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Dynamics of Air Transportation System Transition and Implications for ADS-B Equipage

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The U.S. Air Transportation Systems faces substantial challenges in transforming to meet future demand. These challenges need to be understood and addressed in order to successfully meet future system needs. This paper uses a feedback model to describe the general system transition process and identify key issues in the dynamics of system transition, with particular emphasis on stakeholder cost-benefit dynamics and safety approval processes. Finally, in addition to identifying dynamics and barriers to change the paper proposes methods for enabling transition through the use of levers such as incentives, mandates, and infrastructure development. The implementation of ADS-B is studied as a pathfinding technology for planned Air Transportation System changes. The paper states that overcoming stakeholder barriers and ensuring efficient safety approval and certification process are the key enablers to the successful implementation of ADS-B.

I. Introduction

The US Air Transportation System is facing several substantial challenges. Limited system capacity, in the face of continuously increasing demand for travel, presents the potential for substantial gridlock and disruption in future system operations. In response to this anticipated demand increase and other pressures, the U.S. Joint Planning and Development Office (JPDO) has proposed several ambitious new capabilities for the Next Generation Air Transportation System (NexGen) [1]. Automatic Dependent Surveillance-Broadcast (ADS-B) will be a pathfinding example for the ability to implement other aspects of the NGATS plan. ADS-B is the first NextGen technology to be implemented and many downstream planned operational improvements depend on ADS-B capabilities.

System modernization efforts must engage multiple stakeholders in the decision process while providing continued system safety and security, and reduced environmental emissions. This paper will illustrate challenges to implementing ADS-B through a system transition model developed based on past case studies of change. General issues in system transition and their applicability to ADS-B will be discussed. Understanding and anticipating issues that may arise during transition is critical to achieving the required increases in system performance proposed to meet future demands. In particular, the paper will focus on the value distribution ADS-B provides to different stakeholders as well as barriers associated with conducting the safety review and certification processes. Potential approaches and leverage mechanisms to overcome these barriers and motivate transition will also be discussed.

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II. ADS-B Functionality and Implementation Approach

ADS-B is a pathfinding technology for the modernization of Air Traffic Management and the Next Generation Air Transportation System. ADS-B is a surveillance technology that broadcasts GPS-based position from aircraft to ground-based receivers and other aircraft. This datalink enables a variety of capabilities on the aircraft and in air traffic control, as shown in Figure 1. 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. Applications enabled by ADS-B vary based on the characteristics of the particular ADS-B avionics and aircraft transponder and require separate standards and certification. Benefits delivered to users depend on individual or combinations of applications that are implemented and on a critical mass of equipage by other operators.

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. 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. Service is also continued along the East Coast, Alaska, and other areas with legacy ADS-B equipment [2]. Segment two of the program extends ADS-B ground infrastructure nationwide. A mandate is expected requiring ADS-B out equipage to access high density airspace by 2020 [3]. This phased approach allows focused cost-benefits delivered in each phase, and facilitates early adoption by specific users or geographic areas.

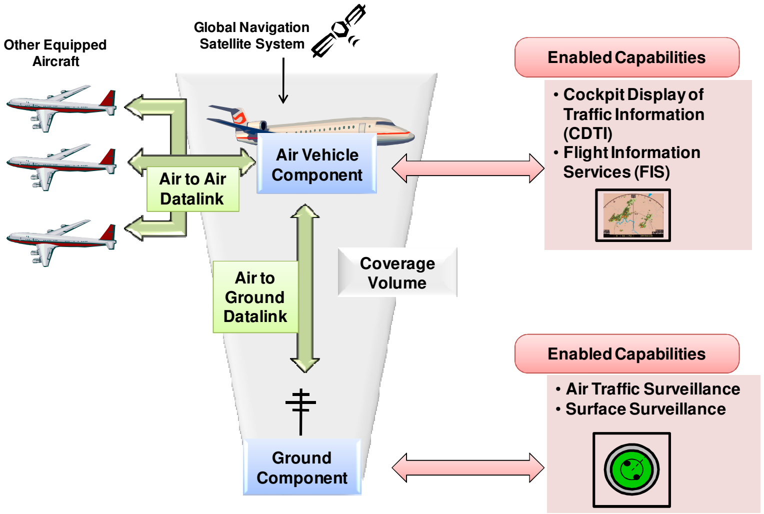


Figure 1: High-Level ADS-B Architecture: *ADS-B broadcasts aircraft information to the ground and other aircraft enabling ground and airborne capabilities.*

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 [4]. 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 [4].

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.

III. System Transition Feedback Model

In order to understand the barriers to transition in the air transportation system a feedback model of transition is used. The model, presented in Figure 2, was developed based on 13 cases of historical transition efforts in the US Air Transportation System. Cases studied include technology and policy changes, successful and unsuccessful changes, as well as safety and capacity driven changes. The framework provided by the model is used to study barriers to ADS-B equipage caused by the multi-stakeholder nature of transition as well as those posed by the complexity of the implementation process.

