monitored to detect previously uncovered and new problems.

### 7.2.2 Security Solutions

Like safety solutions, security measures have traditionally been introduced in response to catalytic events. Both instances of security transition studied indicate that such changes focus on legal and policy changes as well as improved technology to expedite the enforcement of those new policies. Policies affect airport security as well as aircraft security; to a lesser frequency, organizational structure and authority are also changed. The case of 9/11 provided such a strong catalytic event that it resulted in a number of organizational changes, including the formation of the Department of Homeland Security, as well as policy and technical changes (SC2).

Security measures were first introduced into the Air Transportation System during the 1960s following a series of aircraft hijackings to Cuba [27] (SC1). In response to these threats Congress and the FAA worked to amend criminal laws in order to make hijacking punishable by law [27]. The Aviation Act of 1958 was amended in 1961 to criminalize any action that interfered with the crew or pilot performing their duties. Subsequent changes, such as employing air marshals and requiring the screening of passengers and luggage, were made in response to further terrorist acts [27]. Improvements in technology have also played a role in security changes, by providing better detection and scanning technologies as well data gathering and mining capabilities.

Following the attacks of 9/11/2001 numerous changes to security were made. Airport security improvements included increased data gathering and sharing to monitor passengers and identify threats, changes to screening technologies and procedures for both passengers and luggage, and restrictions for carry-on items. Aircraft security changes include added marshals on flights, the fortification of cockpit doors, and a program to license pilots to carry firearms. [115]

Addressing security problems occurs at multiple levels because the problem is inherently difficult to address. Because it is not possible to predict all the ways in which security may be breached reactive policies and procedures are implemented after a breach occurs.

### 7.2.3 Capacity Solutions

In order to address the capacity problem, three categories of solutions were observed: increasing infrastructure, improving the efficiency of operations, and managing demand. Runway, taxi-way, and terminal construction are examples of infrastructure expansion that create more capacity at airports. Operational efficiency can be improved by reducing the spacing between aircraft both during departure and arrivals as well as enroute. An example of such a measure is RVSM (CA11), which reduced the vertical space between enroute aircraft from 2000 to 1000 feet. ITWS (CA17) and CWIN (CA2) are further examples which resulted in more efficient operations during inclement weather. Solutions in these first two categories expand the capability of the system to accommodate more flights. In contrast, the final category stems or stops the growth of demand to a level that the current system can handle. Examples include slot restictions at oversubscribed airports such as LGA, JFK, and ORD. Current plans to modernize the US Air Transportation System include both infrastructure and efficiency improvements.

Efficiency improvements can be gained through the use of technology which more precisely measure the location of aircraft and, as a result, allow them to be spaced closer together. In addition, tools that allow controllers to better track, predict, and as a result control traffic patterns also increase operational efficiency. Radar is an example of a technology implemented for safety reasons that provided controllers with more information and situational awareness and, as a result, allowed them to safely handle and separate an increased amount of traffic (SA3). The currently planned implementation of ADS-B would also enable applications leading to efficiency improvements (CA14).

Some capacity solutions represent a combination of infrastructure, technology and procedures. For example, ADS-B will require aircraft based components, ground stations, as well as new procedures to generates benefits from ADS-B use. Similarly, RVSM was a procedural change that was enabled by improved technology that allowed aircraft to determine their altitude more precisely.

However, capacity can sometimes be improved by changes that require no new technology or infrastructure. Schedule depeaking can be implemented solely by airlines and spreads the load of arriving/departing aircraft at an airport more evenly through the day. Airlines can also choose to fly to secondary airports. These adaptive changes expand the capacity of the system.

Demand management has also been used in the US to address airport capacity problems. In 1968 slot restrictions, limiting the number of departures and arrivals, were implemented at DCA, ORD, JFK, LGA, and EWR [131]. With the exception of EWR, the slot restrictions remained in place until the 2000s. In April 2000, as part of the Aviation Reauthorization Act, Congress decided to remove slots at all the remaining restricted airports except DCA. Removal of slots resulted in a significant increase of flights and a reinstatement of restrictions at both LGA [173] (CA8). Arguments about how to best allocate slots at these airports, and LGA in particular, continue. The use of demand management was successful in limiting flights at congested airports, but resulted in significant stakeholder controversies in response to changes in slot allocation.

Currently there is a question as to the combination of solutions that will be utilized to increase the capacity of the system. While infrastructure and technology changes are both planned they can encounter barriers to implementation which will be discussed further in Chapter 8. Demand management is not part of planned system change but becomes needed when other solutions cannot be rapidly deployed and change is needed.

### 7.2.4 Environment Solutions

Combinations of policies, operating procedures, and technologies are being implemented and planned in order to reduce aircraft $CO_2$ emissions.

Past and recent efforts to reduce aviation emissions in the US have focused on emissions from vehicles and operations at the airport rather than from aircraft [7]. In addition, more efficient operations, which lead to increased capacity, are also being used to minimize fuel burn and as a result create less emissions. However, pressure to limit greenhouse gases continues to build. The Lieberman Warner bill has been proposed in Congress as a way to address $CO_2$ emissions from major industries, including aviation, using market mechanisms. In Europe pressure on airlines to reduce emissions has also been growing and a cap and trade program to limit carbon emissions is currently planned [23] (EN3).

In addition to policy approaches, emissions can also be reduced through cleaner engines. Engine manufactures have an incentive to develop cleaner engines because emissions are correlated with fuel consumption. Fuel prices have increased making more efficient, and therefore cleaner, engines attractive to airlines. Although engine efficiency has significantly improved with time the growth of traffic has been faster than the reduction in emissions creating a net positive contribution of green house gases by aviation [174]. This contribution is expected to continue increasing as traffic grows. However, work is being done to encourage more technology development in this area.

Further improvements in engine efficiency, as well as the investigation of new engine technologies, alternative fuels, new lighter aircraft materials, and other ideas are all being explored as possible ways to reduce aircraft emissions [7]. Many of these ideas are still in early stages of research and will take a significant amount of time to develop. As a result, it is unclear that sufficient technical solutions will be available for implementation when pressure for change becomes so great that an action is taken. Rather, policy actions may need to be used.

The understanding of problem dynamics and effect of potential actions are still uncertainty when addressing environmental issues. As a result, more research and development are needed to better understand problem dynamics and develop capability options.

## 7.3 Solution Availability

It was found that the existence and readiness of a solution impacts how effectively a problem can be addressed. When pressure for change arises, it takes the form of pressure for action. Following catalytic events such pressure can be very strong and directed at decision makers requiring rapid action on their part. As a result, readily available solutions are the ones that tend to be implemented regardless of their quality. This was the case with the CTX-9000 X-ray machines and other scanning technologies implemented at airports following 9/11 (SC2). Pressure for action was very strong and as a result the use of available technologies was required. The utility of the scanners has since been questions and accusations made that they contribute to delays and long lines while only marginally increasing security [117]. The dynamic of implementing an available solution when pressure arises is captured by the garbage can model of policy adaptation [36]. While catalytic events create pressure for change, there often is only a single opportunity to use that attention and pressure to drive implementation [31]. Unfortunately, a solution, once implemented, may become locked-in and remain in the system for a long time [42]. Thus, the existence of a quality solution is integral to efficiently and effectively addressing an issue.

When a stakeholder identifies or anticipates a need and develops actions to address it before strong pressure for change manifests, transition is the most effective. The development and implementation of the ground proximity warning system demonstrates how the prescience of a stakeholder enabled the development of a system that was ready to be deployed when the pressure for implementation came following a major accident in 1974 (SA1). This case one again demonstrates the power of a project champion. In this case Don Bateman who worked to understand the problem, raise awareness, and develop a solution. Radar (SA3) and TCAS (SA3) were also both ready to be used as solutions when pressure for change arose.

If a problem is identified and a solution does not exist, potential solutions must be developed. This can significantly increase the time needed to address an issue. When solutions do not exist, awareness and pressure may be muted [175] and other issues take precedence. However, if pressure does exist it can be used not to implement a specific solution but rather to direct research funding into programs for developing problem understanding and solutions. The level of basic understanding and related technologies will affect how long this research will take. For example, wind shear as a weather phenomena was identified in the early 1970s but a decade of accidents occurred before it was well understood (SA2). The technology needed to provide adequate and reliable warning took another decade to develop and it was not until the early 1990s that TDWR was implemented. Interim solutions were implemented and various research programs undertaken before a final solution was achieved. Solutions to address the capacity problem are also still being developed. Although some actions such as ADS-B (CA14) are planned they are not necessarily ready for immediate and rapid implementation.

The time to develop a solution may depend on the level of existing technologies; improved technology can often lead to better solutions. For example, EGPWS (SA1) became possible and economically feasible with the release of detailed terrain maps and improvements in computer storage technology. Terrain maps allowed for look ahead capability and improved computer technology allowed those maps to be stored cheaply and compactly on aircraft.

RVSM (CA11) is another example where improvements in technology were necessary before the solution could be fully developed. The International Civil Aviation Organization (ICAO) first encouraged RVSM in the 1960s [176], but it took until the 1980s for altimeters to become sufficiently precise that preparations to implement RVSM could begin.

Attempted changes can also fail if expected or planned solutions cannot be developed. One of the significant failures for which the FAA has been sharply criticized is the Advanced Automation System (AAS) (CA1). First announced in 1983 with an estimated completion in 1996 and a cost of $2.5 billion, the goal of AAS was to upgrade all computer hardware and software used by controllers in the towers, TRACONs, and enroute. These upgrades were expected to provide increased automation possibilities to deal with predicted increases in traffic. However, developing the system proved to be more technically challenging than expected and after significant time delays and cost overruns was canceled [27].

When solutions are available for rapid implementation following catalytic events or the generation sufficient pressure to enact change transition is more likely to be successful.

### 7.3.1 Solution Viability

An existing solution must be viable in order to be useful. This means that it must meet system standards and requirements, and ensure that the new capability can be compatible with the existing system. These requirements influence the structure of a solution as it is developed.

In addition to meeting technical requirements and standards, solutions are often shaped by national policy agendas, plans, and goals. Such visions and plans are often developed by leaders and those with authority in the system and can influence the change process by shaping problem definition and outlining the type of solutions that are acceptable. In addition, policy goals often influence the resources available for research and solution development. Since limited resources exist for research and development, in the case of the FAA only 1% of their budget, the allocation of resources can have significant impact on what lines of research and solution development are pursued and which are not. The NextGen plan is an example of a plan that sets research requirements and influences resource allocation. Such plans structure and limit the scope of potential research and solutions which can be helpful and limit the amount of time it takes to develop a new capability. However, by limiting potential options possibility for innovation and creativity is also limited.

## 7.4 Implications

Solution development plays a key role in transition by providing potential capability options that can used to address problems in the system. Based on analyzing past cases of transition in the air transportation system it is evident that developing solution in anticipation of pressure for change is critical to facilitating successful transitions.

In a system where most transitions occurs reactively in response to events, in order to best take advantage of pressure for change when it manifests, solutions must be developed in anticipation of needs. When solutions are ready they can be implemented rapidly leading to improved system capability. As a result, the role of the research and development community is to support transition by pro-actively developing potential solutions. However, if viable solutions do not exist, lengthy development is needed and transition is delayed. In some cases, when pressure for change is high, available but inadequate solutions may be implemented in response to pressure. In such cases it becomes difficult to later implement improved solutions.

Developing solutions in anticipation of need increases the risk that a solution will not be used. The earlier the development the greater the uncertainty of how a problem will develop. A portfolio approach to solution development would help to minimize risk poses by uncertainties in what actions will be needed and used. In addition, the success of a development program should not be judged by whether or not every solution is used. Some amount of failed ideas must be expected in order to develop viable solutions in anticipation of system needs.

# Chapter 8

# Implementation Process

Once an action is selected, it needs to be implemented before a problem is considered addressed. This takes place during the implementation process shown in Figure 8-1 below, which depicts the detail model as constructed so far through the past 3 chapters. During this process stakeholder must develop detailed action plans, receive necessary certification and approval, and finally deploy a new capability in the system as shown in Figure 8-2.

Actions selected during the change process provide the inputs to implementation and specifically to the detailed action development subprocess where technical specifications, detailed policies, and an implementation plan are developed. Once complete, the detailed action plan must pass through the certification and approval processes where safety, environmental, economic and other approvals are issued. These approval processes can be iterative and require changes to the selected actions to ensure that they can be approved. In addition, approval processes include opportunity for interested stakeholders to comment on proposals and influence the final form of the solution. As changes need to be made and stakeholders comment on projects stakeholder disagreements can reemerge and return the transition back to the change process step. This process of solution refinement is represented in the model by the solution refinement loop that feeds back to the change process. This loop can pose a barrier and delay implementation. Once a detailed solution exists and is approved, deployment can

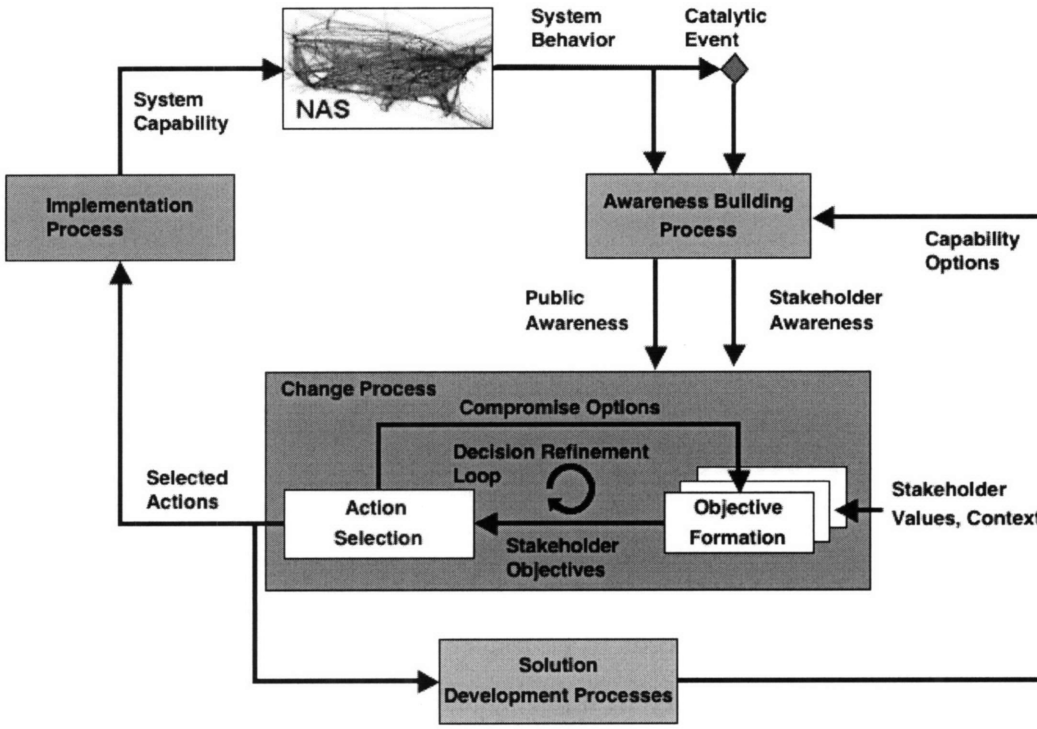


Figure 8-1: Feedback Model Framework

begin. The result of the implementation process is the successful deployment of a new Air Transportation System capability.

