ENCOURAGING AND ENSURING SUCCESSFUL TECHNOLOGY TRANSITION IN CIVIL AVIATION

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Technology transitions are essential to transforming air traffic management to meet future capacity needs. Encouraging and obtaining equipage adoption is one crucial aspect of technology transitions. We propose an approach for developing appropriate strategies to persuade aviation stakeholders to transition to new technologies. Our approach uses cost, benefit, and value distribution across stakeholders and over time to determine which strategies are most appropriate to persuading aircraft operators to adopt new equipage. Equipage that may show an overall positive value can nevertheless fail to provide value to individual stakeholders. Such imbalances in value distribution between stakeholders or over time may lead to stakeholder intransigence and can stymie efforts to transform air traffic management systems. Leverage strategies that correct these imbalances and accelerate the realization of value for all stakeholders can enhance cooperation and increase the likelihood of a successful transition to the new technology. We demonstrate the application of the approach using the case of automatic dependent surveillance-broadcast (ADS-B). The approach is also applicable to a wide range of industries beyond aviation, such as the energy sector and telecommunications.

Keywords: Incentives, value distribution, cost-benefit analysis, aviation

1 Introduction

Air traffic in the United States is expected to double or triple by 2025. This increase in traffic is expected to have many ramifications, including environmental effects, increasing flight delays, and cancellations as traffic approaches the national airspace (NAS) capacity. Several approaches have been developed to increase capacity, such as adding runways and spacing aircraft more closely in en-route or terminal airspace. Other approaches involve changing the way that air traffic management is performed. These approaches often involve some kind of *technology transition*, which may require new hardware or software on the ground or in the air. In this paper we refer to hardware on aircraft, or avionics, as *equipage*. For example, Automatic Dependent Surveillance-Broadcast (ADS-B) technology has been proposed as a key enabling technology for closer aircraft spacing, which allows more aircraft in a given airspace region. The ADS-B system consists of ground stations and equipage and also uses GPS and other satellite services. Successful transition to ADS-B therefore requires that ground stations be deployed across the United States and that a majority of aircraft using the NAS adopt the necessary equipage.

Previous technology transitions in the air transport system have been a mixture of failure and success. Loran (LOng RAnge Navigation) uses land-based radio navigation transmitters to provide airspace users with position and timing information. The FAA was initially not interested but airlines equipped anyway because Loran offered significant immediate benefits. Similarly, airlines rapidly equipped their North Atlantic fleets with new altimeters in order to make use of reduced vertical separation minimum (RVSM). The fleet of aircraft that fly North Atlantic routes is relatively small and dedicated with aircraft generally flying over the Atlantic twice a day. Airlines that equipped were immediately able to fly at more optimal and less congested flight levels and thus realized a rapid return on investment. Conversely, the transition to Controller-Pilot Datalink Communication (CPDLC), though successful in Europe, has been shelved in the United States. The project was over-budget and behind schedule due to inadequate initial resource allocation. In an effort to address these problems, the features of the system were scaled back, resulting in a system with high cost (to airlines) but limited features. Airlines were therefore reluctant to invest and the project had to be shelved.

In this paper we begin by developing a framework for analyzing the value of technology transitions to different aviation stakeholders. It is important to understand the value of equipage to each stakeholder group—the adoption of equipage may be a high value proposition to one stakeholder group but a losing proposition to other stakeholders. Next, we develop an approach to selecting appropriate leverage strategies to encourage aviation stakeholders to participate in such transitions. In particular, we focus on approaches to encouraging aircraft operators to adopt new equipage necessary for technology transitions. We illustrate the use of the approach with an extensive example based on the problem of persuading aircraft operators to install the necessary ADS-B equipment on their aircraft.

The remainder of this paper is organized as follows. Section 2 presents the value analysis framework. Section 3 shows how appropriate leverage strategies can be selected based on value distribution across stakeholders and over time. Section 4 demonstrates the use of the value analysis framework and the leverage selection approach using the case of ADS-B.

2 Value Analysis

In this section we develop an approach to evaluating the costs and benefits of proposed technology transitions to different stakeholder groups. The value analysis is used as a basis for identifying appropriate strategies for transitioning to a new technology, as discussed in Section 3. We define both benefits and costs broadly. Benefits include both those benefits that are quantifiable, such as reduced block times, and those that are not easily quantifiable, such as fulfillment of agency missions. Costs include direct monetary costs as well as indirect costs and unquantifiable costs such as loss of public trust following transition failures. For example, transitioning to a new technology may have environmental as well as the obvious direct (e.g., equipment cost) and indirect financial expenses (e.g., installation downtime).Value is the net benefit, or benefits less costs over the lifetime of the equipage, of adopting.

2.1 Value Distribution

The total value across all stakeholders of a proposed technology transition may be positive, but this does not 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 among stakeholders, as shown in Figure 1. Filled-in circles in the figure indicate that a particular stakeholder derives a particular benefit, or incurs a particular cost. Thus, the first stakeholder (stk_1), derives benefits 1 through m, but incurs no costs. The figure shows a case of value imbalance: the first stakeholder (stk_1) reaps the majority of benefits, and the n^{th} stakeholder (stk_n) bears the majority of the costs. The n^{th} stakeholder may therefore be unwilling to invest in the technology transition. Looking at costs and benefits in this way can reveal imbalances in how they are distributed and help us to identify appropriate leverage studies and effective policies. It is important to perform this type of analysis early in the development process when imbalances can be addressed proactively in order to avoid conflict later in development.

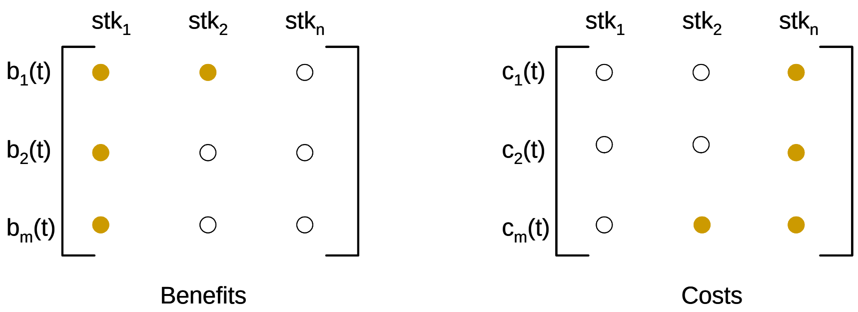


Figure 1: Example cost and benefit distribution across stakeholders

The distribution of costs and benefits can be examined at different levels in order to identify the appropriate strategies at each level. For example, in the case of aviation, the distribution of value between the public, aircraft operators, and aviation agencies can be examined to identify high level strategies for transitioning to the new technology. Looking at value distribution at lower levels (e.g., value distribution among airlines) is useful for developing incentives tailored to specific airlines.