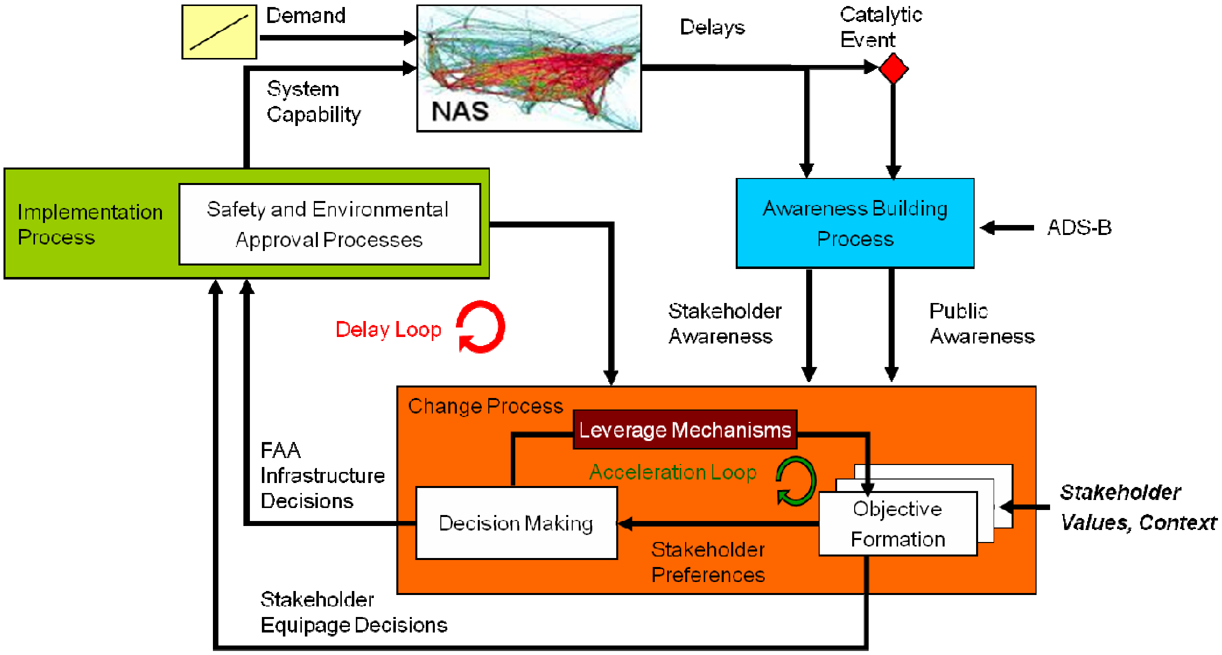


Figure 2: Transition Dynamics Process Model: *Performance of the National Airspace System results in building of awareness of potential problems. Through a change process, stakeholder preferences are formulated and result in infrastructure and equipage decisions. These are implemented to then provide additional system capability.*

Boxes in the model represent high-level processes while arrows represent the resulting states. 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 the awareness building process, stakeholders (a stakeholder is anyone with an interest in the outcome or involved in the process of a transition) develop an understanding and definition of the problem and potential solutions. Each stakeholder forms their own mental model of the situation. This includes projecting future outcomes based on potential actions to address the problem. Awareness of a growing capacity problem in the US Air Transportation System has been increasing among aviation stakeholders and ADS-B is seen as a potential solution to this issue.

Once stakeholder awareness of a problem and potential solutions exist, stakeholders engage in the change process. During this process, stakeholders evaluate the projections for the future and develop preferences based on the formation of their individual objectives. While these preferences are determined separately for each stakeholder, they can be modified as stakeholders act and interact during the decision making process. Stakeholder objectives are formed based on the cost benefit estimate conducted by stakeholders. Cost benefit estimates can include significant levels of risk and uncertainty when outcomes depend on the actions of other stakeholders. Unfavorable cost benefit ratios mean that stakeholders will be resistant to a transition. Expected benefits of ADS-B are application based but include increased information to pilots and controllers and an ability to safely handle increased levels of traffic. In addition, the FAA expects to gain costs cuts by transitioning from a radar to an ADS-B based communication, navigation, and surveillance infrastructure. However, these benefits come at a cost of developing, certifying, buying and installing both the ADS-B ground infrastructure and aircraft avionics.

The negotiation loop occurs during the change process and 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 addition, leverage mechanisms to help overcome stakeholder disagreements can be used. Such mechanisms include structuring the change to provide tangible benefits to stakeholders, mandating equipage, restricting access to airspace based on level of equipage, and providing the necessary infrastructure and approval for technologies and procedures.

The change process terminates when an action to address an issue is selected. As shown in the model, in the case of ADS-B this requires that operators commit to equipping with ADS-B technology while the FAA has to commit to provide the necessary ground infrastructure as well as develop procedures and certify both them and the avionics. Stakeholders must trust that others will fulfill their obligations so that benefits can be realized. If this trust does not exist they will be hesitant to commit to action.