While improving the capability of the system is the goal of transition, case studies indicate that implementation can take a significant amount of time. The time to implement a selected action can be long due to the inherent construction or deployment time of the solution. In addition, required approval and certification processes take time to complete. Finally, stakeholders can deliberately attempt to stall or derail implementation if it would result in an unfavorable change. Such delays can pose a barrier to transition resulting in long implementation time constants and potentially stalled transitions.

The time that a solution takes to implement is important because factors affecting the success of transition perish over time. For example pressure for change dissipates over time, especially if other issues rise to the top of the agenda space. Stakeholder agreements developed during

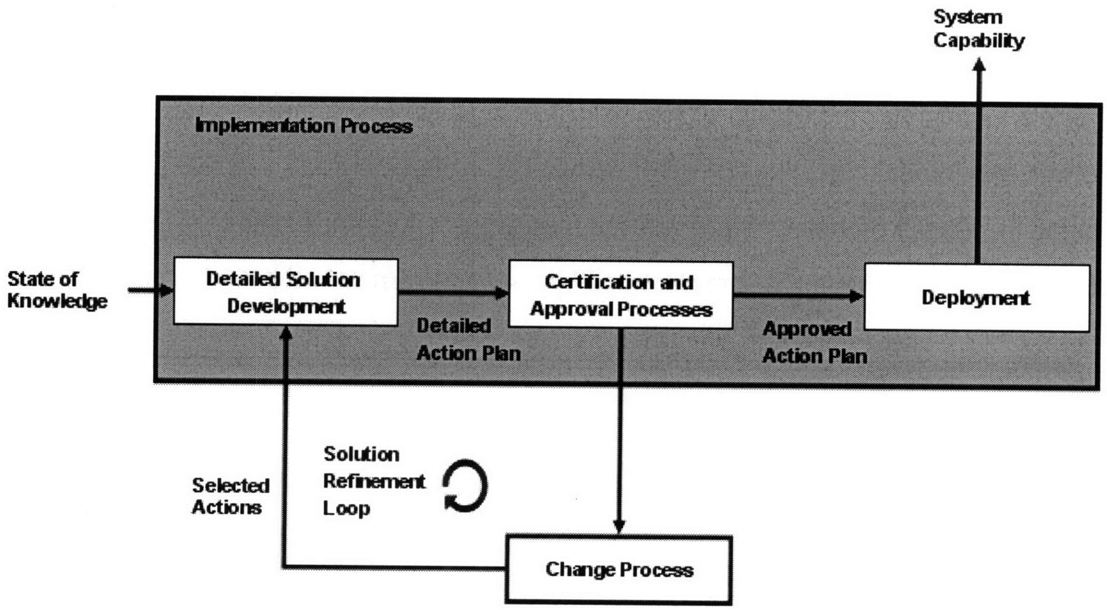


Figure 8-2: Simplified Approval Processes Necessary for Improved Operational Capabilities

the change process can change as time passes and the context in which decisions were made changes. Such changes can result in the shifting of funding to other problems. Finally, technical solutions can be replaced by new better options as time passes potentially restarting the change process to determine if a different action should be selected.

It was found that the safety and environmental approval process, while necessary, can introduce substantial delays into the transition process, in some cases on the order of decades. The multiple steps required during these processes as well as the opportunity they provide for the re-initiation of stakeholder disagreements both contribute to implementation delays. During the implementation process, stakeholders who were outvoted during action selection can receive another opportunity to contest a planned system change. As detailed action plans are made, stakeholder disputes can reemerge and potentially require a new iteration of the change process. In addition, approval and certification processes include review periods during which stakeholders can comment on planned changes. Disagreements between stakeholders can be voiced during these comment periods and if differences cannot be resolved stakeholders may resort to litigation. The environmental approval process has been used by community groups as a leverage point to initiate litigation in an attempt to prevent runway projects from moving forward. As a result, stakeholder issues remain an important dynamics during implementation. Figure 8-3 integrates the impact of review processes that occur during implementation. In addition, this model captures the use of demand management due to its role as a potential solution to capacity problems. Since demand management does not add new system capability, but rather controls demand, it is represented by a separate arrow in the model.

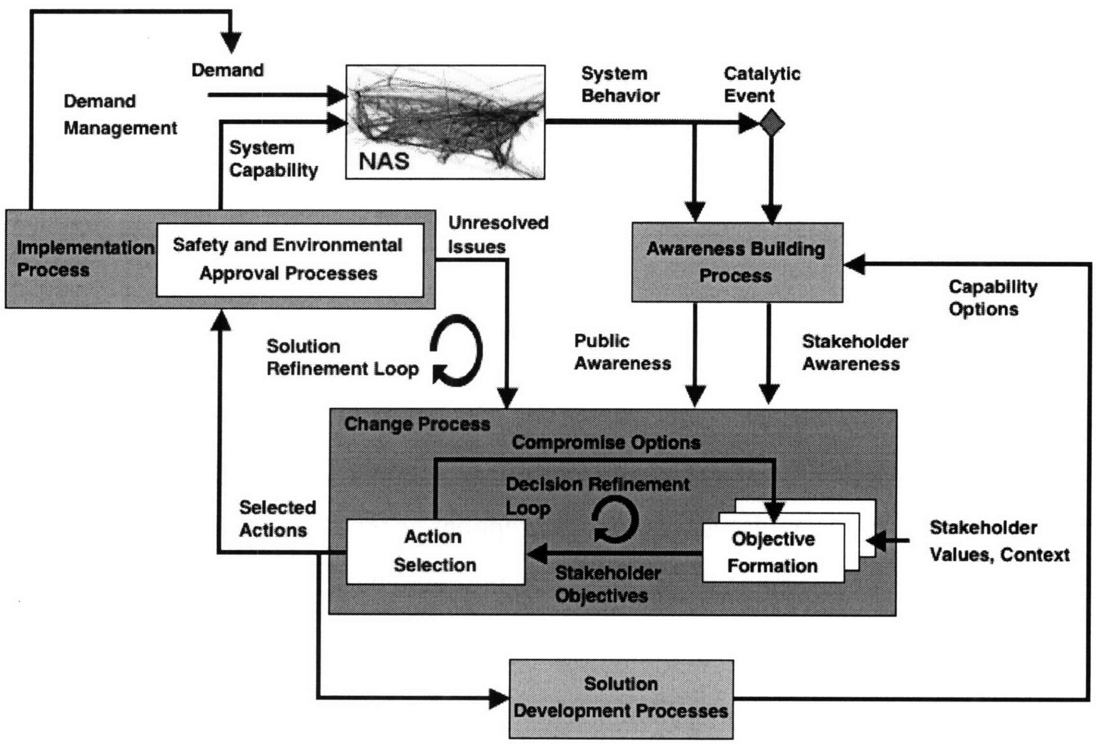


Figure 8-3: Transition Model Including Implementation

Currently many attempted and planned system changes deal with addressing capacity problems. As a result, many of the examples in this chapter deal with plans and attempts to implementing these solutions and the barrier that are being encountered. However, safety and security examples are used to understand cases when implementation can occur more rapidly.

## 8.1 Review Processes and Implementation Barriers

### 8.1.1 Safety Review and Approval Processes

The safety review and approval processes are necessary for new avionics, procedures, ground hardware or software, and airspace changes implemented in the US Air Transportation System [177]. Proving that a solution is safe can be a lengthy and difficult process requiring a substantial amount of resources, effort, and iterations. It is technically difficult to prove that a change to a system as complex as air transportation will be safe. A large amount of analysis may be necessary in order to sufficiently prove that a system meets required safety performance, and in many cases (such as the implementation of ADS-B (CA14), ITWS (CA17), and TDWR (SA2)) limited operational implementations are used to understand safety consequences.

Figure 8-4 shows a simplified version of the approval process that occurs during implementation [16]. The approval process begins with an initial concept of operations to improve the system. Airborne components, ground-based infrastructure, and the air/ground interface and procedures all have to be approved separately. This approval process is closely connected to developing the details of a solution. As approval proceeds, standards for all components are developed and additional requirements identified and refined. Finally, significant coordination between different stakeholders involved in the approval process is necessary. Within the FAA, the Air Traffic Organization is responsible for the performance of the air traffic control system, and the Aviation Safety organization evaluates aircraft certification and changes to flight and operating rules. In the safety analysis process, technical expertise is also often required from air traffic controllers, aircraft operators, and other users of the system.

The safety review and approval process is necessary in order to ensure the safety of the system. However, the complexities associated with carrying out such processes can introduce substantial delays and uncertainty into the transition process. An example where implementation was delayed due to certification includes the implementation of EGPWS (SA1). Delays are

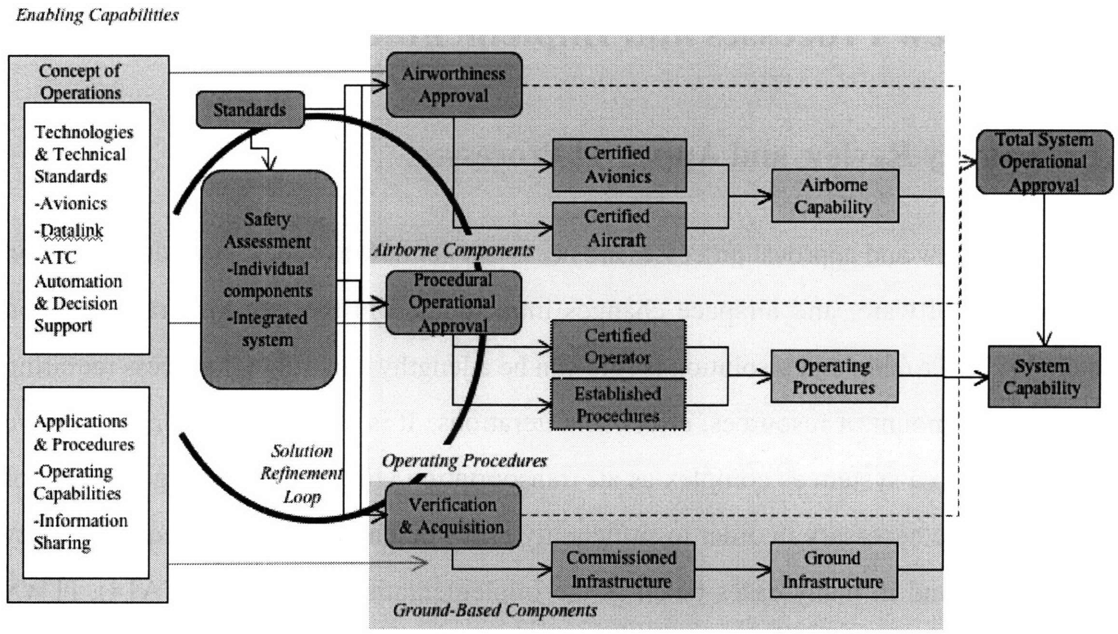


Figure 8-4: Simplified Safety Certification and Approval Processes [16]. Figure courtesy of Roland Weibel.

caused by a number of factors including:

1. Requirements stability: Because standards are developed before certification of procedures, there is significant uncertainty in potential costs of recertification or re-equipage if, for example, the avionics installed by early adopters are later deemed inadequate. As a result, stakeholders may wait for requirements to become clear and stable. Changing requirements occurred in cases such as the implementation of in-situ radar to address microburst accidents (SA2), the implementation of TCAS (SA3), and ADS-B (CA14).

2. Varying criticality levels: A given transition may affect multiple areas of the system and may in fact be used in different applications as the technologies involved evolve. These applications may require different levels of safety certification. For example, if a service is initially only advisory, it may be subject to less critical evaluation. However, if it becomes the primary mechanism, it will then require a critical services level of certification. Confusion as to future applications may lead to confusion about the appropriate level of certification that must be applied.

3. Establishing equivalent versus target levels of safety: Assessing changes to a target level of safety is significantly more difficult because it is performed to an absolute instead of relative standard [16].

Of the three items enumerated above the second two only pertain to one case study analyzed in this thesis (ADS-B). Although only one case has encountered these problems they are pointed out here because ADS-B is a first step in many planned and fundamentally new changes in the Air Transportation System. As a result, subsequent applications build on ADS-B and other planned system transitions may encounter similar obstacles. If currently planned transitions are to succeed understanding potential barriers they will encounter is key.

### Example of Implementation Barriers in the Case of ADS-B

The case of ADS-B provides an example where the approval of applications based on ADS-B poses a significant source of uncertainty to realizing future benefits. Potential operational capabilities of ADS-B, such as reduced separation, will require operational approval by the FAA before benefits can be realized. Because the approval process is complex there is uncertainty surrounding which applications will be approved and when that approval will be granted. In particular, unstable requirements, differing criticality levels, and certifying to equivalent vs. target levels of safety create uncertainty [16]. These uncertainties affect the NPV calculated during the cost benefit analysis and significantly contribute to operators' hesitancy to equip with ADS-B.