2.2 Phased Value Analysis

When examining the distribution of value across stakeholders, it is not sufficient to merely look at total costs and benefits. It is also necessary to examine how value is distributed over time or implementation phases of a project. In particular, a positive long-term net present value (NPV) is necessary but may not be sufficient to motivate investment by aircraft operators. For example, commercial airline boards typically require a positive return on investment (ROI) within eighteen months of investing.

The value analysis shows how costs and benefits accrue over implementation phases for different stakeholders, as shown in Figure 2 for a single stakeholder. Stakeholders are more likely to cooperate if benefits outweigh costs in each phase as well as over the total lifetime of the technology or project. Thus, for aircraft operators, each phase should show a positive business case [Allen, 1996]. The government follows a similar approach when considering investments of public money. Instead of ROI, government investments are typically judged for how much they contribute to accomplishing stated national and agency goals, and maintaining equity among stakeholders.

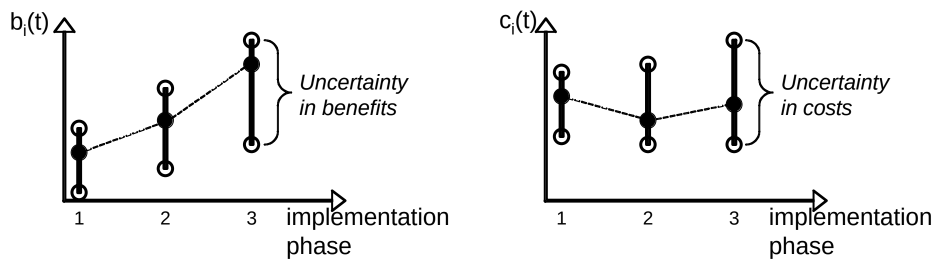


Figure 2: Phased value analysis

Figure 2 illustrates another aspect of the value analysis: uncertainty in costs and benefits. While the nominal case may show a net benefit, uncertainties in costs or benefits can lead to less optimistic results. Uncertainties may be significant for new technologies adoptions. For example, the technology may not perform as expected, or it may cost more than estimated. If the uncertainty in costs (increasing costs) or benefits (decreasing benefits) is large, stakeholders are less likely to invest in a technology. Making a credible case to stakeholders requires that these uncertainties and the risks to cost and benefit realization be clearly identified, highlighted and mitigated.

3 Leverage Strategy to Encourage Technology Transition

The value analysis of a technology transition[1] may reveal imbalances in value distribution across stakeholders or over time. Such imbalances may make stakeholders unwilling to participate in the technology transition. If policy makers determine that the overall value of a transition is compelling and must therefore proceed, it is necessary to find ways to overcome stakeholder reluctance. One way of encouraging cooperation is to reduce or overcome value imbalances so that all stakeholders derive value from a transition. In this section, we develop an approach to selecting appropriate levers to address such value imbalances.

The question of developing appropriate strategies to encourage change in the air transportation industry has been addressed mainly from an environmental perspective. For example, there is a substantial literature on the use of emissions trading to encourage a reduction in aviation emissions [e.g., Carlsson and Hammar, 2002]. Aviation agencies have used a variety of measures to encourage transition to new technologies. For example, phase-outs of stage 2 aircraft is mandated by the FAA. Golaszewski [2003] discusses strategies for aircraft equipage from the point of view of airline investment decisions. However, there is little formal research on the use of incentives and other techniques to encourage transition to new technologies in the air transportation area.

Our focus in this paper is on encouraging equipage adoption by aircraft operators because their reluctance to adopt new equipage is often a limiting factor in technology transitions. The framework is however easily applied to all stakeholder groups.

3.1 Types of Levers

Stakeholders can be expected to be reluctant to invest in new technology if costs are high or if they have a perception that benefits are limited, doubtful, may be delayed, short-lived, or if it is possible to derive benefits without installing equipage (free rider option). Conversely, stakeholders will be more likely to invest in new technology if benefits are rapid, clear, long-lived, and there is no free-rider option.

There are four general approaches to encouraging equipage: (1) proactive infrastructure and standards, processes, and certification development, (2) the features of the technology make it desirable without further action, (3) positive incentives such as discounts and exclusive services, and (4) equipage mandates and punitive approaches such as exclusion from certain airports. Figure 3 shows the value determinants of adopting equipage. The benefits of equipping are determined by the features of the equipage itself and the services offered by the relevant aviation agencies. The costs associated with equipping include the costs of acquiring and installing the equipment and any service fees that are imposed by aviation agencies. We identified the levers by looking at ways of

[1] We assume that the overall value of the technology transition has been determined to be positive.

increasing each source of benefit or decreasing each source of cost. For example, financing and incentive schemes can be used to decrease costs and therefore increase total value. Mandates may include extra service fees for unequipped aircraft and indirectly affect benefits through network effects. The next sections describe in detail how each approach affects the value of equipage.

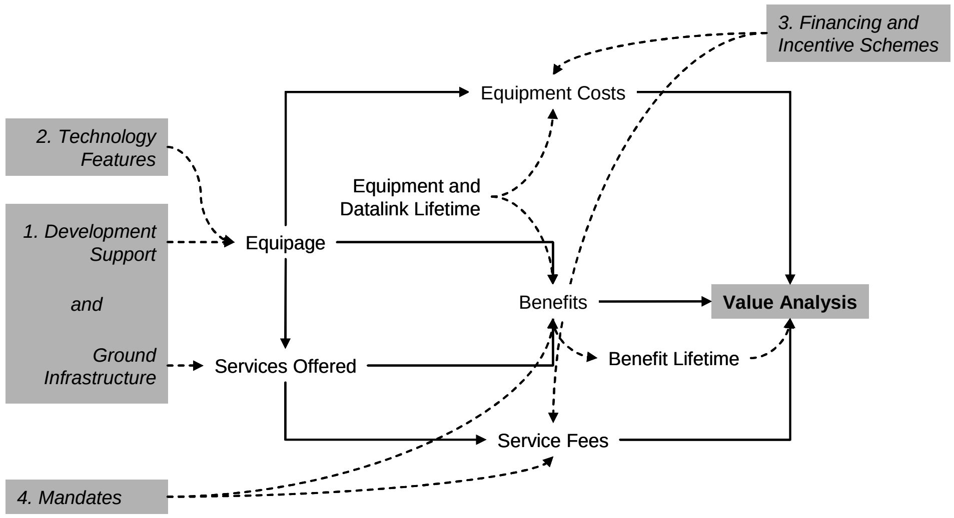


Figure 3: Leverage strategy identification

In general, in cases where the technology does not sell itself equally to all stakeholders, a combination of the other three approaches will be needed. Eurocontrol successfully implemented the *cockpit pilot datalink control* (CPDLC) by a combination of such approaches in the Link 2000+ program [Hughes, 2005]. The agency began by offering financial aid to the first one hundred aircraft that installed the necessary software. Financial aid was coupled with active involvement in the development of the necessary technology and deployment of ground infrastructure. This approach demonstrated the usefulness of the technology to airspace users. Eurocontrol is currently developing a second phase of incentives to ensure sufficient adoption rates by 2009, when CPDLC ground systems are due for deployment across continental Europe. At present Eurocontrol is pushing for a CPDLC mandate coupled with the scheduled continental deployment. Older aircraft will be given a grace period until 2014 before retrofitting is mandated.