Once an action is selected, it proceeds through the implementation process. In this process, stakeholders refine the details of the solution, and approve the chosen solutions. During this process, the complexities of determining the specifics of a solution as well as conducting the necessary safety certification and other approval processes can delay change. While such approval processes are necessary and ensure system safety they are not easy to conduct. In addition, stakeholder disputes can once again arise when details of a solution are being determined and additional leverage mechanisms may be needed to overcome them. Once implementation is complete and successful, the capability of the system is improved and the problem being addressed is reduced or eliminated.

IV. Stakeholder Cost Benefit Dynamics and Barriers to ADS-B Implementation

The distribution of costs and benefits can have a significant impact on the stakeholder dynamics during the process of transition. Understanding and anticipating stakeholder dynamics by analyzing the distribution of costs and benefits to stakeholders is an important aspect of achieving successful transitions. Marais and Weigel [5] 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. This section reviews the framework and expands the ADS-B example to consider also the distribution of costs and benefits when different ADS-B applications are taken into account.

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 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, as shown in Figure 3.

Discrepancies in the distribution of costs and benefits between stakeholders can create a barrier to implementation when some stakeholders have a strong incentive to oppose the implementation of a change. In the case of ADS-B the distribution of costs and benefits needs to be looked at not only on a stakeholder by stakeholder basis, but also for each application enabled by the technology. Costs and benefits are delivered through applications enabled by new operational capabilities which are a combination of operating procedures, aircraft operational capability (i.e. equipage), ATC operational capability, and ground infrastructure changes as shown in Figure 4. Each application of ADS-B is not automatically guaranteed if an operator equips with ADS-B avionics. Instead, it has to be separately certified and approved by the FAA. As a result, benefits are contingent on the operational approval of applications. In addition, since users receive aggregate costs and benefits from a package of applications. As a result, choosing which applications of ADS-B to support influences the total costs and benefits seen by stakeholders.

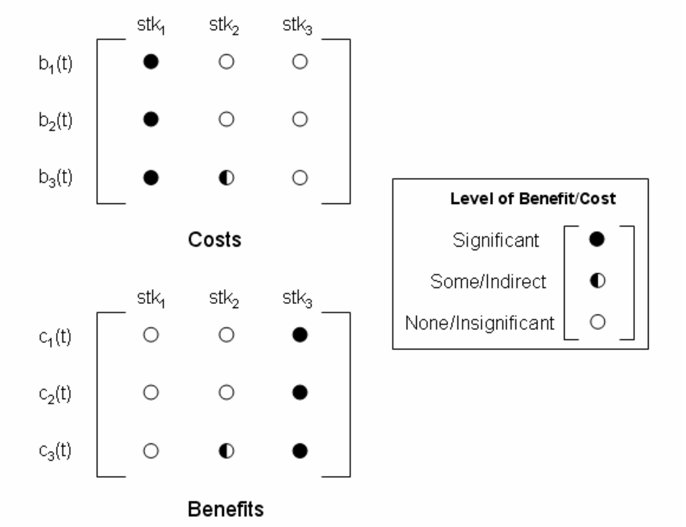


Figure 3: Example Cost-Benefit Distribution across Stakeholders [5]: *Illustration of cost and benefits appropriated across three example stakeholders.*

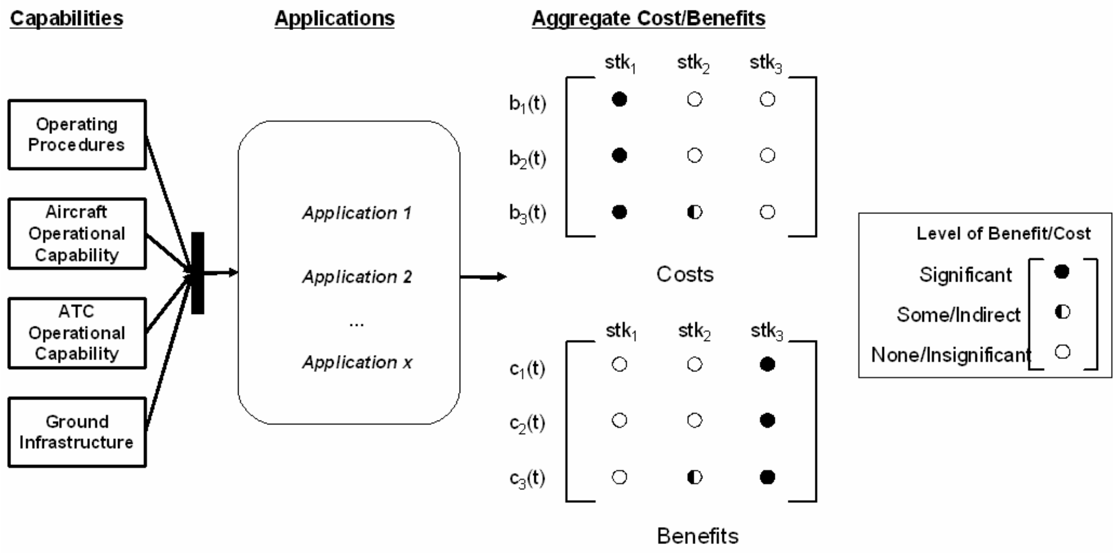


Figure 4: Transitioning from Capabilities to Benefits: *Changes in different systems-level capabilities enable various applications which then deliver aggregate costs & benefits to stakeholders*

In addition to a distribution of benefits between stakeholders the temporal distribution of costs and benefits needs to be considered. Figure 5 shows an example distribution of costs and benefits over time. As stakeholders formulate preferences the decision to equip with ADS-B will be made not only on whether a change results in a net benefit, but also on the timing of that benefit. Investments in equipage are more attractive if benefits are rapidly realized. That is, in addition to a total positive net present value (NPV), a positive NPV over the short term is preferable, especially when initial costs are high.