**Requirements Stability** This problem occurred during the development of DO-260, which is the Minimum Operational Performance Standards (MOPS) for the 1090 MHz extended squitter (1090ES) [178]. Early avionics based on the DO-260 standard allowed for the use of either of two potential measures of position uncertainty. During later revisions of the standards, only one of these measures was determined to be acceptable for use in ATC separation. As a result, the installation of ADS-B avionics in individual aircraft must be modified to use the approved method of broadcasting position uncertainty. [179]

**Varying Criticality Levels** Initially planned ADS-B applications require a essential services level of certification. However, a number of planned future applications, such as self-separation, will require a critical services level of certification. Critical services must meet a higher system availability requirement and a have lower probability of failure. Because of the different levels of criticality for current and future ADS-B applications, there is a concern that current airborne specification of the system may not be sufficient to support future uses. If this occurs, additional standards in equipage would be needed requiring a new round of safety certification and approval.

**Equivalent versus Target Levels of Safety** As currently specified, ADS-B will be a replacement surveillance source for current radar separation procedures. As a result, the use of ADS-B can be certified using an equivalent level of safety approach. This approach requires demonstration that ADS-B performs equivalent to current surveillance sources. Such approval is easier to achieve than performing an analysis to a target level of safety. However, reduction in separation standards requires an assessment to a target level of safety before procedures can be approved [180].

### 8.1.2 The Environmental Review Process

The environmental review process is necessary for any project that can pose significant impact to the environment [181]. However, in the Air Transportation System this process is most often needed for runway and other infrastructure projects. This process exists in order to ensure that projects do not pose too large a threat to the health of surrounding communities and the global environment.

The environmental review process must be carried out not only for runway construction and expansion, but for any project that can significantly impact the environment including airspace changes. The specific rules for what actions require approval and which do not are outlined in order 1050.1E [182].

### Infrastructure Changes and the Environmental Process

Infrastructure projects go through two types of environmental assessments. The first is the Conformity Determination which determines if a project can be allowed under the Clean Air Act. The Environmental Protection Agency (EPA) sets the National Ambient Air Quality Standards (NAAQS) which determine the allowed levels of pollutants. If a region is below the set levels they are considered to be an attainment zone. However, if a region does not meet the standards they are designated by the EPA as a non-attainment zone. Cities with non-attainment zones are required to prepare a State Implementation Plan (SIP) and outline how they plan to reduce pollution levels and become an attainment zone.

Because runway projects are undertaken to increase capacity and thereby the number of operations, a resultant increase in pollution is expected. The Conformity Determination checks to ensure that a project will not change the status of a region from attainment to non-attainment. If an area is already a non-attainment zone the determination checks to ensure that the SIP contains plans for addressing the added pollutants. If a project is in a non-attainment area and the SIP does not contain provisions to accommodate aviation growth it is difficult to receive approval for the project and added time to prepare and receive approval for a revised SIP and proposed mitigation to offset emissions increases is needed.

Unfortunately, most of the top congested areas in the country correspond to non-attainment areas. Figure 8-5 shows the non-attainment areas in the country. Non-attainment areas are located in the most population dense areas of the country, which is also where the most congested airports are. In 2006 the top ten airports in terms of delays in the country were EWR, LGA, ORD, JFK, PHL, ATL, BOS, SFO, IAH, and LAS [6]. Out of that list only IAH and LAS are located in attainment zones. As a result, it can be difficult and time consuming to receive approval for projects in areas where they are most needed.

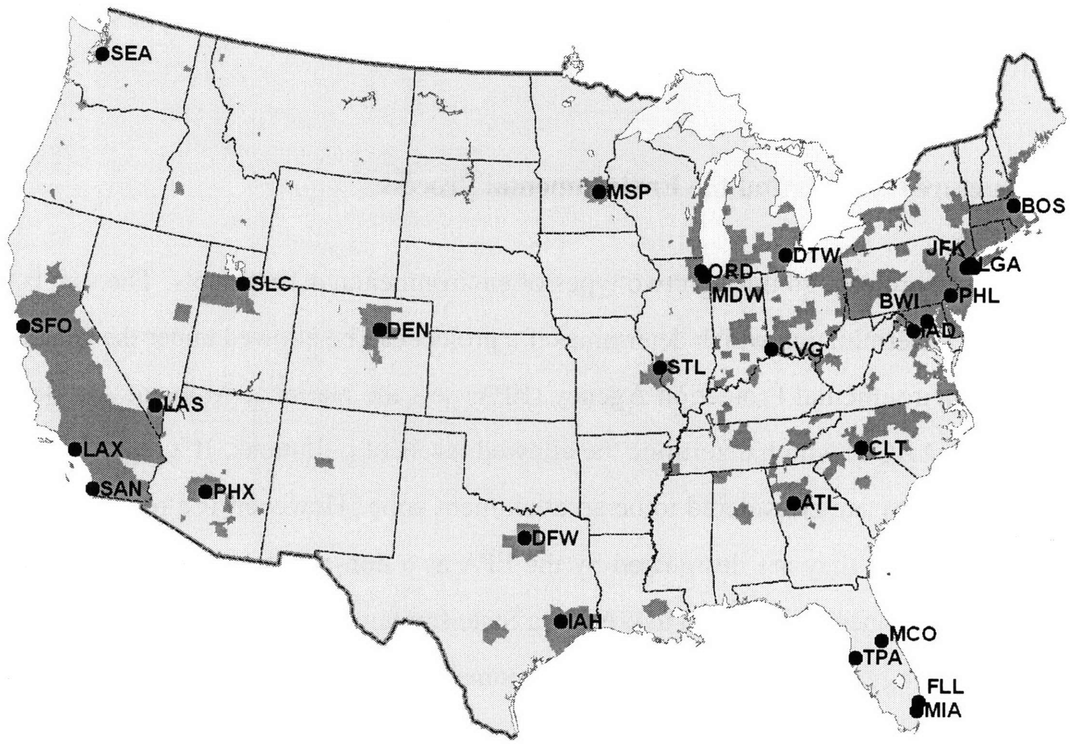


Figure 8-5: Location of Non-attainment Zones and Top 30 US Airports

In addition to the Conformity Determination, infrastructure projects must also pass the requirements set by the National Environmental Plan Act (NEPA). For a runway project, this part of the review takes place once the preliminary design, including the new airport layout, costs, benefits, and possible alternatives, is complete and FAA approval granted [183]. The environmental review process is shown in Figure 8-6. The first step of this process is to conduct an environmental assessment to determine if the project will have significant impact on noise, air quality, water quality, or historical artifacts. If the answer is no, and all state regulations have been met, a project can proceed to acquire permits and than begin construction. However, if significant impacts are expected an Environmental Impact Statement (EIS) must be prepared. From the cases studies used in this thesis all projects involving runway construction or relocation required an EIS. A notice of intent is first required, followed by a draft EIS which is reviewed by interested stakeholders including the public. Incorporating comments from the review process, a final EIS is prepared and submitted for review. If the statement is approved a record of decision is issued and the project can proceed to permitting and construction [183].

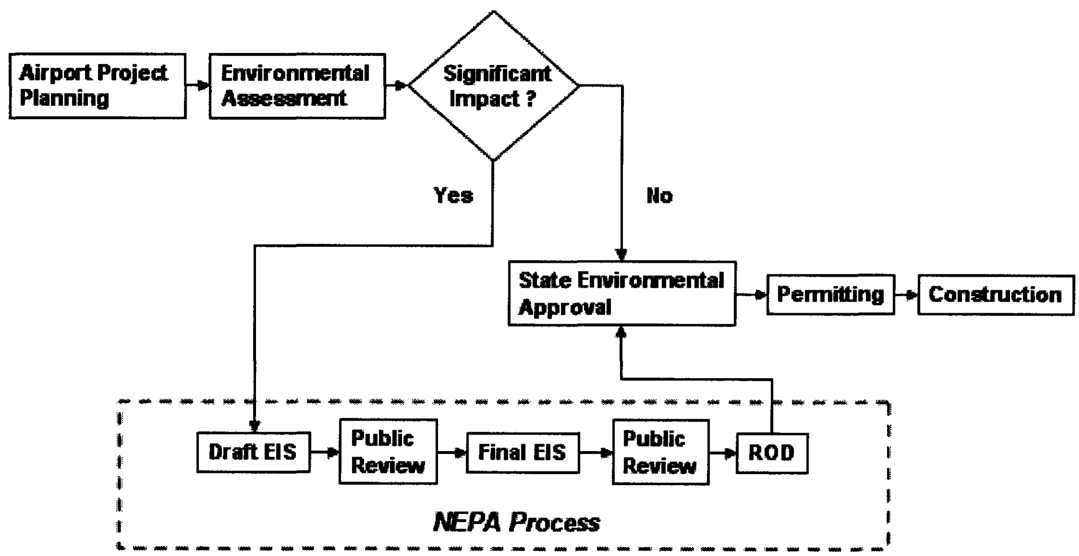


Figure 8-6: Environmental Review Process

As shown in the following section, the environmental review process can take several years including time to prepare, review, and approve the environmental impact statement. This can add a significant amount of time to the overall transition process. In addition, the EIS is often used by those opposing a runway project as the object of litigation thereby further delaying construction and increasing the implementation time constant.

**Example of Implementation Barriers in Airport Expansion Projects** A study conducted by the General Accounting Office surveyed the top 50 airports in the US and shows that a significant number of airports in the US experience project delays due to the environmental review process. 92% of study participants said that it was more difficult to balance envionmental concerns with airport operations than it was in 1989. Noise was listed as the largest concern by 58% of participants, followed by water quality listed by 24% of participants, and local land and air issues listed by 16%. 88% of the participats stated that the environmental review process contributed to delaying runway projects and 72% said that it was the primary cause of delay. It is important to point out that those participating in the survey are stakeholders in the change process who are attempting to expand infrastucture and as a result respopnses may contain bias. The median time for an airport project amount the participating airports was 10 years [24].

The FAA Operational Evaluation Partnership (OEP) includes a plan to expand existing airports. Figure 8-7 shows the airports with recent (completed in the last 5 years) and current (ones for which the Environmental Assessment has been completed) OEP projects as compared to the top 30 most congested airports in the country. Projects include new runways as well as runway extensions and relocations. The figure shows that only a small fraction of the airports that are congested are attempting to expand capacity. This indicates that additional airport capacity will be needed in the future as demand continues to increase. However, with lengthy construction times and barriers to implementation, expansion projects may not be possible or realized in time to accommodate the growth rate in demand. For completed projects the figure shows the duration of the projects and for pending projects the number of years since initiation. It can be seen that runway projects can take about 10 years to complete in the best case and almost 30 years in the worst case.

### Procedure and Airspace Changes and the Environmental Process

In addition to infrastructure changes, airspace and traffic flow changes may also need environmental approval before they can be implemented. Air traffic control procedures can be modified without conducting an environmental review process as long as they take place above 3000 feet; however, changes below this altitude must undergo the environmental review process [182]. In current plans for increasing the efficiency of the Air Transportation System, in order to accommodate an increased number of operations, Area Navigation Routes (RNAV) play a significant role. Such routes allow for more precise and narrow tracks of traffic and

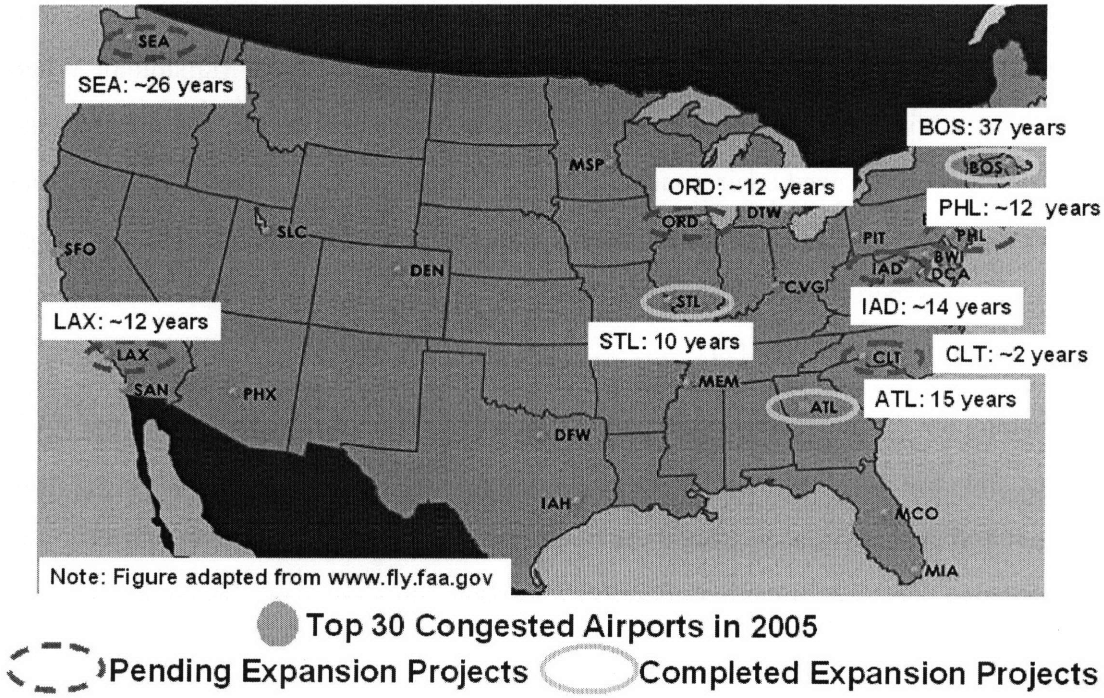


Figure 8-7: Recent and Pending Airport Runway Projects

potentially would allow for the existence of more tracks spaced closer together or for more re-routing flexibility during inclement weather. In addition, such routes can be more fuel efficient resulting in environmental benefifts. Under current rules the establishment of these routes is exempt from the environmental review process when they are above 3000 feet. However, cases are emerging where this exempted status is being questioned by neighborhoods opposing planned changes. Two such cases were studied as part of this work and include a planned RNAV route from BOS over Marshfield Massachusetts (CA12), and the restructuring of the New York airspace (CA13).