Figure 4 illustrates how the four approaches are interrelated. Infrastructure and development support is the basis on which the other three approaches build. Without this support any adoption effort is likely to fail. Consider now each type of lever more closely.

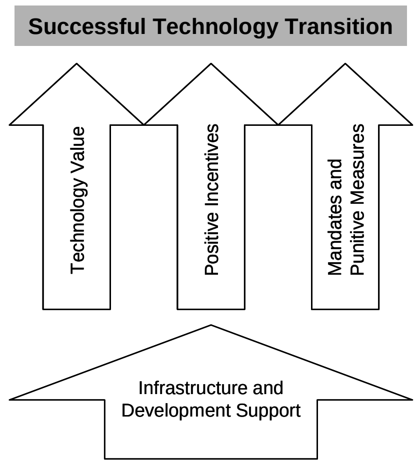


Figure 4: Levers to Encourage Adoption

3.1.1 Infrastructure and Development Support

The first step in ensuring successful equipage adoption is ensuring that the equipage and associated services are available. For example, certification processes for the new equipage should be in place and the necessary ground equipment (e.g., ground stations for ADS-B) must be deployed in a timely manner so that equipped aircraft can start using their new equipage immediately.

Pioneer schemes are a special case of development support. Government agencies may decide to fund initial installations of equipage on a subset of aircraft from one or more commercial airlines or from the general aviation community to facilitate testing and development of equipage and the related air traffic control procedures. This approach enlists aircraft operators as partners in the transition process and can help build stronger ties between aviation stakeholders. For example, under the Capstone program, UPS partnered with the Federal Aviation Agency (FAA) in Alaska to develop and implement ADS-B equipage. Partnerships do not guarantee success however, as evidenced by the cancellation of the CPDLC project despite initial successful collaboration between the FAA and American Airlines.

3.1.2 Persuasive Technology Value

In some cases the technology itself may provide sufficient benefits at low enough costs to make a strong business case to aircraft operators without the need for further incentives or mandates. For example, by installing RVSM compliant altimeters aircraft operators gained immediate access to more efficient and less congested flight levels. In such cases aviation agencies have only to ensure that the necessary ground infrastructure and standards and procedures are in place to allow implementation and use of the equipage.

Stakeholders' perception of the value of a technology transition is partly driven by the functionality of the new technology, which takes three general forms. First, the technology may be necessary for the continuation of an existing service. For example, it may be necessary to install new equipage to interface with the replacements for obsolete ground equipment. In this case, the value of equipping may not be readily apparent to aircraft operators. By refusing to equip, operators may be able to both avoid cost and force aviation agencies to continue maintaining the old equipment. Second, the technology may provide an improvement in an existing service. For example, adding a display unit to existing ADS-B ability allows pilots to monitor air traffic in their vicinity. Third, the technology may provide access to a new service. For example, installing improved altimeters allowed aircraft operators to make use of reduced vertical separation minimum (RVSM) standards and gain use of new flight levels. If we assume equal cost and value distribution for different possible technology transitions, improved or additional services generally provide a more persuasive benefit case.

3.1.3 Positive Incentives

Where equipage does not offer significant technology value alone to a particular stakeholder, incentives can be used to increase the effective value of equipping. Positive incentives can be divided into four general categories. First, service discounts may be offered to aircraft that are equipped with the new equipage. This option would be difficult to implement by the FAA because users are not charged on a per-use basis. Agencies that do charge on a per-use basis may find this option a powerful lever because it directly affects the business case for equipage from the aircraft operator's point of view. Second, equipped aircraft may be granted special access. In the case of the transition to RVSM, aircraft equipped with the necessary altimeters gained access to previously unavailable, and on occasion more optimal, flight levels. Third, the equipage may be used to provide additional service. In the case of ADS-B, the FAA has proposed offering traffic and weather information services free of charge to equipped general aviation aircraft. Finally, financing schemes can be used to postpone, spread, decrease or limit the cost of equipping.

Several approaches to financing have been proposed and summarized in the 2002 aerospace commission report [Walker, 2002]. The most extensive suggestion is that the federal government provide full funding for system-critical airborne equipment. The commission argued that the total cost to the government of fully financing the communication, navigation, and other airborne equipment required for a next-generation ATM network would be less than the costs to the economy arising from system delays and inefficiencies. One lower cost option for the government is to partially fund the initial cost of equipage by vouchers or tax incentives. However, tax incentives are unlikely to be effective when aircraft operators are not making a profit. Another lower cost option is for the government to offer to pay for initial investments with repayment only required if the equipage shows a minimum benefit to the aircraft operator. Finally, auctioned investment credits could be used to motivate initial adoption by a limited number of users and simultaneously use market forces to determine the minimum level of federal support needed.

3.1.4 Mandates and Fees

Mandates are the final approach to obtaining equipage adoption. Mandates can be complete, i.e., unequipped aircraft are not allowed in any controlled airspace, or more selective, requiring equipage for operation in specific airspace classes or for access to specific regions or airports. They can also be applied only to certain classes of aircraft. For example, commercial airlines are required to equip their aircraft with traffic collision and avoidance systems (TCAS) but general aviation aircraft are not. A less extreme approach is to charge a surcharge for unequipped aircraft. Like mandates, this surcharge can be applied selectively to airspace classes, regions or airports, or aircraft classes. This option may be difficult to implement in countries like the United States where the FAA budget is appropriated by Congress. Aviation agencies in other countries (e.g., EU states, Australia) that collect user fees typically have more flexibility with fee and discount structures.