When the levels and distribution of both costs and benefits is certain the NPV can be calculated and used to determine if equipage makes sense. However, 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 equipage. Figure 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.

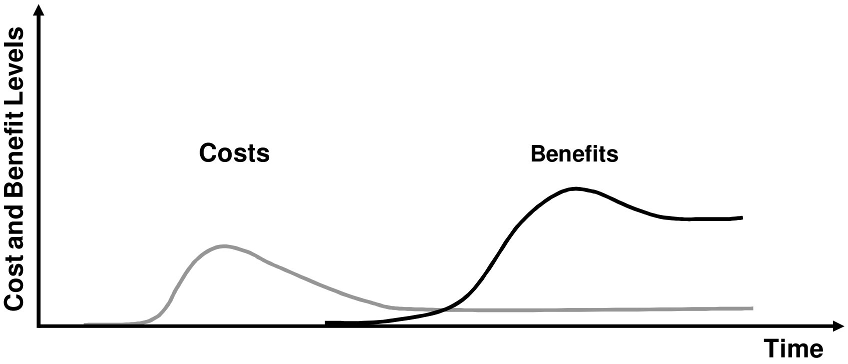


Figure 5: Temporal Distribution of Costs and Benefits: *In this example, costs occur before benefits in time, although benefits outweigh costs. Adapted from [5]*

There are three significant 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 dependant 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. However, as each stakeholder postpones equipage benefits are also postponed resulting in a less favorable NPV.

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 [6].

The second risk deals with which applications of ADS-B will be supported and when. Both the level and timing of benefits will be impacted by the selected applications and their timing.