**Example of Environmental Barriers in Response to Air Route Changes** The case of implementing an RNAV route out of Boston Logan airport provides an example of the potential difficulties with such planned changes. Currently the city of Marshfield in Massachusetts is suing the Massachusetts Port Authority as well as the FAA. The lawsuit is over an RNAV route that the FAA plans to establish out of Boston Logan airport. The route would narrow traffic departing the airport and direct it over the harbor rather than over inhabited areas. The route would then turn south and direct aircraft over land starting above Marshfield. When overflying Marshfield aircraft would be at an altitude higher than 3000 feet and therefore the new procedures do not need environmental approval. However, Marshfield is claiming that Massport must carry out the state environmental approval process (MEPA) before the change can be made. Massport disagrees stating the change would be made by the FAA and therefore is not subject to state approval. [71]

No decisions have been made in the case between Marshfield, Massport, and the FAA. However, the case may set the precedence for future RNAV changes. If such opposition is encountered in many places around the country it will create a significant barrier to the implementation of RNVA routes and therefore to capacity improvements. Massport fears that even if the court decides that an environmental review process is not necessary, they may be required to hold public hearings. Such hearings would take both resources and time and would significantly delay the implementation of new routes.

The dispute between Massport and Marshfield signifies a shift in stakeholder dynamics between the communities surrounding the airport and Massport. When the communities were fighting the construction of runway 14/32 they were unified into one group (CA7). However, only Marshfield is fighting the RNAV route. In fact, the Community Advisory Committee (CAC) approved the RNAV route with a majority vote. This shift may signal a new dynamic where every community litigates over individual proposed changes. If this occurs, Massport and the FAA will become embroiled in many lawsuits creating gridlock to change.

The case in Massachusetts is not the only example of stakeholder fights over airspace redesign. The FAA has approved an plans a significant redesign of the airspace around the New York, Newark, and Philadelphia airports [184]. The town of Elizabeth New Jersey and Rockland County in New York have both filed lawsuits against the change. Groups in Philadelphia and Connecticut are also considering litigation [72]. The communities oppose to the planned changes due to the potential for increased noise.

### 8.1.3 Deliberate Blocking of Transition

Case studies showed that the safety and environmental approval processes can be used deliberately by stakeholders to block or stall planned changes. Even with the use of mitigation, not all stakeholders can be convinced to accept a change during the change process. Those stakeholders that feel they would lose significantly by the implementation of a proposed change have a large stake in continuing a fight even when a decision has been agreed on by others. Stakeholders most likely to try to block implementation are those who were marginalized or not represented at the original decision process or those who believe that the selected solution is so negative to them that the status quo is preferable to the change. Such stakeholders also usually do not have the ability to unilaterally change the decision. As a result, their objective becomes to get in the way of implementation in the hopes of preventing it, restarting negotiations, or waiting for a more favorable political administration.

Stakeholders can build support and coalitions, in some cases attempting to involve the public or lawmakers. This can increase the power asserted in favor of a particular solution or even any solution. To do this, they need to frame the argument in a way that gets the attention of others [30]. A standard framing tactic is the use of established values that others will resonate with. In the policy arena common values used to frame disputes are equity, efficiency, security, liberty, and community [185]. In the Air Transportation System a powerful value is safety. Maintaining and promoting safety has been one of the main goals of the system since its inception and many past changes occurred because of safety drivers. In particular, accidents provide a powerful catalyzing event for change. They create widespread awareness and engage the general public who in turn engage legislators. Because it is such a strong value, it can also be used to block change. All a stakeholder needs to do is to gain media attention and successfully create doubts about a proposed change's safety and that change will be delayed or even canceled. Accusations on lack of safety were made during the implementation of STARS (CA15) as well as during the ADS-B Capstone program (CA14) resulting in delays in the delivery of new capabilities.

Another tactic for preventing or stalling change is to argue about the validity of data, models, or predictions. Discrediting the basis of the understanding of the problem as well as the basis for evaluating the effects of solutions can stall the process or send it back to earlier stages. Such tactics were have been used in the environmental debate where some still argue that global warming is not caused by human activity. In addition, in cases of litigation over runway projects many disputes arise over predictions and modeling of noise contours. Unfortunately, models and especially predictions always contain assumptions which can be attacked. Issues of credible knowledge assessment becomes a powerful tool in policy disputes. It raises the question of how accurate models have to be, and also who has the credibility use them and be believed.

When stakeholder differences become entrenched, and a marginalized stakeholder cannot be pacified with mitigation, stagnation of a transition can occur. As a result, the time to bring a change about can increase significantly.

### Deliberate Blocking Using the Environmental Review Process

If an action to build or extend a runway is selected despite stakeholder opposition, community groups can still fight the implementation of an expansion project during the solution refinement loop. Specifically, community groups use the environmental review process to block construction. Because projects need to pass through federal and state environmental review processes stakeholders opposing expansion projects can contest the EIS to block change. This can result in lengthy debates or litigation often surrounding the data and models used to estimate impacts of construction projects.

Blocking of change can significantly add to the implementation time constant. An extreme example is a runway opened at Boston Logan International Airport in November 2007 (CA7). Due to litigation over the EIS and other permits the fight over the new runway continued for over 30 years [128]. The fights focused in no small part around the assumptions made in predicting the effects that the runway would have on local communities. While this example is that of the worst case scenario, it illustrates how strong of an effect stakeholder disputes can have in bringing about change. Runway projects in Chicago, Seattle, and other places exhibited similar behavior.

A similar pattern is occurring with the objections that community groups are raising to changes in route structure, such as the RVAV route from BOS airport. Communities are litigating to bring such changes under NEPA requirements. If this occurs it would mean that each change would require an EIS which could then also be contested by community groups opposing the planned change.

### Deliberate Blocking using the "Safety Veto"

Changes other than runway and airspace can be deliberately impeded by stakeholders. In order to block equipment changes, stakeholders may use the safety review process as a way to stop change during the refinement loop. Because safety is such an important value in the system, stakeholders can very legitimately raise the question of whether a change will maintain the safety of the system. This question can block the progress of a change as it is difficult to prove that new technologies or procedures are truly "safe": In effect, stakeholders can exercise a "safety veto." [186] This method can be particularly effective if the media becomes engaged. This mechanism is needed and can be used to raise legitimate safety concerns that should be addressed. However, it can also be used by stakeholder as a stalling or blocking tactic.

An example of the "safety veto" occurred during the implementation of a controller workstation upgrade called the Standard Terminal Automation Replacement System (STARS) (CA15). The system was to be implemented starting in 1998; however, the Professional Airways System Specialists (PASS) questioned the safety of the technology interface and caused a $460 million increase in costs and a 4 year delay in the start of implementation [73]. The safety of the technology was questioned at the same time as the PASS union was renegotiating their labor contract [74].

ADS-B (CA14) may also face opposition in the future. One of the potential future applications of ADS-B is self separation which would move the responsibility for separating aircraft from controllers to pilots. If such a change were to take place controllers may feel that their jobs are threatened and block the change using safety as a potential argument against it.

## 8.2 Overcoming Barriers — Catalytic Events

While implementation and transitions have often been delayed by barriers, changes have have been implemented as a result of catalytic events. As shown in Chapter 5, this dynamics has been most evident in the case of safety problems, where accidents have provided the necessary public pressure to overcome stakeholder disputes and implement change.

The case of Controller Flight Into Terrain (SA1) demonstrates the power a catalytic event can exert on the implementation process. On December 20, 1995 an American Airlines Boeing 757 crashed into a mountain while approaching Cali Columbia. This CFIT accident generated pressure for the implementation of EGPWS. The pressure was especially high on the hill because Secretary of Commerce Brown and other business leaders were on the aircraft. Among those vocal for equipage with EGPWS was Al Gore who at the time was the vice president [93].

In response to the pressure the FAA mandated equipage with EGPWS in 2000. Unlike in 1974 it took 5 years between the accident and the mandate even though pressure for change was significant. This delay occurred because EGPWS was not yet certified in 1995. In oder to mandate equipage the FAA had to expedite the certification and approval process. The speed of approval was increased by basing requirements on the technology developed by Honeywell allowing for a more rapid availability of a solution [187]. The catalytic event created sufficient pressure to overcome the complexities of the implementation process and allowed for accelerated certification and approval processes.

Security changes have also been made as a result of security failures, with the aftermath of 9/11 being the most notable example. As a result, it can be expected that capacity or environmental catalytic events would also provide a rapid change, but it is not clear what such events would be or if they occur.

In the case of capacity, delays are an obvious symptom of capacity constraints but, because they increase slowly and can cycle with seasons, they do not necessarily raise public pressure. However, a problem that causes extreme delays, such as those that occurred at LaGuardia (LGA) following the removal of slot restrictions in 2000, can result in significant pressure and a rapid reaction to remedy the problem. A similar dynamic is now taking place at Kennedy airport. These two examples indicate that rapidly growing delays of sufficient magnitude can act as a catalyst for capacity driven transition.

### 8.2.1 Example of a Capacity Catalytic Event in the Case of LaGuardia Slot Restrictions (CA8)

The case of LGA provides an interesting case study of what a capacity catalytic event may be. LGA is one of the four slot restricted airports in the US, which means that the number of operations at the airport is capped thereby managing demand. The restrictions were first implemented in 1968 in response to congestion problems [130]. The initial plan was to impose the restrictions for one year until a better solution could be identified and implemented. However, in 1969 the restrictions were extended until 1970, than again until 1973. In 1973, when a better solution was still not identified, it was decided that the slot restrictions would remain in place indefinitely [67].

The next decision regarding slot restrictions at LaGuardia did not occur until the passage of the AIR-21 Act in 2000. With the goal of further deregulation and making increased competition possible, the act announced that slot restrictions would be removed at the airport in 2007 and that exemptions to current limits would be immediately granted to certain operators [67]. Following the implementation of exemptions, the demand for the airport increased to about double the capacity of the airport as shown in Figure 8-8. The result of this increase was a rapid growth in both departure and arrival delays. Figure 8-9 shows that average delays per aircraft reached 80 to 90 minutes for both departures and arrivals. At one point in this period, delays from LaGuardia accounted for 25% of all delays in the nation. This rapid increase in delays and a 1.5 hour average delay per aircraft acted as a catalytic event requiring change. However, it is important to note that this case is unique in that it was artificially caused by the decision of Congress to remove slot restrictions at LaGuardia.

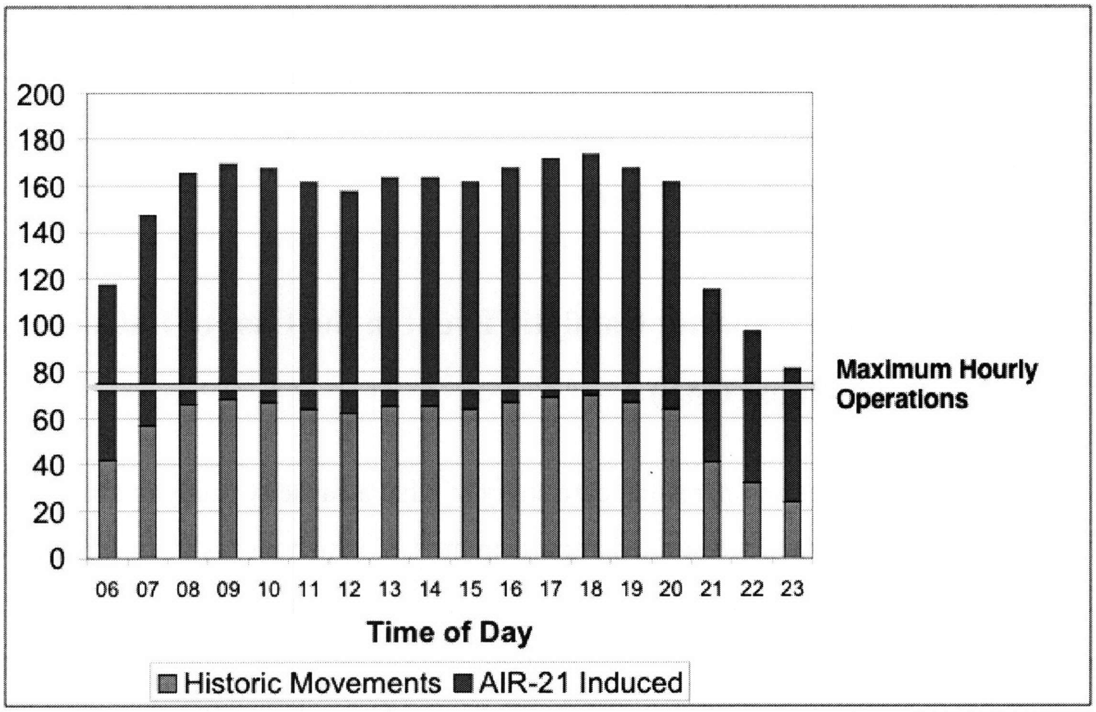


Figure 8-8: LaGuardia Scheduled Operations Following Slot Exemptions [12](Maximum operations are approximated)

In response to the rapid increase in delays, the Port Authority of New York and New Jersey, the operator of LaGuardia, quickly moved to reinstate caps on the number of flights allowed. The moratorium on additional flights was implemented on September 19, 2000. While this move was not strictly within their authority, it was soon backed by the FAA and received support from the public and local Congressional representatives [132]. The FAA showed support by officially limiting the number of slot exemptions offered at LGA [67].