Mandates and rulemaking tend to be slow and must be tailored to the lowest common denominator [Walker, 2002]. When aircraft operators and other aviation stakeholders are resistant to mandates they may lobby to fight or slow the mandate effort. When mandates are enacted, the worst case scenario has aircraft operators and aviation agencies waiting for the other party. When the mandate deadline arrives, there is a rush to deploy ground infrastructure and equip. This process tends to be inefficient and more costly for all parties.

Mandates have been most successful when they are related to safety. Successful safety mandate efforts include ground proximity warning sensors (GPWS), extended ground proximity warning sensors (EGPWS), and traffic collision and avoidance systems (TCAS).

3.2 Leverage Strategy Selection

The appropriate leverage strategies depend on the network effects of how benefits are realized, the relative timing of costs and benefits, the value of the equipage, and the uncertainty in costs and benefits, as shown in Figure 5. The *structure* of the leverage strategy, that is, the appropriate combination of lever types, is determined by the benefit network effects, cost-benefit timing, and cost-benefit uncertainty, as discussed below.

The *extent* of the leverage strategy, that is, how many resources should be expended, or the extent of punitive measures and mandates, is determined by the overall value of the transition to the stakeholder under consideration (e.g., aircraft operator) and to the public. Here the term "public" includes air passengers, the aviation industry, and airport communities, as well as the general public. All else being equal, equipage that offers significant value to aircraft operators is more likely to be adopted without further incentives or mandates than equipage that offers lower value. Thus the required extent of incentives, support and mandates increases as the lifetime value of equipage decreases. The cost of equipage relative to the aircraft in which they are installed is important. Equipage that costs $10,000 may be a negligible investment for commercial airlines but prohibitively expensive for general aviation pilots. Thus general aviation stakeholders may require stronger incentives than commercial airlines. Aircraft operators incur several costs in addition to the cost of the equipment itself when adopting new equipage. These costs include installation, training of pilots and technicians, and the lost revenue as a result of downtime for installation. Equipage that can be installed during minor maintenance checks is more likely to be viewed favorably by aircraft operators. In the extreme case where new equipage offers a significant benefit to the public, but is prohibitively expensive for aircraft operators, the government could choose to fund the cost of equipage to the extent that a positive business case emerges for the operators.

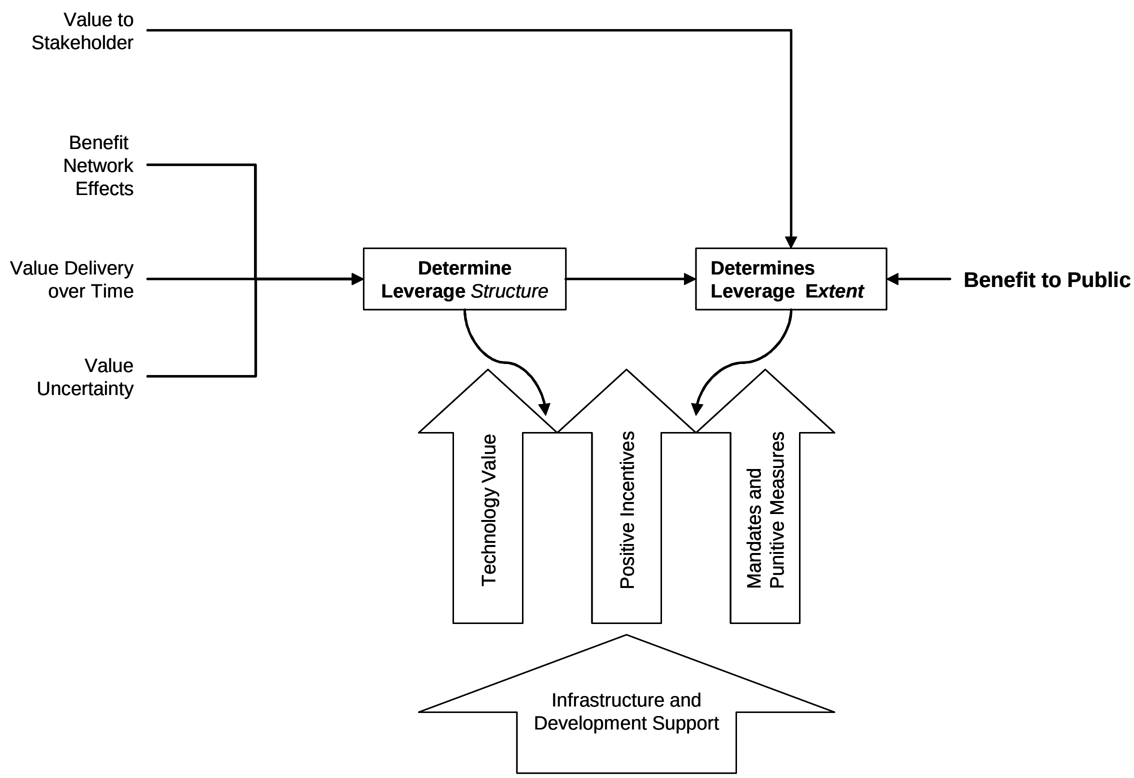


Figure 5: Overall Leverage Strategy Selection

All other factors being equal, uncertain value decreases the attractiveness of equipage, even if the nominal value is significant. That is, the expected value of an investment is lower in the presence of uncertainty than when there is no uncertainty. The appropriate leverage strategy in this case depends on the source of the uncertainty. Uncertainty related to the performance of new technologies can be reduced by allowing the technology to mature further. Allowing the technology to mature further through additional research or increased validation and verification can reduce uncertainty related to the performance of new technologies. The negative effect of cost uncertainty can be reduced by means of financing schemes that buffer aircraft operators against cost increases. This approach of course does not remove the cost uncertainty, but merely shifts it onto the financiers and agencies.

In the next paragraphs we discuss how benefit network effects and value timing determine the appropriate combination of strategies.

3.2.1 Leverage Strategies According to Benefit Network Effects

Benefit network effects refers to how the benefits of equipage to a particular aircraft scale with the number of equipped aircraft or the extent of ground infrastructure. Figure 6 shows representative cases of how individual user benefits scale with the number of equipped aircraft. Note that these scenarios ignore other mechanisms, such as bandwidth congestion, that could lead to a loss of benefits. The ADS-B example discusses this type of situation further.