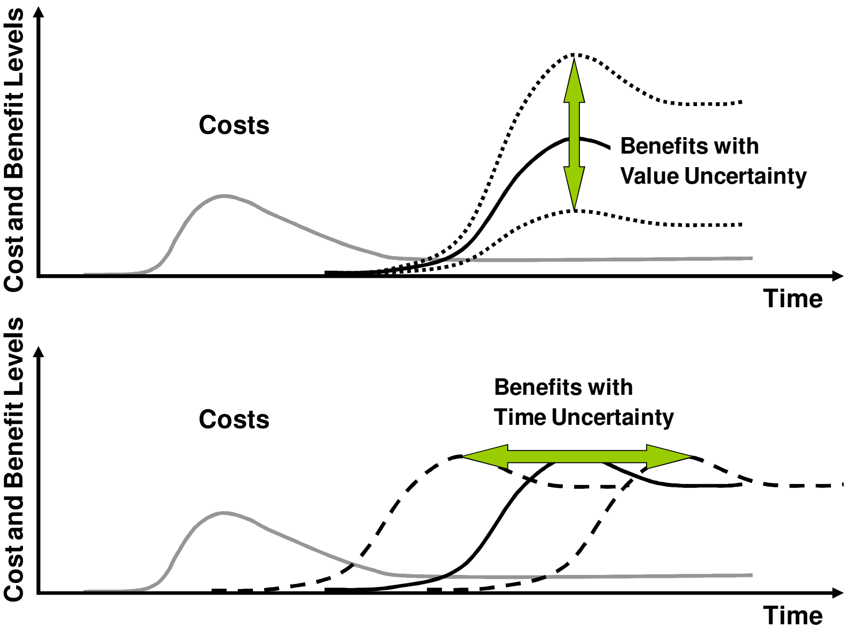


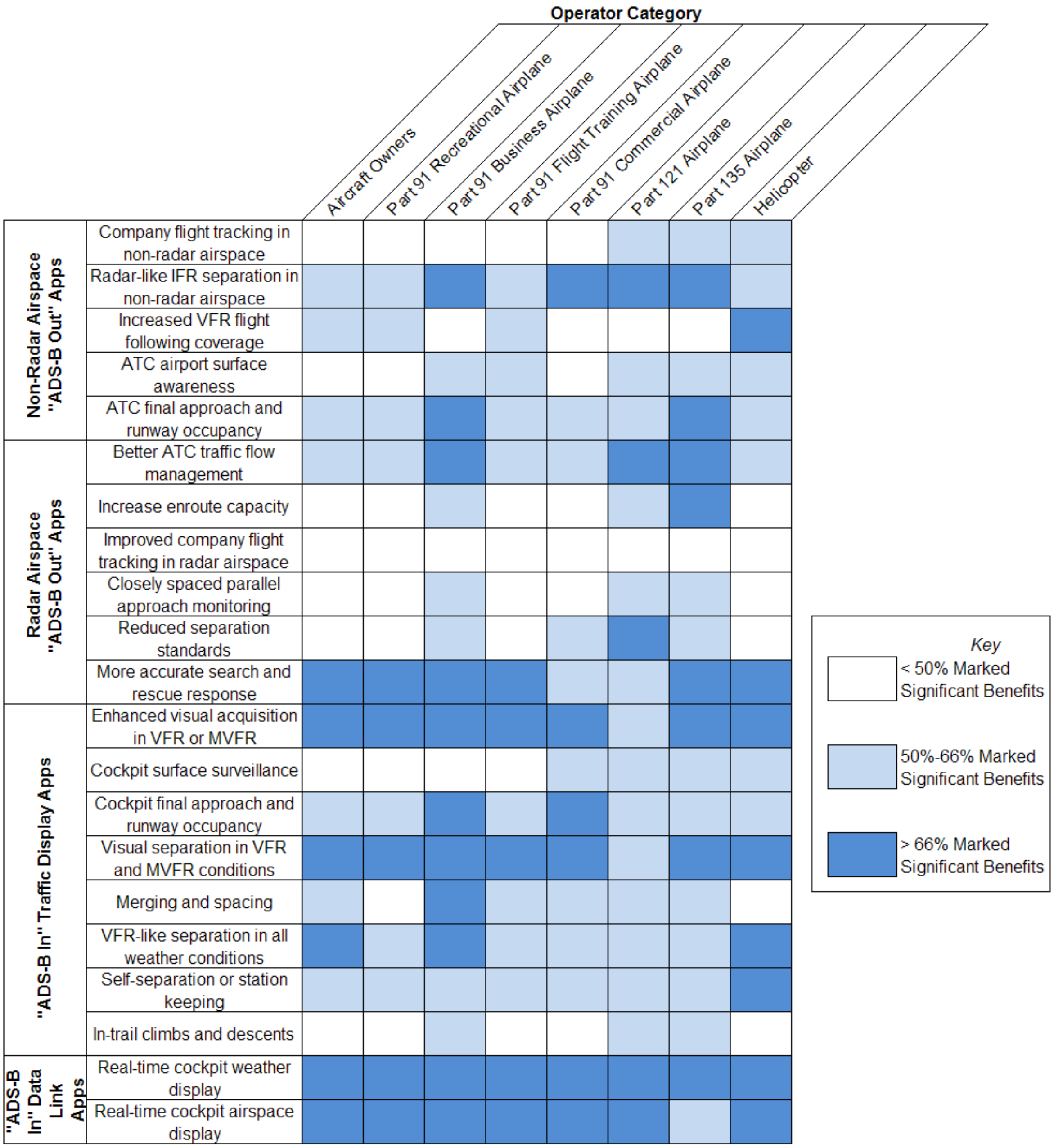
Figure 6: Time and Value Uncertainty in Benefit Distribution: *Value uncertainty can change the expected magnitude of benefits, while time uncertainty shifts the time at which benefits are realized.*

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.

V. Stakeholder Perception of ADS-B Benefits

The distribution of costs and benefits can have a significant impact on stakeholder dynamics during the transition process. In order to understand what benefits operators are expecting from ADS-B equipage, a survey of potential user benefits was conducted. This survey can be used to identify which benefits are already planned and which can be added and used as incentives to motivate operator equipage.

U.S. aviation stakeholders were surveyed and asked to rank their perceived level of benefit for a variety of potential ADS-B applications including those currently planned by the FAA and potential future applications. Applications were divided into those enabled both by ADS-B-out in radar and non-radar airspace and ADS-B-in with different enabling avionics. Benefit trends for each application were examined by self-identified stakeholder groupings. These eight groupings differentiate between type of aircraft operation and operators and include: aircraft owners, Part 91 recreational pilots, Part 91 business traveling airplane pilots, Part 91 flight Training airplane pilots, Part 91 commercial airplane pilots, Part 135 airplane pilots, part 121 airplane pilots, and helicopter pilots. The results are shown in Figure 7. The online survey was open to aviation stakeholders (primarily pilots), throughout the US. The survey was internet-based and posted in June & July 2007 and received 1136 valid responses. A detailed description of the methodology and results is reported by Lester and Hansman [7].