Intervention on the part of the Port Authority and the FAA was necessary due to the incentives

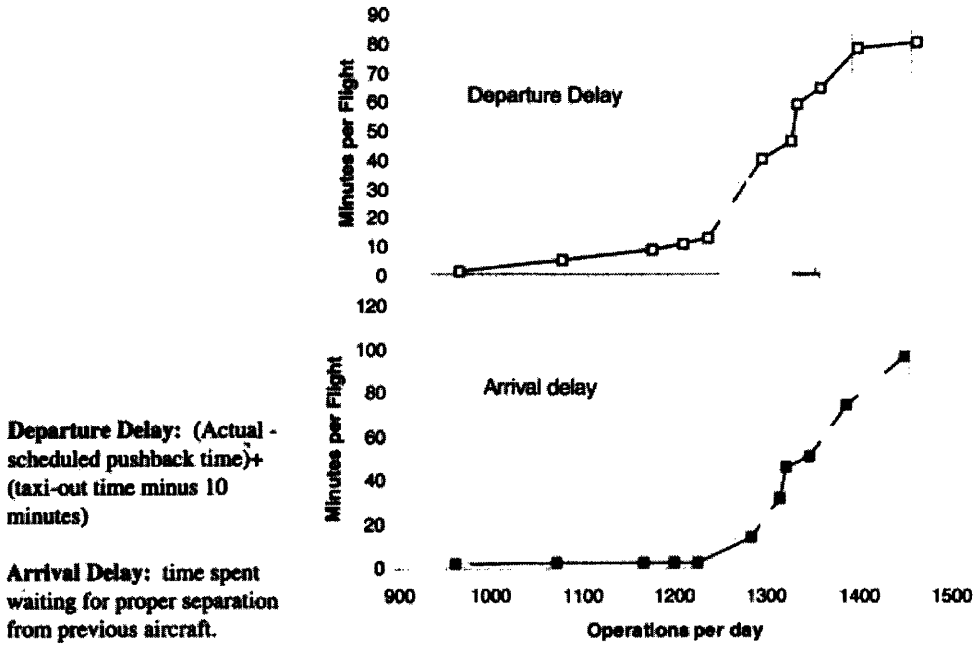


Figure 8-9: LaGuardia Delays Following Slot Exemptions [12]

for airline behavior. Following the initial passage of AIR-21, airlines wanted to take advantage of the latent (but until then unaccessible) demand for additional flights to and from LaGaurdia. However, leaving allocation of resources at the airport to the airlines resulted in a commons problem where each airline stood to benefit by adding flights, even if it was ultimately to everyone's detriment. In addition, even once it became clear that action to reduce the number of flights would have to be taken, airlines had the incentive to continue adding flights in anticipation of slots being reinstated and assigned, at least in part, based on who already held them.

The actions taken by the Port Authority and the FAA reinstated, in a slightly new incarnation, the slot restrictions at LGA. The capping of traffic was followed by a string of actions similar to those taken in the 1960s and 1970s. When the FAA responded to the NY Port Authority's moratorium on additional flights it capped the number of exceptions at 159. This cap was to be temporary and last about 9 months. However, the cap was extended 4 times until a new cap of 75 flight per hour was announced in August 2006. In 2008, disputes over how to allocate slots still continue. The reason for extending the initial emergency cap was to allow for the solution refinement loop to take place. Stakeholders lobbied the FAA to influence the final rule and especially how the available slots would be parceled out to airlines. Time could be allowed for this because a temporary solution was already in place and because the attacks of 9/11/2001 reduced demand.

The case of LGA illustrated both what a catalytic event in capacity may be and also the actions that can be expected following it. When a catalytic event generates pressure for change decision makers needs to act rapidly to address the problem. Because of the long time constants of building new infrastructure and proving the safety of large scale technology or procedural changes a faster solution becomes necessary. When rapid action is required, demand management, which can be implemented in days rather than years, becomes the likeliest solution.

As demand for air travel continues to grow the US Air Transportation System will become less robust to interruptions and potential capacity catalytic events are likely to occur. In addition, such events are likely to increase in frequency as demand continues to increase. These events will occur at busy airports around the country and will act as a catalyst for rapid change to address the capacity problem. The example of LGA suggest that once pressure for change exists the implementation of demand management becomes a likely reaction to capacity catalytic events. However, the current edition of the NextGen plan does not include any discussion of demand management [21]. The localized manifestation of the problem as well as the lack of planning for demand management creates the risk of developing a haphazard and complex system of restrictions that may be suboptimal for the system as a whole. There are a number of possible options to prepare for this situation. The first is to plan for the implementation of demand management so that it can be implemented in the most beneficial way. The second is to investigate alternative methods of generating awareness and pressure for solving the capacity shortfall. Such pressure, if sustained, would allow for the expansion of capacity to accommodate growing demand. In addition to implementing demand management decision makers can use the pressure generated by catalytic events to set in motion longer term plans for addressing capacity needs.

## 8.3 Long Implementation Times

The inherent time to deploy changes, the required approval processes, and attempts by stakeholders to block or derail proposed changes can significantly increase the implementation time for system transition. Such delays create a number of consequences for addressing problems and bringing about change the Air Transportation System.

Long implementation times can have the consequence of rendering transition efforts irrelevant. Pressure for change dissipates over time, especially if other issues raise to the top of the agenda space. Stakeholder agreements developed during the change process can change as time passes and the context in which decisions were made changes. Such changes can result in the shifting of funding to other problems.

The rapid pace of technology development means that, if a change is delayed, the next generation solution could be developed and available before the existing solution can be implemented in the system. This may force stakeholders to decide to abandon an existing change effort and try to begin again with the new technology. The problem with such a strategy is that it can occur repeatedly as technology development progresses and the transition process is restarted with each new development.

Long implementation times can also mean that problems become moot before they are addressed because the environment has changed or stakeholders have adapted in a number of other small ways. Examples include the Microwave Landing System (MLS) (CA3) and expansion projects in Saint Louis (STL) where expected demand did not materialize [188]. While this can be beneficial because a problem has been solved, it may be that small local solution have been put in place and are inefficient for the system as a whole. Even in cases where the transitions have proved to be successful and efficient, a transition process may not be halted just because the problem no longer exists. In these cases, money will still be spend on the original attempted solution.

Finally long implementation times can mean that a much needed solution to a problem is not implemented in time. In these cases system performance can be compromised causing rippling economic effects. Such a potential exists if the capacity problem is not addressed in time. Growing delays can lead to poor reliability and loss of revenue both to operators but also to businesses who depend on air transportation.

## 8.4 Implications

Safety and environmental approval, as well as stakeholder barriers, can delay implementation and the delivery of a new system capability. However a number of steps can be taken to mitigate these barriers.

Existing airport resources must be protected. In addition to difficulties in adding airport infrastructure, the number of airports in the US has been decreasing as shown in Figure 8-10. Smaller and underutilized airports have been closing. However, these airports can then be utilized as demand grows, but once closed are difficult to reopen.

In addition to protecting airport resources, overcoming barriers to expansion may also be possible. One way to help resolve stakeholder issues is to make redesigning airport projects easier. Currently, the environmental review process can pose a barrier to resolving stakeholder conflicts when redesigning a construction project would mean that the environmental approval process would have to be redone, causing a delay. Methods for revising and iterating on the design of runway projects, while maintaining the validity of the environmental impact statement, could be developed to make the process more efficient.

Studying the safety certification and approval process to determine how it can be streamlined and made more efficient would also help speed the time to implementation. Currently the process is complex and lengthy, reducing both these factors would help reduce uncertainty

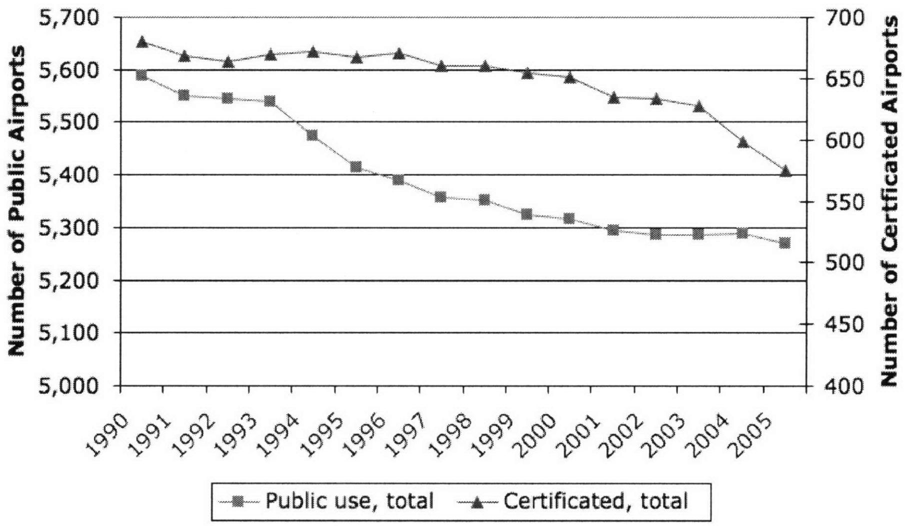


Figure 8-10: Number of Public and Certificated Airports in the US [17]

of approval and, as a result, make stakeholder equipage or participation decisions more clear.

Understanding and preparing for the impact of catalytic events in capacity and environment is important to future transitions. It cannot be assumed that these catalytic events will result in the same dynamics as safety accidents. In the case of capacity, demand management may be the only rapid viable alternative in response to a catalytic event.

Emissions, as a driver for change, can be expect to behave similarity to capacity in response to catalytic events. Because there are few technical solutions which could be rapidly implemented in response to pressure a policy response is likely. Such responses could include a cap and trade program and/or demand management. The first approach attempts to internalize the costs of emissions and the second stems the growth of traffic and, as a result, emissions as well. While it is not at all clear what an environmental catalytic event would be, having solutions ready to take advantage of the pressure that arises when one occurs may provide an opportunity to create positive change in the system.

# Chapter 9

# Conclusions and Implications

The US Air Transportation System plays a major role in supporting the economy and our daily lives. Currently, the system is faced with a number of issues creating a need for system transition. Meeting growing demand, maintaining safe, secure, reliable and robust operations, and meeting increasingly important environmental standards are just some of the major challenges faced by the system. While the need for transition is clear, the multi-stakeholder nature of the system as well as challenges during the implementation process can make system change difficult to carry out.

This thesis improves our ability to meet system challenges by increasing the understanding of transition dynamics in the US Air Transportation System. Such an understanding can be used to anticipate barriers to planned changes and to structure changes in a way that increases the likelihood of a successful implementation.

Transition dynamics were identified and incorporated in a model of transition processes. This was done based on 27 cases studies including technology, infrastructure, policy, and procedure changes as well as implemented, failed, and pending changes addressing safety, security, capacity, and environmental drivers for change. The transition dynamics studied include:

- the role of crisis events as catalyst for change,
- the role that multi-stakeholder objectives play in the change process,
- the effect that timing of solution development has on the overall time constant for change, and
- the use of approval and certification processes by stakeholders to stall or block change.

This chapter concludes the thesis by summarizing the key results and examining the implications for future transitions.

## 9.1 Transition Model

The full version of the model, as developed throughout the thesis, is shown in Figure 9-1: this version maintains the original feedback structure but elaborates on the dynamics that were obscured by the earlier simplified representation. Components of transition that were observed in the cases are represented as processes, depicted as boxes, that take inputs from and produce outputs for other processes.

**Awareness Building Process** The Air Transportation System process produces a series of outputs that represent the system behavior. Chapter 5 demonstrated how stakeholders monitor these outputs in order to develop an initial awareness of a problem in the system. The model captures the aspects of awareness building as a process, analogous to the concept of measurement in control theory. This process receives system behavior as an input and results in stakeholder and public awareness. In this process, stakeholders develop and share an understanding and definition of the problem and potential solutions. As a result, capability options are also an input to the awareness building process, since stakeholders must become aware of potential actions that can be taken to address a problem.

Based on patterns observed in the early phases of case studies and literature it was determined

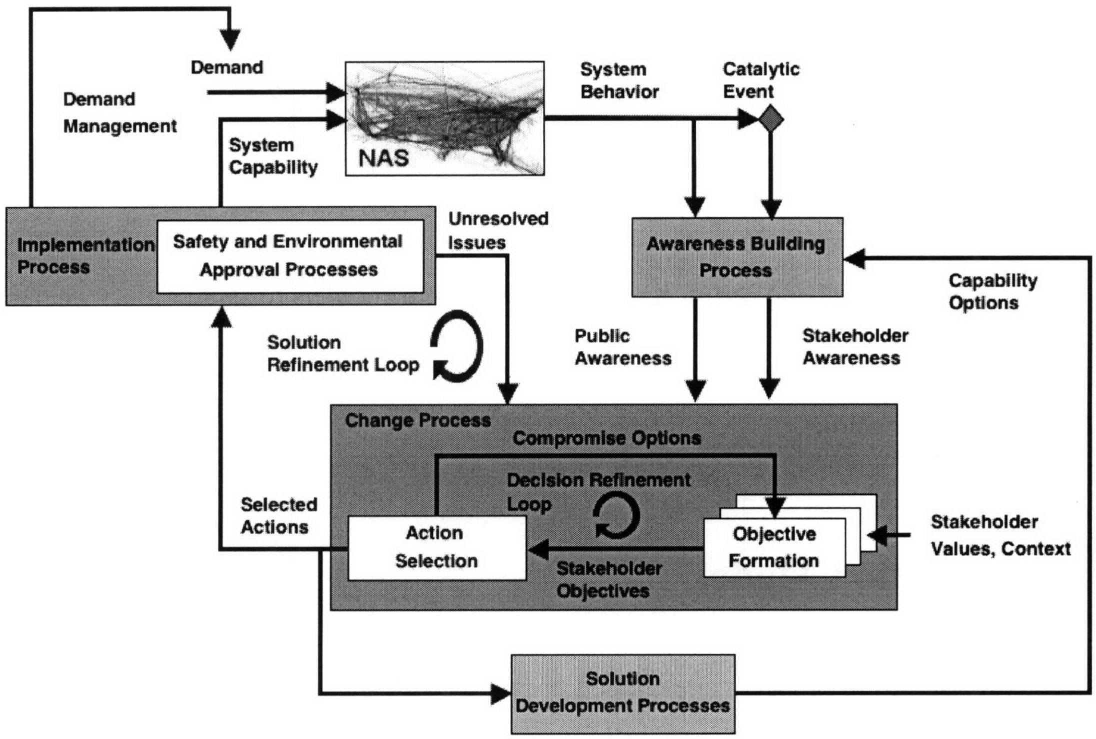


Figure 9-1: Transition Model

that catalytic events play a significant role during this process. Catalytic events are events that draw significant attention from the media: such events highlight that a problem exists and spread awareness not only to the aviation stakeholders but also to the general public. It is this widespread awareness that creates a window of opportunity and pressure for system transition [30, 31]. The model highlights this dynamic by separating stakeholder and general public awareness states.