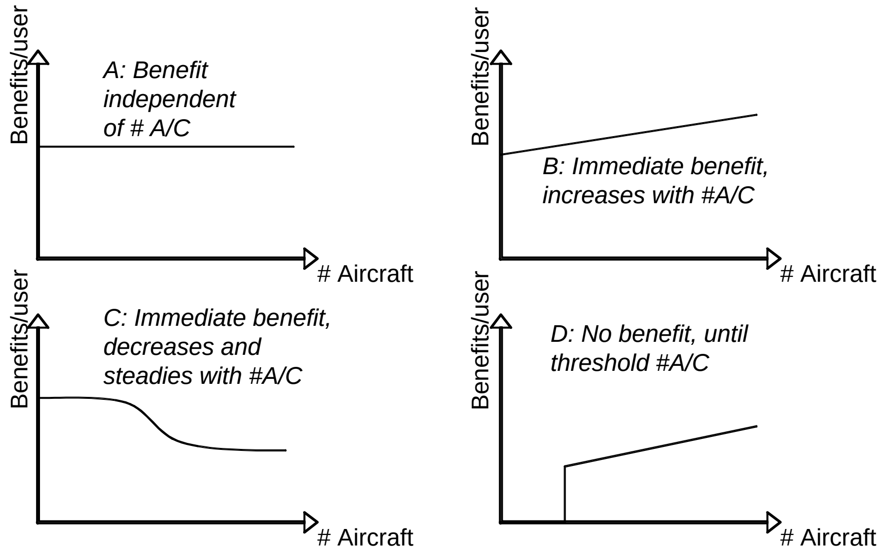


Figure 6: Benefit network effects for an individual aircraft as a function of number of equipped aircraft

The first graph in Figure 6 represents cases where benefits are independent of the number of equipped aircraft. For example, the ADS-B package for general aviation includes weather and traffic information services. Receiving these services does not require that other aircraft be equipped. The second graph represents cases where there is an immediate benefit to an individual equipped user and additional benefits are realized when more aircraft equip. For example, CPDLC allows equipped aircraft to immediately reduce voice traffic. As more aircraft equip, CPDLC will enable improved traffic management leading to an increase in airspace capacity. The third graph represents cases where equipped aircraft have an initial advantage which decreases as more aircraft equip. For example, initial adopters of RVSM equipment gained access to relatively empty flight levels. As more aircraft equip, the flight levels will fill up, thus decreasing the initial advantage. The initial benefit of access to more optimal flight levels remains however. Lastly, the fourth graph represents cases where a threshold equipage level is necessary before benefits can be realized. For example, ADS-B does not offer a significant benefit to “lone” individual commercial airline aircraft because they already have access to weather and traffic information. The benefit of reduced separation only becomes possible when a certain minimum number of aircraft are equipped.

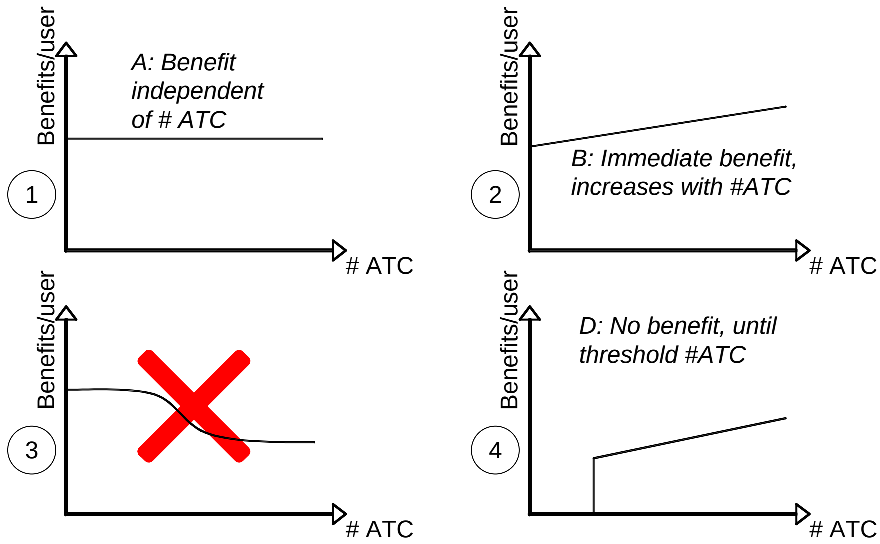


Figure 7: Benefit network effects with number of ground stations

Figure 7 shows representative cases of how benefits scale with the extent of ground infrastructure. The first graph represents cases such as TCAS where ground equipment is not needed. The second graph represents cases where aircraft operators derive an immediate benefit from the equipage and where the installation of ground infrastructure delivers additional benefits. For example, general aviation pilots derive immediate benefit from ADS-B enabled weather and traffic information. This benefit increases as more ground stations are installed. The third case where benefit decreases with number of ground stations is assumed not to occur. Finally, the last graph represents cases where a threshold level of ground infrastructure is required before benefits can be realized. For example, the reduced separation benefits of ADS-B only become possible once at least one ground stations is deployed in a particular aircraft's operating region. Note that as illustrated by the ADS-B example the same system may exhibit different benefit network effects depending on stakeholder perspective.