Operator Category

		Aircraft Owners	Part 91 Recreational Airplane	Part 91 Business Airplane	Part 91 Flight Training Airplane	Part 91 Commercial Airplane	Part 121 Airplane	Part 135 Airplane	Helicopter
Non-Radar Airspace "ADS-B Out" Apps	Company flight tracking in non-radar airspace	□	□	□	□	□	▨	▨	▨
	Radar-like IFR separation in non-radar airspace	▨	▨	■	▨	■	■	■	▨
	Increased VFR flight following coverage	▨	▨	□	▨	□	□	□	■
	ATC airport surface awareness	□	□	▨	▨	□	▨	▨	▨
	ATC final approach and runway occupancy	▨	▨	■	▨	▨	▨	■	▨
Radar Airspace "ADS-B Out" Apps	Better ATC traffic flow management	▨	▨	■	▨	▨	■	■	▨
	Increase enroute capacity	□	□	▨	□	□	▨	■	□
	Improved company flight tracking in radar airspace	□	□	□	□	□	□	□	□
	Closely spaced parallel approach monitoring	□	□	▨	□	□	▨	▨	□
	Reduced separation standards	□	□	▨	□	▨	■	▨	□
	More accurate search and rescue response	■	■	■	■	▨	▨	■	■
"ADS-B In" Traffic Display Apps	Enhanced visual acquisition in VFR or MVFR	■	■	■	■	■	▨	■	■
	Cockpit surface surveillance	□	□	□	□	▨	▨	▨	▨
	Cockpit final approach and runway occupancy	▨	▨	■	▨	■	▨	▨	▨
	Visual separation in VFR and MVFR conditions	■	■	■	■	■	▨	■	■
	Merging and spacing	▨	□	■	▨	▨	▨	▨	□
	VFR-like separation in all weather conditions	■	▨	■	▨	▨	▨	▨	■
	Self-separation or station keeping	▨	▨	▨	▨	▨	▨	▨	■
	In-trail climbs and descents	□	□	▨	□	□	▨	▨	□
"ADS-B In" Data Link Apps	Real-time cockpit weather display	■	■	■	■	■	■	■	■
	Real-time cockpit airspace display	■	■	■	■	■	■	▨	■

Key

□	< 50% Marked Significant Benefits
▨	50%-66% Marked Significant Benefits
■	> 66% Marked Significant Benefits

Figure 7: User-Perceived ADS-B Application Benefits: *User responses to ADS-B application benefits. Users identified significant benefits for Search & Rescue, Enhanced Visual Acquisition, Visual Separation, and Weather and Airspace Display.*

The survey showed that stakeholders perceive a high potential benefit stemming from ADS-B. Applications which received strong responses of significant benefit across stakeholder categories are likely to provide the highest leverage to encourage early individual equipage. Such applications include: *Enhanced Visual Acquisition* and *Visual Flight Rule (VFR) separation* in Marginal VFR (MVFR) conditions provided by ADS0B-in. Both require CDTI implemented to augment situation awareness. This is likely to be lower cost than a higher level of certification design assurance. These applications also lead to benefits in dense traffic areas such as busy terminal areas that already have ATC radar coverage, and the FAA plans to support them in current ground infrastructure deployment for Segments one and two as discussed previously. Additionally, cockpit weather and airspace provide significant benefits to all operators, including part 121 and part 135 operators, and can be used with a display that supports situation awareness in the cockpit.

The two ADS-B-out applications with the highest identified benefits are radar-like Instrument Flight Rule (IFR) separation and Improved Search and Rescue Accuracy. These benefits require ground infrastructure deployment in regions without current radar coverage. However, currently the FAA plans to only use ADS-B within existing radar coverage volumes. Strong consideration should be given to adding ADS-B coverage in areas of mountainous terrain or low altitude where procedural separation is currently used.

Pilots did not perceive strong benefits from surface surveillance applications, either from the tower or in the cockpit with a CDTI. However, general aviation and part 135 operators who operate primarily under IFR (part 91 commercial, part 91 business), do see significant benefits from final approach and runway occupancy awareness from the tower or from within the cockpit. All other operators see some benefits from final approach and runway occupancy applications.

Based on the survey results, the strongest leverage mechanisms to accelerate the realization of ADS-B-out benefits are to provide radar-like separation services in areas where radar coverage is currently lacking. Therefore a strong leverage strategy would be to add ADS-B coverage volumes where current use of procedural separation limits access to airspace and airports. For equipage of ADS-B-in, expected to be equipped along with ADS-B-out, the highest benefits rated by users relate to traffic separation in VFR and MVFR conditions, requiring development of procedures and avionics to utilize cockpit-based CDTI. Information services also offer strong benefits across the aviation community, even to scheduled airline pilots.

VI. Operational Approval Process and Uncertainty in ADS-B Benefits

A. Overview of the Operational Approval Process

One of the greatest sources of uncertainty to realizing future ADS-B benefits is receiving operational approval in the implementation process shown in Figure 2. Potential operational capabilities of ADS-B, such as reduced separation, will require operational approval by the FAA before benefits can be realized. The complexities of the safety and approval process, while necessary, can introduce substantial delays and uncertainty into the transition process. Delivery of operational approval impacts the decision to invest in technology both by increasing uncertainty around the time at which benefits from applications are available to users, and by increasing the uncertainty that benefits will ultimately be realized. Increasing the level of certification requirements can also significantly increase the cost of equipage. Understanding and addressing potential barriers to achieving operational approval is critical to delivery of benefits from ADS-B capabilities. The uncertainties surrounding implementation affect the NPV calculated during the cost benefit analysis and significantly contribute to operators' hesitancy to equip with ADS-B.