In the US Air Transportation System most catalytic events have been aircraft accidents, and addressing safety drivers following catalytic events has been one of the dominant mechanisms for past system changes. Accidents tend to generate significant media attention and a resulting public outcry to correct the problem that led to the crash. However, security changes were also made following events and some evidence exists to illustrate what a capacity catalytic event may be.

**Change Process** Once awareness of a problem and potential solutions exists, stakeholders engage in objective formation and from objectives as to what actions they would like to see taken. Stakeholders then engage in an action selection process to select a solution or set of solutions. A solution is selected when resources to implemented it have been allocated. This can be done independently if only one stakeholder is involved or collectively if multiple stakeholders must resolve their objectives in order to select an action. The model captures both of these actives in the change process.

The inputs to the change process are stakeholder and public awareness. Objective formation takes stakeholder awareness and stakeholder values and context as inputs and outputs stakeholder objectives. This process is conducted independently by each stakeholder or stakeholder group as represented by the stacked boxes in the figure. In this step each stakeholder evaluates the potential projections formed during the awareness building process to form preferences for potential actions to implement. As discussed in Chapter 6 these preferences are formed based on a cost benefit analysis conducted by the stakeholders. In addition to evaluating options stakeholders also form preferences as to what action they want to see taken given the range of possibility.

In multi-stakeholder situations, stakeholders must interact and engage to resolve possibly conflicting objectives and choose a collective action. The interaction that occurs between stakeholders to select a collective action is captured by the decision refinement loop. Decision refinement captures the dynamics of decision selection in a situation with multiple stakeholders who have different agendas, value structures, and are affected differently by potential changes to the system. During this process stakeholders work to influence decision makers and interact with others to determine if concessions and agreements can be reached. In some cases, stakeholders with opposing interests but comparable political power can lead to a gridlock in adaptation efforts. Incentives and mitigation measures can be used to resolve stakeholder differences, but are not always successful.

When stakeholders are unable to resolve their differences on problem understanding, the correct action to address the problem, or the details of how a selected action should be implemented delays to transition are created.

**Solution Development Process** While some aspects of research are conducted within processes already depicted in the general model structure presented in Chapter 2 the development of solutions does not happen within any of these processes. The solution development process provides the capability options that can be taken to address a problem.

Solution development can occur prior to or in parallel with the change process if a stakeholder or group of stakeholders determines that it is to their benefit to take the initiative of development. In this way the solution development process fills the Garbage Can [36] from which potential actions are drawn. However, it is possible that a decision to address an issue is made without the existence of viable capability or solution options. In these cases the actions taken include the development of capabilities including the allocation of funding and initiation of research programs.

The timing of solution development can play a role in how successful attempts to address a system problem are. If viable solutions exist when pressure for change manifests it becomes more likely that a problem can be addressed. In particular, if a catalytic event generates significant pressure for change an action will become necessary, and the resulting change is likely to be more beneficial if a solution is ready for implementation. Developing solutions in anticipation of need is the primary recommendation of this work.

**Implementation Process** Once a decision is made to take an action, stakeholders move to implement that decision. In this process stakeholders refine the details of the solution, approve the chosen solutions, and deploy them. As part of these subprocesses detailed technical specifications, detailed policies, and an implementation plan are developed.

Barriers to transition can also arise during the implementation process. Once complete, the detailed action plan must pass through the certification and approval processes where safety, environmental, economic and other approvals are issued. These approval processes can be iterative and require changes to the selected actions to ensure that they can be approved. In addition, approval processes include opportunity for interested stakeholders to comment on proposals and influence the final form of the solution. As changes need to be made and stakeholders comment on projects, stakeholder disagreements can reemerge and return the transition back to the change process step. Thus, the complexities of conducting the necessary safety, environmental, and other approval processes can delay change. This dynamics is indicated by the solution refinement loop.

Finally, the approval processes that occur during implementation can be deliberately used by disenfranchised stakeholders as a mechanism to block change. Environmental approval in particular was shown to be used by stakeholders to block pending runway changes.

Once a detailed solution exists and is approved deployment can begin. The result of the implementation process is the successful deployment of a new Air Transportation System capability. However, in the case of addressing capacity drivers demand management is also a potential solution to the situation. Such an action does not result in an new system capability, but rather stems the growth of demand in the system.

## 9.2 Implications

Safety transition drivers have been the dominant mechanism for past changes in the system. This driver was particularly successful because accidents acted as catalytic events and led to increased awareness and pressure for change. Due to the power of accidents to motivate changes the system now provides a high level of safety with few accidents.

Current efforts to improve the safety of the system have been predictive rather than reactive. Such efforts focus on better tracking and understanding precursors to safety events. By understanding such precursors, the hope is to eliminate problems before events occur. However, due to lessened awareness and pressure for change it can be expected that predictive safety changes will encounter more stakeholder barriers and the resulting rate of improvement is likely to be smaller.

Like safety changes, security drivers have been addressed reactively following catalytic events. In the case of 9/11/2001 the event was so large it generated sustained and lasting pressure to implement a series of changes. In addition, it displaced other issues from the national agenda. Security will continue to be important as long as it is part of national agenda. If over time, threats diminish and no attacks take place awareness will slowly diminish. However, if attacks do occur or a belief that threats continue to exist persists, then more reactive changes can be expected.

Capacity is the dominant driver for currently planned system changes. Capacity problems manifest as delays and service disruptions and are likely to become more acute as demand grows. While numerous changes to address system capacity problems are currently planned, they face both stakeholder and approval barriers to change. Planned airport infrastructure improvements are met with strong community opposition. These communities are opposed to the increase in noise resulting from increased operations and block transitions using the environmental review process as a mechanisms to engage in litigation. Planned efficiency improvements also encounter stakeholder barriers when change requires coordination and trust between different parties. In addition, efficiency enhancing technologies and procedures must pass through the safety review and approval processes which can be time-consuming and may not ultimately succeed.

In the near term it can be expected that capacity constrained areas in the system will start to break down under the stress of continuously growing demand. Such breakdowns are likely to result in catalytic events as occurred at LaGuardia. While the case of LaGuardia may demonstrate that capacity can cause localized catalytic events and create pressure for change, the only rapid response to such a situation is the implementation of demand management because runway projects and efficiency improvements are too slow to be used as a response to an event. As more break downs occur, pressure for change will mount. For example, the implementation of demand management is likely to occur at JFK in response to mounting delays and growing pressure. Unfortunately, demand management does not provide a way to achieve equity among stakeholders and parties lobbying against demand management are likely to exist. A plan for how demand management will be implemented and the leadership to act on such decisions is needed.

Given the importance of stakeholder dynamics, understanding stakeholder positions will be crucial to helping facilitate successful transitions. By analyzing the breakdown of costs and benefits between stakeholders, appropriate mitigation measures and incentives can be identified. Utilizing these measures can help facilitate the change process and also prevent stakeholder barriers from occurring during the implementation process. In addition, the use of mandate and authority power must be used when change is in the best interest of the system, but stakeholder consensus cannot be built.

Environmental drivers are emerging as a strong driver of need for system change. Both awareness and scientific consensus about emissions and global warming are increasing. In aviation, aircraft emissions, which contribute to global warming and are growing as traffic grows, will increasingly lead to pressure for action. However, addressing environmental issues will be challenging since stakeholders disagree about the problem and the optimal way to handle the situation. In addition, addressing aviation $CO_2$ emissions is a global problem with international stakeholders which can make implementing change an even larger challenge. The dispute between the EU and ICAO over cap and trade programs demonstrate that strong stakeholder barriers can be expected at the international level. In international negotiations there are rarely clear authority figures that have the power to mandate and enforce decisions. The global nature of the emissions problem also means that local remedies are not always effective. In addition, it is unclear that environmental catalytic events exist in aviation. As a result, they cannot be depended up to stimulate change. Without these events, overcoming stakeholder barriers to change will be difficult. However, since aviation emissions occur in a broader context of global climate it is possible that non aviation events, such as natural disasters, which are attributed or perceived to be caused by humanities actions will act as catalysts for environmental changes in aviation and elsewhere.

By providing a model of transition this thesis has contributed to an understanding of how change occurs in the Air Transportation System. In addition, barriers to current planned changes were identified. This work can be used as a framework for analyzing planned and future transitions in order to better anticipate and overcome the potential barriers they may face. Finally, while the model was developed and used to understand transition in the US Air Transportation System applications to other systems are possible.

## 9.3 Applications to Other Systems

The model developed as part of this thesis has applications to systems other than US Air Transportation System. The simplest version of the model applies to any system where stakeholders detect problems and respond by modifying system capability. The more detailed insights gathered from studying past Air Transportation System changes and used to refine the model apply to any system that implements new capabilities in response to problems and where the public can influence and pressure leadership figures to make changes. In addition, the model's change process description is most suited for systems with multiple stakeholders who have potentially disparate agendas and levels of power while interacting to select an action. Finally, the implementation process is relevant to systems where actions (be they technical or procedural) pass through some form of approval process. These conditions for transition were of particular interest in the air transportation system due to their strong impact on transition; however, they also appear in other system. Specifically, public systems—those involving some level of local, state or national government—are likely to exhibit similar behavior. Examples of such systems include:

- ground transportation systems
- energy/power generation and distribution systems
- emergency response systems
- food production and distribution systems

- healthcare systems and other social support systems such as social security

From air transportation, the model naturally extends to different ground transportation systems such as car travel, the national rail system, or mixed-mode transport within a locality. Ground transportation, like air transportation, faces similar problems of increasing demand and congestion problems. Road congestion is largely dealt with in the same manner as air transportation: construction of new infrastructure (i.e., new roads), or congestion pricing to manage demand (as was implemented in London in 2003). These similarities result in similar transition dynamics and multi-stakeholder barriers to change. For example, road construction, just like runways, faces opposition from community groups who use the environmental review process to block transition resulting in fights that can last decades.

Outside of transportation, any system with government regulatory oversight will undergo similar transition dynamics. In many cases change in such systems is driven by catalytic events in the same way as safety changes in air transportation. Examples of catalytic events in other systems include: the Northeast US power outage in 2003 in the energy/power generation system, the disorganized US response to Hurricane Katrina in 2005 which led to sharp criticism of the emergency response system, or the *E.coli* bacteria outbreak in 2006 which led to changes in the food production and distribution systems. Each of these events was tremendously visible in the media, resulted in significant public outcry, and the Federal government took action in each case to investigate or otherwise address the cause of these failures.

Examples also exists where the lack of catalytic events is preventing problems from being addressed for lack of pressure to place them on the agenda space and follow through with a transition. The social security system provides an example of a system that was instituted in response to a catalytic event—the Great Depression of the 1930s—and where the current lack of clear catalytic events and the popularity of the system's benefits have led to an inability to make improvements despite the fact that social security has had projected future funding shortfalls for some time.

A natural direction for future work stemming from this research would be to examine transition dynamics in other similar systems, as listed above. Such work would allow for the extension of the transition model developed here and would provide insight into how changes could best be structured in these systems to overcome potential barriers.

# Bibliography

[1] Ryan Tam and R. John Hansman. An analysis of the dynamics of the us commercial air transportation system. Master's thesis, Massachusetts Institute of Technology, Cambridge, MA, November 2003.

[2] Statistical summary of commercial jet airplane accidents. http://www.boeing.com/news/techissues/statsum.pdf. Last accessed 29 Sep 2005.

[3] R. John Hansman. Overview of recent forces and trends in the airline industry. http://icat-server.mit.edu/Library/fullRecord.cgi?idDoc=236.

[4] Philippe Bonnefoy and R. John Hansman. Emergence of secondary airports and dynamics of regional airport systems in the United States. Master's thesis, Massachusetts Institute of Technology, May 2005. http://hdl.handle.net/1721.1/34908.

[5] Aleksandra Mozdzanowska. Evaluation of regional jet operating patterns in the continental United States. Master's thesis, Massachusetts Institute of Technology, June 2004.

[6] US Federal Aviation Administration. Operational networks (OPSNET) database: Delays by cause updated daily. http://www.apo.data.faa.gov/opsnet/entryOPSNET.asp. Last accessed Sep 2007.

[7] Aviation and emissions: A primer. Technical report, Federal Aviation Administration: Office of Environment and Energy, January 2005.

[8] Committee on Aeronautics Research and Technology for Environmental Compatibility.

For greener skies: Reducing environmental impacts of aviation. Technical report, National Academy of Sciences, 2003.

[9] Justin Fisher. http://www.math.unl.edu/~jfisher/NSF_96/windshear.html, 1996. Last accessed 17 May 2006.

[10] Barry Breen. Controlled flight into terrain and the enhanced ground proximity warning system. *IEEE Aerospace and Electronic Systems Magazine*, 14(1):19–24, Jan 1999.

[11] Federal Aviation Administration. Airport diagram: Boston / General Edward Lawrence Logan Intl (BOS). http://naco.faa.gov/d-tpp/0803/00058AD.PDF. Last accessed 13 March 2008.

[12] William DeCota. Personal communication, 2001.

[13] Aleksandra L. Mozdzanowska, Roland E. Weibel, and R. John Hansman. Feedback model of air transportation system change: Implementation challenges for aviation information systems. *IEEE Special Issue on Aviation Information Systems*, 2007. (In submission).

[14] Edward A. Lester and R. John Hansman. Benefits and incentives for ads-b equipage in the national airspace system. Master's thesis, Massachusetts Institute of Technology, Cambridge, MA, August 2007.

[15] Calvin L. Scovel III. FAA's FY 2008 budget request: Key issues facing the agency, 10 May 2007. Statement before the Appropriations Committee Subcommittee on Transportation, Housing and Urban Development, and Related Agencies, United States Senate.