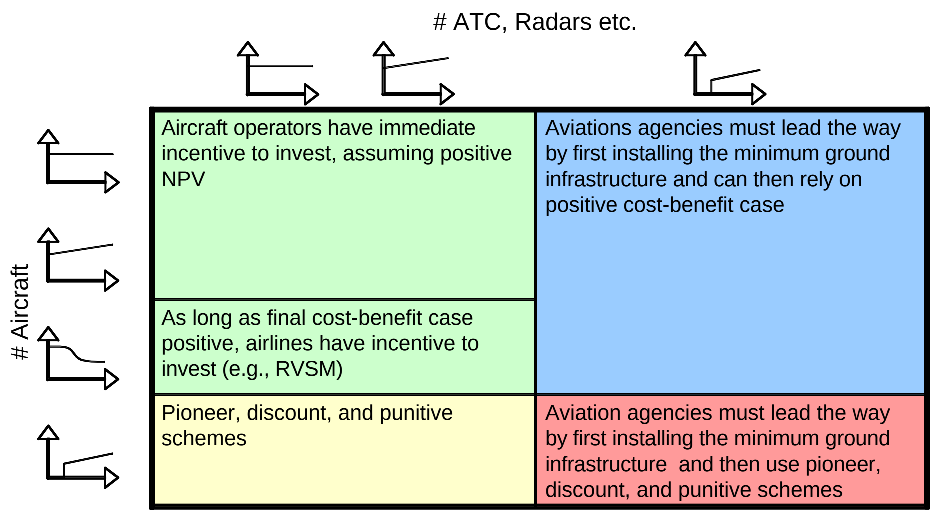


Figure 8: Leverage strategies according to network benefits

Now consider the most appropriate strategies for each possible combination of equipage adoption and ground deployment, as shown in Figure 8. For simplicity we assume that both the short term and lifetime value to the aircraft operators of equipping is positive. The next section shows how value delivery timing affects the determination of appropriate leverage strategies. The first three cases reflect situations when benefits to operators can be realized with minimal or no ground infrastructure. In these cases immediate ground deployment is not essential. In the first case where individual adoptions result in immediate benefits, little action other than ensuring that procedure and equipage certification are in place is required from government agencies. In the second case where benefits deteriorate over time, aircraft operators still have an incentive to equip, assuming that the steady-state benefits still result in a positive cost-benefit case. In the third case where a threshold level of aircraft equipage adoptions is needed, pioneer and incentive schemes can be used to obtain the necessary initial adoption levels. In the fourth and fifth cases, a threshold level of ground infrastructure deployment is needed. Aviation agencies should lead the way by deploying at least the minimum level of ground infrastructure. In the fourth case where operators derive immediate benefit once infrastructure is deployed, operators can be expected to equip on their own given a positive value case. Finally, in the fifth case where a threshold level of aircraft equipage adoptions is also needed, aviation agencies should couple the deployment of ground infrastructure with pioneer schemes and positive incentives.

In each case mandates and other punitive approaches should only be considered once the benefits of the technology have been convincingly demonstrated. It may be possible to obtain the necessary levels of initial equipage without resorting to mandates. In cases where both the need for and the effectiveness of particular equipage has been demonstrated, early mandates may be a way of "leveling the playing field" between competing aircraft operators and obtaining rapid and pervasive equipage adoption. In the longer term, it will usually be necessary to issue forward fit mandates followed by retrofit mandates to ensure that legacy ground systems need not be maintained.

3.2.2 Leverage Strategies According to Value Distribution over Time

The discussion of strategies according to benefit network effects assumed that the equipage delivered both short and long term value. Consider now the effect of the timing of equipage value delivery. Figure 9 illustrates a notional case of costs and benefits over time. 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. The short-term NPV can be increased by delaying costs or accelerating benefits. Costs can be delayed by means of financial tools (see Section 3.1.3) such as tax incentives and vouchers. Benefit realization can be accelerated by rapidly deploying ground equipment and by ensuring that the necessary procedures and certifications are in place. Coordinating adoption across aircraft operators can result in quicker benefit realization where there are strong network effects such as at airports where commercial airline traffic accounts for the vast majority of operations.

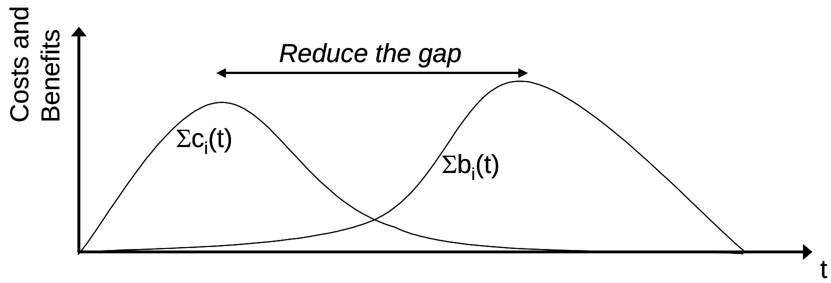
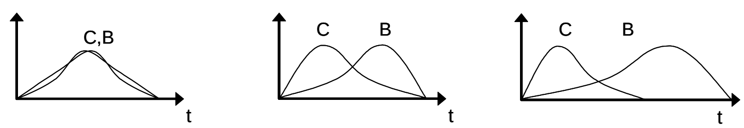


Figure 9: Relative timing of costs and benefits

Figure 10 illustrates the appropriate leverage strategies for three general cases of value delivery over time. We assume that the long-term value of equipping to aircraft operators is positive. In the first case costs and benefits coincide, or benefits are realized rapidly. This scenario occurs when individual adoptions provide immediate benefits. For example, the traffic and weather information services bundled with ADS-B for general aviation users are intended to be immediately available on installation of the necessary equipage. Similarly, aircraft that equipped for RVSM were immediately able to make use of new flight levels in certain air sectors. In the case where benefits are significant relative to cost, aircraft operators should have sufficient incentive to invest without the need for additional schemes. When benefits are immediately realized but are significantly smaller than costs over the short term, additional incentives such as service discounts or financing schemes may be needed.



Timing	Costs and benefits coincide	Costs precede benefits	Long delay to benefits
Scenario Examples	Individual adoptions provide benefits.	Benefits realised only when other A/C equipped. Delays in ground infrastructure deployment.	Benefits realised only when *many* other A/C equipped. Long delays to ground infrastructure deployment.
Strategies	Significant benefits realised concurrently with costs provides incentive to airlines to invest. When short-term benefits are smaller than costs positive incentives may be needed to improve the value case.	May be possible to make ROI cases based on operational benefits of technology without resorting to positive incentives such as discounts and financing schemes.	Pioneer schemes, positive incentives, and mandates. Strong incentives and aid schemes in addition to technology benefit are needed to mitigate the slow ROI.
Comments	Great situation, but rarely occurs.	More realistic scenario.	When benefits take this long to realise it may be a signal that the technology is not appropriate.

Figure 10: Leverage strategies according to value delivery over time

In the second case costs precede benefits but benefits are still realized in the medium term[2]. This scenario can occur when there are benefit network effects or when there is a delay in ground infrastructure deployment relative to aircraft equipage adoption. When initial benefits are low,

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[2] The definition of 'medium' and 'long' term is somewhat subjective. The principal difference between the medium and long term cases is the extent of leverage necessary.

financial incentive schemes may be necessary to overcome the short-term negative value of equipping. When the delay in benefit realization is due to a projected delay in ground infrastructure deployment, accelerating the deployment should also be evaluated (e.g., practicality, cost) as a way of improving value delivery over time

In the third case, there is a long delay on the order of years before benefits are realized. This scenario occurs when there are strong network benefit effects or when there is a long delay to the necessary ground infrastructure deployment. For example, ADS-B does not offer a significant benefit to commercial airlines unless a majority of aircraft flying in a particular region is equipped. However, when benefits take this long to be realized aggressive strategies are needed to delay costs or accelerate benefit realization. Pioneer schemes should be used to demonstrate value and to gain a foothold in the aviation community. Aggressive positive incentives may be needed to delay or offset costs and encourage initial adoption so that benefit network effects become significant. Region-selective mandates coupled with aggressive ground infrastructure deployment can be used to simultaneously force and encourage adoption. When benefits take this long to be realized it may also be an indication that the equipage is not the most appropriate solution or that additional applications for the equipage should be considered.