A simplified representation of the specification and approval processes relevant to implementing NAS-wide ADS-B capabilities is shown in Figure 8. The process begins with an initial operational concept to improve the system, which can be divided into three aspects of the operational capability: airborne components, the air/ground interface & procedures, and ground-based infrastructure. Standards are then developed for components of the system, including the air/ground interface, applications, and ground-based infrastructure. Next, analysis is conducted and additional requirements are identified for all components of the system. Finally, approval and implementation processes result in an airborne operational capability, established procedures, and ATC operational capability. These three capabilities combine to create overall system operational capability. The approval process is performed incrementally and typically multiple iterations are needed to approve different applications or sets of applications.

B. Example Sources of Uncertainty in the Approval Processes

1. Requirements Stability

Because standards are developed before certification of procedures, there is significant uncertainty in potential costs of recertification or re-equipage if the avionics installed by early adopters are not adequate to perform desired functions. This problem occurred during the development of DO-260, which is the Minimum Operational Performance Standards (MOPS) for the 1090 MHZ extended squitter (1090ES) [8]. Early avionics based on the DO-260 standard allowed for the use of either of two potential measures of position uncertainty. During later

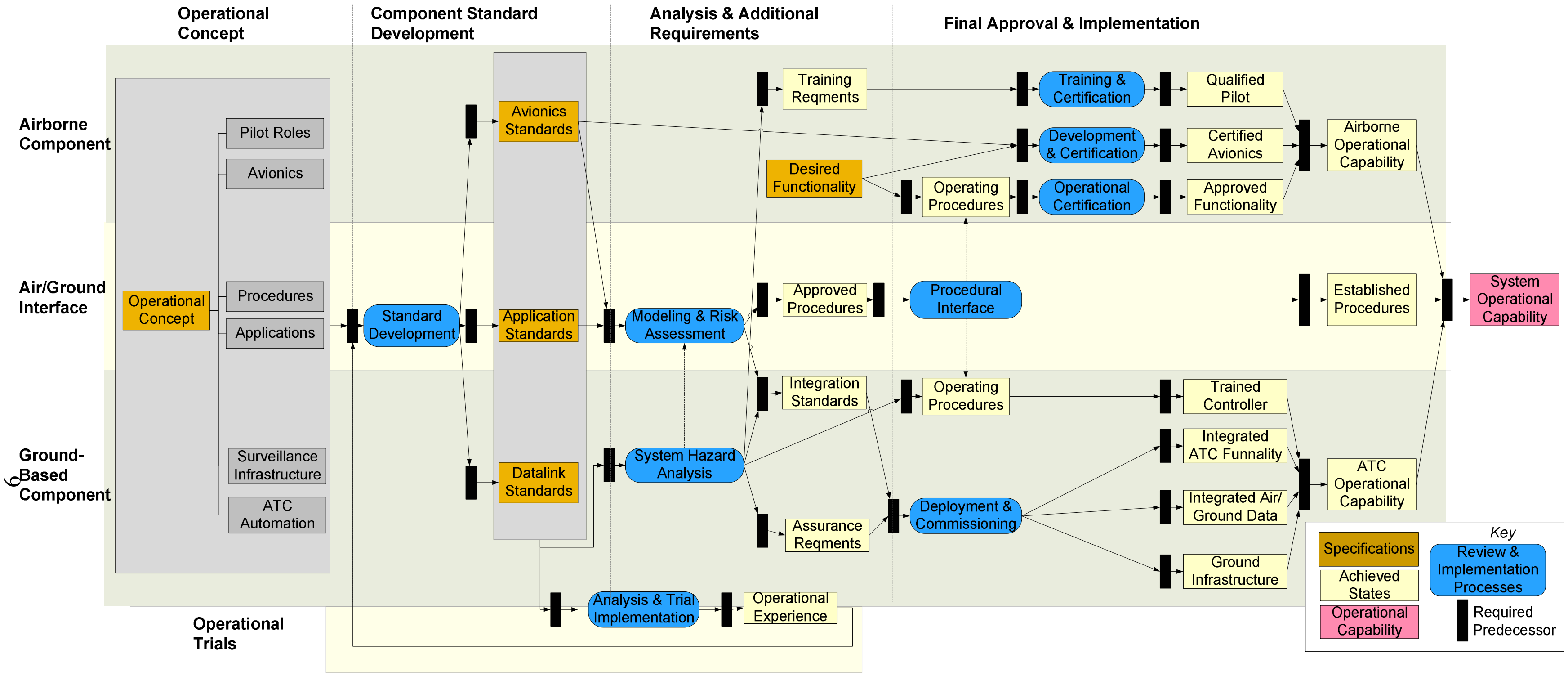


Figure 8: Simplified Specification and Approval Processes for New Operational Capability: *Several processes are performed in the implementation stage to transition from an operational concept to an implemented operational capability.*

revisions, 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. As an example, Airservices Australia currently has to certify each individual airframe before the aircraft can utilize ADS-B for ATC separation [9].