[16] Aleksandra Mozdzanowska, Roland Weibel, Edward Lester, and R John Hansman. The dynamics of air transportation system transition. In *In Proceedings of the 7th Air Traffic Management Conference*, Barcelona Spain, 2007.

[17] Bureau of transportation statistics. http://www.bts.gov/, 2004.

[18] FAA. Cy 2003 passenger boarding and all-cargo data. http://www.faa.gov/arp/planning/stats/#cy03data, 2005. Last accessed 7 May 2005.

[19] NASA and FAA. *Scenario-Economic Demand Forecast Study*, 2003.

[20] Gerald L. Dillingham. National airspace system: Experts' views on improving the US air traffic control modernization program. Report GAO-05-333SP, US General Accounting Office, April 2005.

[21] 2005 progress report to the next generation air transportation system integrated plan. Technical report, Joint Planning and Development Office, March 2006. Last accessed 3 January 2007.

[22] Gerald L. Dillingham and Randall B. Williamson. National airspace system: Long-term capacity planning needed despite recent reduction in flight delays. Technical Report GAO-02-185, US General Accounting Office, December 2001.

[23] US says European aviation emissions trading scheme to end up as WTO dispute. *Bridges Trade BioRes*, 7(17), October 2007.

[24] Gerald L. Dillingham. Aviation and the environment: Results from a survey of the nation's 50 busiest commercial service airports. Report GAO/RCED-00-222, US General Accounting Office, August 2000.

[25] US Federal Aviation Administration. Operation evolution plan 7.0. http://www.faa.gov/programs/oep/.

[26] Gerald L. Dillingham. National airspace system: Progress and ongoing challenges for the air traffic organization. Report GAO-05-485T, US General Accounting Office, April 2005.

[27] Edmund Preston. *FAA Historical Chronology: Civil Aviation and the Federal Government, 1926–1996*. US Government Printing, 1998.

[28] Allen Li. Advanced automation system: implications of problems and recent changes. Report GAO/T-RCED-94-188, US General Accounting Office, April 1994.

[29] Barney G. Glaser and Anselm L. Struass. *The discovery of grounded theory: strategies for qualitative research.* Aldine Pub Co., 1967.

[30] Roger W. Cobb and Charles D. Elder. *Participation in American Politics: The Dynamics of Agenda Building*. The Johns Hopkins University Press, Baltimore, 2nd edition, 1983. Third edition, forthcoming. Dewey Library - Stacks I JK1764.C54 1983.

[31] John Kingdon. *Agendas, Alternatives, and Public Policies*. Longman, 2nd edition, 2002.

[32] James S. Coleman and Thomas J. Fararo. *Rational Choice Theory: Advocacy and Critique*. Newbury Park: Sage, 1992.

[33] Charles Lindblom. The science of muddling through. *Public Administration Review*, 19(2):79–88, 1959.

[34] Charles Lindblom. *The Policy-Making Process*. Prentice-Hall, 1992.

[35] Grant McConnell. *Private Power and American Democracy*. Alfred A. Knopf, New York, NY, 1966.

[36] Michael D. Cohen, James G. March, and Johan P. Olsen. A garbage can model of organizational choice. *Administrative Science Quarterly*, 1972.

[37] Jeff Frooman. Stakeholder influence strategies. *The Academy of Management Review*, 24(2):191–205, April 1999.

[38] Ronald K. Mitchell, Bradley R. Agle, and Donna J. Wood. Toward a theory of stakeholder identification and salience: Defining the principle of who and what really counts. *The Academy of Management Review*, 22(4):853–886, October 1997.

[39] Karen Marais and Annalisa Weigel. A framework to encourage successful technol-

ogy transition in civil aviation. In *Proceedings of the 25th Digital Avionics systems Conference*, pages 1–12, Portland, OR, October 2006.

[40] Hans Klein. System development in federal government: How technology influances outcomes. *Policy Studies Journal*, 28(2), 2000.

[41] Douglas J. Puffert. Path dependence, network form, and technological change. *History Matters: Economic Growth, Technology, and Population*, November 2003.

[42] James Q. Wilson. The dead hand of regulation. *Public Interest*, 25:47, Fall 1971.

[43] George Stigler. The theory of economic regulation. *Bell Journal of Economics and Management Science*, 2:3–21, Spring 1971.

[44] Joseph Sussman. Ideas on complexity in systems—20 views. Working Paper Series 2000-02A, MIT Engineering Systems Division, 2000.

[45] M. E. J. Newman, A.-L. Barabasi, and D. J. Watts. *The Structure and Dynamics of Networks*. Princeton University Press, Princeton, NJ, 2006.

[46] Robert M. Axelrod. *The complexity of cooperation agent-based models of competition and collaboration*. Princeton University Press, Princeton, NJ, 1997.

[47] Jan Rotmans, René Kemp, and Marjolein van Asselt. More evolution than revolution: transition management in public policy. *Foresight: the journal of future studies, strategic thinking and policy*, 3(1):15–32, February 2001.

[48] Rutger van der Brugge. Transition dynamics: the case of dutch water management. In *Proceedings of the 2004 Berlin Conference on the Human Dimensions of Global Environmental Change*, Dec 2004.

[49] James Utterback. *Mastering the dynamics of innovation*. Harvard Business School Press, Boston, MA, 1996.

[50] Derk Loorbach. *Transition Management*. PhD thesis, Erasmus University, 2006.

[51] Barry Smit, Ian Burton, Richard J.T. Klein, and J. Wandel. An anatomy of adaptation to climate change and variability. *Climactic Change*, 45:223–251, 2000.

[52] International Panel on Climate Change. Working group II: Impacts, adaptation and vulnerability. http://www.grida.no/climate/ipcc_tar/wg2/642.htm, 2001.

[53] D.L. Allen, A. Haraldsdottir, R.W. Lawler, K. Pirotte, and R.W. Schwab. The economic evaluation of CNS/ATM transition. In *Proceedings of the 16th Digital Avionics systems Conference*, Seattle, WA, 1997.

[54] Edward Lester and R. John Hansman. Preliminary analysis of potential ADS-B user benefits for hawaiian helicopter air tour operators. Technical Report ICAT-2007-1, MIT International Center for Air Transportation, June 2007.

[55] Andrew Malwitz, Timothy Yoder, Sthya Balasubramanian, Gregg Fleming, and Ian Waitz. Assessment of the impact of reduced vertical separation on aircraft-related fuel burn and emissions for the domestic United States. Technical Report PARTNER-COE-2007-002, Partnership for Air Transportation Noise and Emissions Reduction, November 2007.

[56] Transition Working Group of the Air Traffic Services Subcommitee. Transitioning air traffic management research into operational capabilities, September 2005.

[57] Federal Aviation Administration. Windshear training aid, February 1987.

[58] National Transportation Safety Board. Most wanted transportation safety improvements: Aviation issue areas. http://www.ntsb.gov/recs/mostwanted/aviation_issues.htm, 2008.

[59] National Transportation Safety Board. Most wanted transportation safety improvements: Federal issues. http://www.ntsb.gov/Recs/mostwanted/runways.htm, 2008.

[60] Lincoln Laboratory. Runway status lights system. http://rwsl.ll.mit.edu/, 2008.

[61] National Commission on Terrorist Attacks. *The 9/11 Commission Report: Final Report*

*of the National Commission on Terrorist Attacks Upon the United States*. W. W. Norton & Company, 2004.

[62] Michael Elliott. The shoe bomber's world. *Time*, February 2002.

[63] BBC. 'airlines terror plot' disrupted. http://news.bbc.co.uk/2/hi/uk_news/4778575.stm, August 2006. Last accessed 9 March 2008.

[64] Jeffrey C. Tu. Cockpit weather information (CWIN) system. 1:29–32, May 1996.

[65] Richard Marchi. Personal interview. August 6, 2007.

[66] Margot Botsford. Memorandum of devision and order for judgement in the case of Massachusetts Port Authority vs. City of Boston and City of Chelsea, 18 November 2003. Superior Court Civil Action No.01-2731 BLS 2.

[67] Hearing on air traffic congestion in the New York City area. http://www.house.gov/transportation/aviation/07-16-01/07-16-01memo.html. Last accessed 11 October 2006.

[68] FAA. FAA operational evolution plan: Executive summary. http://www.faa.gov/programs/oep, 2004.

[69] Federal Aviation Administration. Congestion and Delay Reduction at Chicago O'Hare International Airport. *Federal Register*, 70(57):15519–15539, March 2005.

[70] Federal Aviation Administration. Reduced vertical separation minimum. http://www.faa.gov/about/office_org/headquarters_offices/ato/service_units/enroute/rvsm/. Last accessed 17 March 2008.

[71] Flavio Leo. Personal interview. 1 August 2007.

[72] Barbara S. Peterson. Plane rerouting landing in court. *The New York Times*, 18 November 2007.

[73] National airspace system: Status of FAA's standard terminal automation replacement system. Technical Report GAO-02-1071, United States General Accounting Office, September 2002.

[74] Matthew Brelis. Union accuses FAA of degrading safety, botching modernization. *The Boston Globe*, August 5 1999.

[75] Federal Aviation Administration. Collaborative decision making: General information. http://cdm.fly.faa.gov/whatscdm.html. Last accessed 17 March 2008.

[76] Federal Aviation Administration. Integrated terminal weather system (ITWS). http://www.tc.faa.gov/its/cmd/visitors/data/ACT-300/itws.pdf. Last accessed 17 March 2008.

[77] Joe Sharkey. Virtual hostages on a plane. *The New York Times*, 6 February 2007.

[78] GovTrack.us. H.R. 700–106th congress: Airline passenger bill of rights act of 1999. http://www.govtrack.us/congress/bill.xpd?bill=h106-700. Last accessed 5 March 2008.

[79] JetBlue. Jetblue's customer bill of rights. http://www.jetblue.com/about/ourcompany/promise/index.html. Last accessed 17 March 2008.

[80] John-Paul Clarke. Development, design, and flight test evaluation of a continuous descent approach for nighttime operation at lousville internation airport. Technical Report PARTNER-COE-2005-002, Partnership for Air Transportation Noise and Emissions Reduction, 9 January 2006.

[81] Boeing. Timeline of aircraft noise certification and phaseout rules. www.boeing.com/commercial/noise/timeline.pdf. Last accessed 17 March 2008.

[82] ICAO. Air transport bureau (atb) environmental unit: Aircraft noise. http://www.icao.int/icao/en/env/noise.htm. Last accessed 17 March 2008.

[83] The Brussels Connection. Aviation: Another thing the us and the eu can't agree on. http://www.thebrusselsconnection.be/tbc/?page=detail\&id=515\&cat=38, 28 September 2007. Last accessed 29 January 2008.

[84] Werner Reh. International aviation body fails to act on climate plans. News release, Friends of the Earth, 28 September 2007.

[85] Daryl R. Smith. *Controlling Pilot Error: Controlled Flight into Terrain (CFIT/CFTT)*. McGraw-Hill, 2001.

[86] Don Bateman. Introduction of the ground proximity warning system (GPWS) into airline service. In *Proceedings of the Flighty Safety Foundation 29th International Air Safety Seminar*, pages 208–239, 1976.

[87] Air safety: Selected review of FAA performance, December 1974.

[88] Don Bateman. How to terrain-proof the world's airline fleet. In *Proceedings of the Flighty Safety Foundation 44th International Air Safety Seminar*, pages 139–171, 1991.

[89] James K. Kuchar. *A unified methodology for the evaluation of hazard alerting systems*. PhD thesis, Massachusetts Institute of Technology, 1995. http://hdl.handle.net/1721.1/11732.

[90] Don Bateman. Development of ground proximity warning systems (GPWS), November 2006.

[91] Don Bateman. Past, present and future efforts to reduce controlled flight into terrain (CFIT) accidents. In *Proceedings of the Flighty Safety Foundation 43rd International Air Safety Seminar*, pages 285–296, 1990.

[92] Ralph A. Astengo. Ground proximity warning system utilizing radio and barometric altimeter combination. Patent 3715718, Sundstrand Data Control, Inc (assignee), 1973. Filed 11 August 1970, issued 6 February 1973.

[93] Don Bateman. Personal interview. 24 June 2005.

[94] Bruce Landsberg. Landmark accidents: Cleared for the approach. http://www.aopa.org/asf/asfarticles/sp9806.html, June 1998. Last accessed 1 August 2006.

[95] Reinhard Menzel. Analysis shows that CFIT continues to account for the heaviest loss of life worldwide. *ICAO Journal*, April 1998. Last accessed 10 October 2004.

[96] Investigation of controlled flight into terrain: aircraft accidents involving turbine-

powered aircraft with six or more passenger seats flying under FAR part 91 flight rules and the potential for their prevention by ground proximity warning systems. Technical report, Volpe Center.

[97] FAA. Controlled flight into terrain: Education and training aid. http://faa.gov/education_research/training/media/cfit/volume1/titlepg.pdf, 2006. Last accessed 1 August 2006.

[98] Ground proximity warning system inventor Don Bateman is inducted in to the hall of fame. http://www.airbus.com/en/myairbus/features/features_items/don_bateman.html, 2005. Published 17 March 2005. Last accessed 2 August 2006.

[99] Mark V. Rosenker. Safety recommendation. Technical Report A-06-44–A-06-47, National Transportation Safety Board, 2006.

[100] Jim Evans. Personal interview. 5 April 2007.

[101] Lesson 5: Wind shears and microbursts. http://www.nwas.org/committees/avnwxcourse/lesson5.htm, November 2003. Last accessed 17 May 2006.

[102] NASA facts online: Making the skies safe from windshear. http://oea.larc.nasa.gov/PAIS/Windshear.html, June 1992. Last accessed 18 May 2006.

[103] James Evans and Donald Turnbull. Development of an automated windshear detection system using Doppler Weather Radar. *IEEE*, 77(11):1661–1673, November 1989.

[104] Lane E. Wallace. *"The Best That We Can Do:" Taming the Microburst Windshear*, chapter 5. National Aeronautics and Space Administration, 1994.