As an aside, note that the mix of aircraft ages in an operator's fleet may affect the operator's willingness to cooperate with adopting new equipage. If the fleet is composed largely of old aircraft the operator may be reluctant to equip. In such cases equipage mandates can be selectively applied based on aircraft age or time to retirement. Mandating equipage on new aircraft is likely to be less contentious as forward fitting is cheaper than retrofitting and allows aircraft operators to avoid costly downtimes for equipage installation. Operators with a mixed fleet of older and newer aircraft present the most challenging problem. In this case relying solely on forward fit is infeasible. Since aircraft service lifetimes in the United States are currently about thirty years, it can decades for the entire fleet to turn over. Maintaining both old and new systems in this case (e.g., radar and ADS-B) may be excessively costly for the aviation agency. Selective retrofitting of newer aircraft therefore becomes essential to program success. The threshold aircraft age for retrofitting is determined by the desired date at which the transition to the new technology is to be complete.

4 ADS-B Value and Leverage Strategy Analysis

ADS-B adoption in the United States has not proceeded at the pace initially hoped for by the FAA. We show using the value analysis approach developed in Section 2 that the reluctance of aircraft operators can be explained in terms of value imbalances. Next, we use the leverage strategy selection framework developed in Section 3 to develop a strategy for encouraging adoption of ADS-B by both commercial airlines and general aviation operators.

4.1 Overview of Automatic Dependent Surveillance-Broadcast (ADS-B)

ADS-B is a system for monitoring and transmitting an aircraft's identification, position, altitude, airspeed and intent (whether the aircraft is turning, climbing or descending) to air traffic controllers and to other aircraft. The system uses global positioning satellites (GPS) to determine aircraft position, and ground stations or satellites to transmit this information to air traffic control centers or other aircraft.

ADS-B offers safety and performance benefits because aircraft position and other dynamic data can be determined more accurately and more frequently than with current radar systems. In en-route and approach traffic the more accurate and timely ADS-B data allows air traffic controllers to space aircraft more closely and thus increase airspace capacity. Currently uncertainty about aircraft positions results in separations far greater than the minimum permitted separation, thus decreasing airspace capacity. In the future, if safety concerns are resolved, aircraft may also be able to ‘self-separate’ using cockpit displays of ADS-B traffic information. Self-separation decreases controller workload and also increases airspace capacity by allowing decreased spacing between aircraft. During final approach, ADS-B can enable more closely spaced parallel approaches and enhanced visual approaches. The eventual goal is to allow visual meteorological conditions (VMC) like approaches even in adverse weather conditions that would otherwise require instrument meteorological conditions (IMC) approaches. These features will increase the capacity of ADS-B equipped airports. Lastly, ADS-B can also be used on airport surfaces to improve traffic management and reduce runway incursions.

4.1.1 ADS-B System Architecture

The ADS-B system consists of ground stations and on-board equipage and also uses GPS and other satellite services, as shown in Figure 11. Aircraft position and dynamics data are obtained from GPS and on-board instruments, respectively. These data are transmitted to air traffic control ground stations or communications satellites or directly to other ADS-B equipped aircraft. This capability is referred to as *ADS-B out*. Communications satellites are proposed for use in regions that are not equipped with ground stations, such as oceanic and sparsely populated regions. Aircraft that are equipped with display units such as a cockpit display of traffic information (CDTI) unit or an electronic flight bag (EFB) can display ADS-B data from other aircraft as well as traffic information services (TIS-B) and flight information services (FIS-B) from air traffic control centers. This capability is referred to as *ADS-B in*.

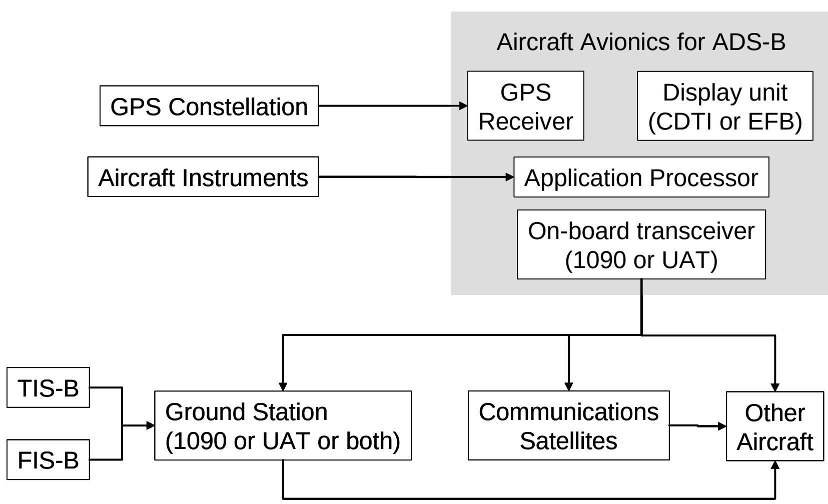

Figure 11: ADS-B system block diagram

ADS-B ground stations are expected to cost about one third as much as the radar stations currently used to track aircraft. Maintenance for these stations is also expected to be cheaper because unlike the rotating radar ground stations ADS-B ground stations do not require moving parts.

4.1.2 ADS-B Datalink Selection

One important and somewhat contentious aspect of ADS-B is the link configuration that is used to transmit ADS-B data. Several link configurations are under consideration for ADS-B. In the United

States the 1090 MHz Mode-S extended squitter has been selected as the standard for commercial aircraft. This link configuration can be used by modifying existing Mode-S transmitters. These transmitters are required on all commercial aircraft for use in the traffic collision avoidance system (TCAS). In order to ensure compatibility, Eurocontrol has also selected this link configuration. There are concerns however that this link will become congested in high-traffic areas in the next ten years [Evans, 2004]. This period is well within the lifetime of many in-service aircraft. However, there do not appear to be any precise estimates of when this congestion will occur. This lack of certainty about the future performance of the selected datalink is one of the problems in constructing a cost-benefit case for ADS-B (see section 4.2.3).

A second data link, which uses the relatively inexpensive Universal Access Transceiver (UAT), has been selected for private and non-commercial aviation in the United States. This link has been implemented by UPS Aviation Technologies and installed on up to 200 aircraft as part of the successful FAA Capstone ADS-B demonstration program in Alaska. Included in this link definition is the option to transmit traffic and flight information services such as weather data. This type of information is currently not available on most general aviation aircraft and is an added benefit for adopting ADS-B.

A third link configuration, VHF Datalink (VDL) Mode 4 is being proposed by Swedish and Russian authorities but is currently not supported by the FAA or Eurocontrol. VDL Mode 4 has been proposed as a replacement for 1090 MHz Mode-S when this datalink becomes congested. But while 1090 MHz Mode-S and UAT operate in a similar frequency range and can therefore use the same antenna, VLD Mode 4 operates in a different frequency range and converting would therefore require the addition of a new antenna in addition to other equipage upgrades.