The DO-260 specification has been changed once, to the current specification being DO-260 Change 1. The second version of the 1090 ES MOPS, DO-260A, has been changed three times, with the current version published as DO-260 Change 3. The MOPS for the Universal Access Transceiver (UAT), the datalink standard which supports graphical weather information, has also gone through two major revisions, with the current revision being DO-282A. These revisions illustrate that there is no guarantee that further changes will not occur. In fact, the contract award for broadcast services is likely to stimulate further avionics development and standard revisions. Uncertainty in standards creates a disincentive for operators to equip with a technology that meets the current standards if their avionics may not be usable in the future or if revised standards provide a higher level of benefits.

2. *Varying Criticality Levels*

Rulemaking is anticipated to require ADS-B-out equipage for access to certain areas of airspace by 2020 [6]. It is expected that some users will evaluate a decision to equip earlier than the mandate based on benefits of both ADS-B-out and ADS-B-in applications. For segments one and two, a limited set of ADS-B-in applications are being implemented. While air traffic control surveillance is classified as a critical NAS service, the currently supported cockpit-based applications augment situation awareness and are therefore classified as essential services [10]. Classification of services as higher criticality means that more stringent requirements are placed on system performance. As examples, critical services have higher system availability requirements and lower probability of failure requirements than essential services. In addition, and specific cockpit design attributes, such as placement in the primary field of view may be required to receive airworthiness certification. Several lower-level performance measures also depend on the higher level specifications, such as system latency and update rate.

Several applications envisioned for future use of ADS-B, such as self-separation, would require airborne avionics to support a higher level of flight criticality in ADS-B-in applications. Because of the mismatch between design assurance levels to support essential cockpit-based services, and potential future flight-critical uses, there is a concern that current airborne specification of the system may not be sufficient to support future uses, and additional standards in equipage would be needed.

There is also a potential that ground infrastructure design assurance, including software and data integrity, may not be sufficient to support future flight-critical cockpit-based applications. While some safety assessment and modeling activities are used to inform the development of RTCA standards, the FAA is ultimately responsible for safety certification of ADS-B procedures. This analysis is performed to determine ground infrastructure requirements and procedural mitigations to arrive at an acceptable level of safety, according to the FAA's Safety Management System (SMS) process [11].

Avionics and operational procedures are approved through a different process. Intended uses of avionics are certified as part of operator type certification, and specific avionics packages are certified through the airworthiness certification process. Avionics development and certification usually occurs after ground infrastructure has already been specified and deployed. As a result, ground infrastructure requirements are fixed while avionics are still changing potentially resulting in incompatible systems.

3. *Equivalent vs. 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 and is therefore 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 [12]. Assessing changes to a target level of safety is significantly more difficult because it is performed to an absolute instead of relative standard. As an example, performing a target level of safety assessment to support the implementation of Reduced Vertical Separation Minima (RVSM) in domestic EU airspace required approximately 10 years to conduct [13].

VII. Conclusions

ADS-B will be a pathfinding capability for additional system modernization as planned for the Next Generation Air Transportation System. Implementation of ADS-B faces a number of barriers that need to be addressed to achieve system-level benefits. The benefits from ADS-B applications will influence individual equipage decisions. However, there are a variety of sources of uncertainty in both the time and magnitude of benefits delivery that reduce the potential attractiveness of ASD-B to stakeholders. The benefits case for ADS-B can be accelerated by increasing high value applications to encourage early adoption, and by reducing uncertainty in the delivery of benefits through ensuring certification of new operational capabilities.

A survey of stakeholder's perception of benefits derived from ADS-B applications revealed that ADS-B-in display of weather and airspace information, as well as search and rescue capability provided by ASD-B-out have strong benefits to a broad range of system stakeholders. In particular, general aviation users are interested in these capabilities. These applications complement strong perceived ADS-B benefits in operational efficiency improvements in VFR and marginal VFR approach spacing.

The implementation of applications with strong perceived ADS-B benefits should be accelerated to encourage early adoption of technology by users to create corresponding system-level benefits in capacity and safety enhancement. In addition, sources of uncertainty in the operational approval process should be reduced to ensure confidence in delivery ADS-B applications and benefits. Effective means must also be used to ensure future proposed ADS-B applications. In particular, ground infrastructure and airborne requirements must be sufficient to address planned future uses.

VIII. Acknowledgements

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IX. Biographies

Aleksandra Mozdzanowska received her undergraduate degrees in Aeronautics and Astronautics and in Literature, from MIT in 2002. She completed her Master's degree at the MIT International Center for Air Transportation in 2004. Her thesis focused on the impact of regional jet growth on the national airspace system. She is currently a PhD student in the Technology Management and Policy program in the Engineering Systems Devision at MIT. Her research focuses on understanding the transition dynamics in the air transportation industry. She can be reached at: 17-110 MIT, Cambridge, MA 02139, 671-253-2428, email: alexm@mit.edu

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X. Key words

cost-benefit, system transition, stakeholder, ADS-B, incentives, air transportation

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