[105] US House of Representatives. *Aviation Safety: Improving the Detection and Dissemination of Severe Weather Information to Pilots. Hearing before the Subcommittee on Investigations and Oversight of the Committee on Public Works and Transportation.* Government Printing Office, June 1987. http://ntlsearch.bts.gov/tris/record/tris/00482298.html.

[106] National Commission on Terrorist Attacks. The 9/11 commission report: Executive summary. http://www.gpoaccess.gov/911/pdf/execsummary.pdf, 2004.

[107] ProQuest Search Results: Historical newspapers the new york times (1851–2004). http://proquest.umi.com/, 2008. Query terms were "(crash or attack) and PDN(>9/11/2001) AND PDN(<12/31/2008)".

[108] Xigen Li and Ralph Izard. 9/11 attack coverage reveals similarities, differences. *Newspaper Research Journal*, 24(1):204–219, Winter 2003.

[109] Giovanni Bisignani. The air transport industry since 11 september 2001. http://www.iata.org/NR/rdonlyres/92FC0755-1D63-4931-A983-847CC1EA897A/0/airtransportsince911.pdf. Last accessed 8 March 2008.

[110] CNN. Exchange between Reid, judge follows life sentence. http://www.cnn.com/2003/LAW/01/30/shoebomber.sentencing/, December 2003. Last accessed 9 March 2008.

[111] James Schubert, Patrick Stewart, and Margaret Ann Curran. A defining presidential moment: 9/11 and the rally effect. *Political Psychology*, 23(3):559–583, September 2002.

[112] Amy Gershkoff and Shana Kusher. Shaping public opinion: The 9/11-iraq connection in the Bush administration's rhetoric. *Perspectives on Politics*, 3:525–537, 2005.

[113] President Bush: Job ratings. http://www.pollingreport.com/BushJob1.htm. Last accessed 9 March 2008.

[114] Michael Traugott, Ted Brader, Deborah Coral, Richard Curtin, David Featherman, Robert Groves, Martha Hill, James Jackson, Thomas Juster, Robert Kahn, Courtney Kennedy, Donald Kinder, Beth-Ellen Pennell, Matthew Shapiro, Mark Tessler, David Weir, and Robert Willis. How Americans responded: A study of public reactions to 9/11/01. *Political Science and Politics*, 35(3):511–516, September 2002.

[115] Chasing the sun: Timeline 2000–2009. http://www.pbs.org/kcet/chasingthesun/timeline/2000.html. Last accessed 22 October 2007.

[116] Airport finance: Using airport grant funds for security projects has affected some development projects. Report to the Committee on Transportation and Infrastructure, House of Representatives GAO-03-27, US General Accounting Office, October 2002.

[117] Checked baggage screening systems–planning for the December 31, 2002 deadline. Committee Serial 107-58, Committee on Transportation and Infrastructure, House, December 2001.

[118] Bruce Schneier. *Beyond Fear*. Springer, 2004.

[119] George Naccara. Personal interview. 11 July 2007.

[120] Aviation Security: DHS Has Made Progress in Securing the Commercial Aviation System, but Key Challenges Remain. Testimony Before the Subcommittee on Transportation Security and Infrastructure Protection, House Committee on Homeland Security GAO-08-139T, US General Accounting Office, October 2007.

[121] Transportation Security: Efforts to Strengthen Aviation and Surface Transportation Security are Under Way, but Challenges Remain. Testimony Before the Subcommittee on Transportation Security and Infrastructure Protection, House Committee on Homeland Security GAO-08-140T, US General Accounting Office, October 2007.

[122] Homeland Security: Progress Has Been Made to Address the Vulnerabilities Exposed by 9/11, but Continued Federal Action Is Needed to Further Mitigate Security Risks. Report to Congressional Requesters, House of Representatives GAO-07-375, US General Accounting Office, January 2007.

[123] Aviation Security: Vulnerabilities Exposed Through Covert Testing of TSA's Passenger Screening Process. Testimony Before the Committee on Oversight and Government Reform, House of Representatives GAO-08-48T, US General Accounting Office, November 2007.

[124] John Silva. Logan Airside Improvements Planning Project (EOEA #10458), Construction and Operation of a New Unidirectional Runway 14/32, Centerfield Taxiway and

Add'l Taxiway Improvements, New Information, Providing Clarification of the Delay Problems, Boston Int'l Airport, Federal Funding, Airport Layout Plan and NPDES Permit, Boston, MA. Final EIS 020264, Federail Aviation Administration, August 2002.

[125] Dorothy Nelkin. *Jetport: The Boston Airport Controversy*. Transaction Publishers, 1974.

[126] Fred Salvucci. Personal interview. 17 May 2007.

[127] Regina M. Marchi. Reframing the runway: A case study of the impact of community organizing on news and politics. *Journalism*, 6(4):465–485, 2005.

[128] Peter J. Howe. The 30-year saga of 14/32. *The Boston Globe*, November 19 2006.

[129] Patty Clark. Personal interview. 30 July 2007.

[130] Federal Aviation Administration. High density airports; notice of extension of the lottery allocation at laguardia airport. *Federal Register*, 69(128), July 2004.

[131] Frank Berardino. History of the slot exchange market in the US and some implications, 6 June 2007. Presented to Nextor Workshop on Allocation and Exchange of Access Rights.

[132] The slot lottery at LaGuardia Airport. http://commdocs.house.gov/committees/Trans/hpw106-114.000/hpw106-114_1.HTM, December 2005. Last accessed 2 June 2007.

[133] Federal Aviation Administration. Congestion Management Rule for LaGuardia Airport; Proposed Rule. *Federal Register*, 71(167):51359–51380, August 2006.

[134] Federal Aviation Administration. Operating Limitations at New York LaGuardia Airport; Notice of Order. *Federal Register*, 72(216):63224–63228, November 2007.

[135] Vincent Capezzuto. Personal interview. March 21, 2008.

[136] Federal Aviation Administration. The role of ADS-B in NGATS.

http://www.faa.gov/about/office_org/headquarters_offices/ato/service_units/enroute/surveillance_broadcast/program_office_news/ind_day/, June 2006.

[137] ADS-B by 2020? http://www.aopa.org/whatsnew/newsitems/2007/070118ads-b.html, 19 January 2007.

[138] David Hughes. FAA administrator says ADS-B going nationwide by 2014. *Aviation Week (Online)*, 3 May 2006.

[139] David Hughes. The FAA's New Deal. *Aviation Week and Space Technology*, 165(4), 24 July 2006.

[140] Federal Aviation Administration. Automatic dependent surveillance broadcast (ADS-B). http://www.faa.gov/airports_airtraffic/technology/ads-b/. Last accessed 30 August 2007.

[141] John Scardina. Overview of the ADS-B link decision. Technical report, Federal Aviation Administration, June 2002.

[142] John Scardina. The approach and basis for the FAA ADS-B link decision. Technical report, Federal Aviation Administration, June 2002.

[143] Work Group 6. Proposed revisions to ADS-B masps: Integrity and accuracy monitoring. Technical Report 242A-WP-6-23A, RTCA, 2001.

[144] International Civil Aviation Organization Air Transport Bureau (ATB). Environmental (Env) Unit Climate Change. http://www.icao.int/icao/en/env/ClimateChange.htm. Last accessed 17 March 2008.

[145] Carl Burleson. Personal interview. March 12, 2008.

[146] Dabiel Calleja Crespo and Mike Crompton. The European Approach to Aviation and Emissions Trading: Speak the Truth and Shame the Devil. *The Air and Space Lawyer*, 21(3), 2007.

[147] Climate Action Network Europe. CAN-Europe's beginner's guide to the EU ETS. http://www.climnet.org/euenergy/ET.html. Last accessed 17 March 2008.

[148] Nancy Young. Personal interview. March 21, 2008.

[149] Carl Burleson. The EU Emissions Trading System Proposal: History often Rhymes. *The Air and Space Lawyer*, 21(3), 2007.

[150] Lourdes Maurice. Personal interview. March 11, 2008.

[151] ICAO commits to aggressive action on aircraft emissions. News Release PIO 10/07, International Civil Aviation Organization, 28 September 2007.

[152] Regina Marchi. Communities against runway expanson: A case study in contesting dominant news frames. In *Proceedings of the International Communication Association*, New Orleans, LA, May 2004.

[153] Sepncer R. Weart. *The Discovery of Global Warming*. Harvard University Press, Cambridge, MA, 2003.

[154] Roger W. Cobb and David M. Primo. *The Plane Truth: Airline crashes, the media, and transportation policy*. Brookings Institute Press, Washington, DC, 2003.

[155] Dedre Gentner and Albert L. Stevens, editors. *Mental Models*. Lawrence Erlbaum Associates, 1983.

[156] M. R. Endsley. Toward a theory of situation awareness in dynamic systems. *Human Factors*, 37(1):32–64, March 1995.

[157] Air carrier operational approval and use of TCAS II. Advisory Circular 120-55, Federal Aviation Administration, October 1991.

[158] Paul Slovic and Elke U. Weber. Perception of risk posed by extreme events. In *Proceedings of Risk Management strategies in an uncertain world*, Palisades, NY, 2002.

[159] Judy Rumerman. Aviation security. In *Essays on the History of Flight*. 2003.

[160] Phillippe a Bonnefoy and R. John Hansman. Overview of recent forces and trends in the airline industry and challenges for future operations. In *Lufthansa - European Business School Conference 2008*, Oestrich-Winkel, Germany, January 2008.

[161] Susan Carey. Anatomy of a debacle: Airline report shows how many miscues piled up. *The Wall Street Journal*, 24 February 1999.

[162] GovTrack.us. S. 2891–106th congress: Air travelers fair treatment act of 2000. http://www.govtrack.us/congress/bill.xpd?bill=s106-2891. Last accessed 2 March 2008.

[163] GovTrack.us. H.r. 1734–107th congress: Airline passenger bill of rights act. http://www.govtrack.us/congress/bill.xpd?bill=h107-1734. Last accessed 5 March 2008.

[164] GovTrack.us. S. 678–110th congress: Airline passenger bill of rights act of 2007. http://www.govtrack.us/congress/bill.xpd?bill=s110-678. Last accessed 5 March 2008.

[165] Peter Morrell. An evaluation of possible EU air transport emissions trading scheme allocation methods. *Energy Policy*, 35(11):5562–5570, November 2007.

[166] Planning, budgeting, aquisition, and management of capital assets. Circular A-11, Part 7, Section 300, Office of Management and Budget, July 2007.

[167] Martin McOmber. Our billion-dollar runway: Who will pay? *The Seattle Times*, 4 July 2004.

[168] Automatic Dependent Surveillance-Broadcast (ADS-B) Out Performance Requirements to Support Air Traffic Control (ATC) Service. *Federal Register*, 72(193):56947–56972, 5 October 2007.

[169] Lisa Conant. *Justice Contained: Law and Politics in the European Union*. Cornell University Press, Ithaca, NY, 2002.

[170] EurActiv.com. Aviation and emissions trading. http://www.euractiv.com/en/climate-change/article-139728, 12 October 2007. Updated 10 January 2008; Last accessed 29 January 2008.

[171] Norm Fujisaki. Personal communication, 3 August 2007.

[172] Aviation safety reporting. http://www.asias.faa.gov/pls/portal/docs/PAGE/ASIAS_PAGES/LEARN_ABOUTS/ASRS_LA.html. Last accessed 1 March 2008.

[173] High density airports; notice of lottery of slot exemptions at LaGuardia Airport. *Federal Register*, 65(221):69126–69129, 15 November 2000.

[174] Ian Waitz, Jessica Townsend, Joel Cutcher-Gershenfeld, Edward Greitzer, and Jack Kerrebrock. Aviation and the environment: A national vision statement, framework for goals and recommended actions. Report to the United States Congress, Partnership for Air Transportation Noise and Emissions Reduction, December 2004.

[175] Deborah A. Stone. Causal stories and the formation of policy agendas. *Political Science Quarterly*, 104(2):281–300, Summer 1989.

[176] A brief history of the reduced vertical separation minimum (RVSM). http://www.faa.gov/ats/ato/drvsm/docs/seminar8/P14_History_OCT2.ppt, October 2004.

[177] RTCA. Executive summary of the final report of task force 4 certification, February 1999.

[178] Minimum operational performance standards for 1090 mhz Automatic Dependent Surveillance-Broadcast (ADS-B) and Traffic Information Services (TIS-B). Technical Report DO-260, RTCA, 13 September 2000.

[179] G. Dunstone. Consideration of Existing ADS-B Avionics, Australian Strategic Air Traffic Management Group, ADS-B Implementation Team. Report ABIT10-IP007 V2, 2007.

[180] International Civil Aviation Organization. Manual on airspace planning methodology for the determination of separation minima. Document 9689, Amendment 1, 30 August 2002.

[181] US Congress. National Environmental Policy Act of 1969. *Federal Register*, 43:55990, July 1978.

[182] Federal Aviation Administration. FAA Order 1050.1E; Environmental Impacts: Policies and Procedures; Correction. *Federal Register*, 64(223):63362, November 1999.

[183] Aviation infrastucture: Challenges related to building runways and actions to address them. Report to the Subcommittee on Aviation, House Committee on Transportation and Infrastucture GAO-03-164, US General Accounting Office, January 2003.

[184] John G. McCartney. Corrected record of decision: New York/New Jersey/Philadelphia metropolitan area airspace redesign. http://www.faa.gov/airports_airtraffic/air_traffic/nas_redesign/regional_guidance/eastern_reg/nynjphl_redesign/, 5 October 2007.

[185] Deborah Stone. *Policy Paradox: The Art of Political Decision Making*. W.W. Norton and Company, 2002.

[186] Y. Bar-Yam. When systems engineering fails—toward complex systems engineering. *IEEE International Conference on Systems, Man and Cybernetics*, 2:2021–2028, October 2003.

[187] R. John Hansman. Personal interview, 2005.

[188] James Ott. Pavement paradox; new U.S. runways will add needed capacity even as reorganizing airlines pull down flights. *Aviation Week & Space Technology*, 163(16):46, October 24 2005.