The different link standards are not compatible. Aircraft using different standards cannot communicate directly with each other and ground stations required dual/triple capability to interface with aircraft of each type. Some manufacturers are making two-media (UAT/1090) units to allow aircraft to communicate using either or both bands.

4.2 ADS-B Stakeholder and Value Analysis

Table 1 summarizes the high level United States aviation industry stakeholders and their needs (with input from [Carlock and Decker, 1998]).

Table 1: ADS-B Stakeholders

Stakeholder	Needs
Public	Affordable transportation Convenient flight times Few delays Safety Comfort
Commercial Airlines	Collaborative decision-making and information sharing Flexible routing Predictable scheduling Increased capacity at lower cost
General Aviation	Low-cost services Low-cost equipage Minimum restrictions
Military	No changes that result in high retrofit costs Positive control of special-use airspace

Stakeholder	Needs
Airports	Sufficient capacity to serve surrounding communities and aircraft operators
Airport Communities	Reduced noise and emissions
Equipage and Airframe Manufacturers	FAA strategic acquisition planning information Faster certification of new equipage and technologies Increased sales of products
Domestic Aviation Agencies	Safe and efficient work environments by regulatory side Productivity enhancing tools by service delivery side
International Aviation Agencies	Compatible standards, international cooperation

Ideally, the overriding concern with any technology transition is to bring value to the majority of stakeholders. In aviation, it is also required that technology transitions do not compromise safety. The values, needs and constraints of all stakeholders must be considered when designing and implementing any such efforts. We therefore begin the value analysis by looking at the value of ADS-B to the major stakeholders. Next, we focus on ways of obtaining the cooperation of commercial airlines and general aviation stakeholder groups in technology transition efforts.

4.2.1 ADS-B Value to Public

ADS-B is one of a number of programs aimed at improving airport and airspace capacity as well as safety. Strong arguments have been made that growth in commercial air transportation is not merely correlated with economic growth but may actually enable a significant proportion of economic growth [e.g., NASA/FAA, 2003]. If these arguments are valid, then any technology that increases airspace capacity has the potential to encourage economic growth, provided that transition costs do not exceed overall benefits. ADS-B therefore provides benefit to the public if it provides the anticipated increase in capacity and if it shows overall positive value. The relative effectiveness and efficiency of ADS-B, as opposed to other approaches, in increasing airspace capacity and safety must also be determined. These questions can be answered by technical modeling and financial analysis.

4.2.2 ADS-B Value to Aviation Agencies

ADS-B offers two main types of benefits to aviation agencies. First, by potentially increasing safety, airspace capacity, and airspace traffic monitoring coverage it helps aviation agencies to fulfill their missions to enable safe and efficient use of their respective airspaces. Second, it allows aviation agencies to avoid some of the substantial costs of operating and maintaining radar monitoring of air traffic. A smaller and more unclear benefit is potential staff savings resulting from decreased controller workload.

Table 2: ADS-B benefits to aviation agencies

Value Category	
Safety benefits	Reduced mid-air collisions Reduced runway incursions
Performance benefits	Increased airspace and airport capacity Tracking outside radar coverage
Avoided costs	Radar purchase and maintenance Navaid replacement and maintenance
Improved air traffic	Marginal staff savings

control efficiency	

The value of ADS-B to the FAA has been quantified to some extent. Figure 12 shows one estimate of the total cost that the FAA can potentially avoid by transitioning to ADS-B under the current spiral development plan [Fontaine, 2005]. The first peak in the graph represents cost savings from not replacing ageing radar ground stations. The steady-state cost savings result from decreased maintenance costs and improved controller productivity, assuming that ADS-B is successfully mandated in all airspace classes by 2019.

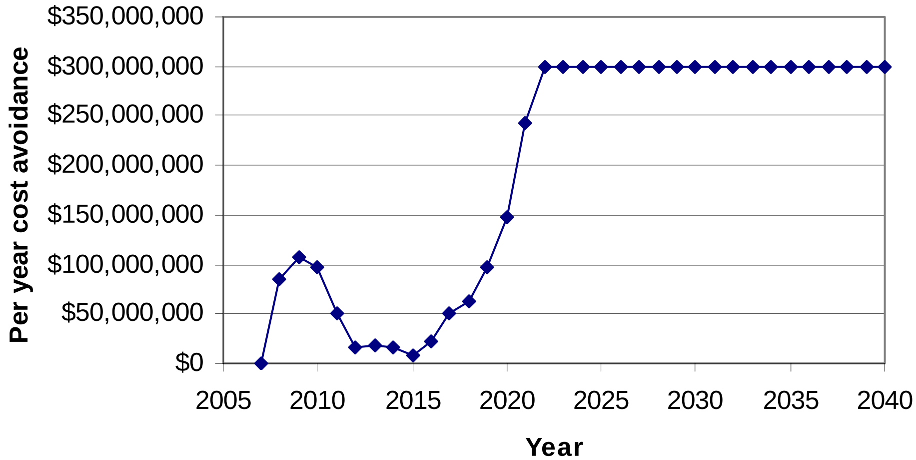

Figure 12: FAA total avoided cost per year

Lower than assumed equipage rates could significantly alter the value of ADS-B to the FAA (and to aircraft operators, see next section). For example, if equipage is not mandated and aircraft operators are slow to equip it will be necessary to maintain radar ground stations. The cost of maintaining old systems is highly dependent on how rapidly ADS-B is adopted and must be taken into account when considering different adoption strategies. For example, relying on adoption through forward-fit only will result in a long transition period and therefore high transition costs. The total cost of maintaining these stations as well as new ADS-B ground stations may drive the value of ADS-B down dramatically. Before further action is taken on ADS-B, the sensitivity of costs and benefits to different adoption percentages should be calculated.

In the ideal scenario where ADS-B is adopted by a significant proportion of aircraft operators, transitioning to ADS-B offers significant cost savings to the FAA. Consider now how ADS-B appears from aircraft operators' perspectives.

4.2.3 ADS-B Value to Commercial Airlines

The transition to ADS-B will not be successful if ADS-B is not installed on a significant proportion of commercial airliners. It is therefore necessary to understand what shapes airlines' perception of the benefits and costs of ADS-B. Airlines will be reluctant to invest in equipage in general and ADS-B in particular if they perceive the investment as having low or negative value. The primary benefit to commercial aviation of equipping with ADS-B is the potential for reduced delays in en-route and terminal airspace. Reduced delays result in fuel savings and make faster turnarounds possible, thus allowing improved aircraft utilization rates. The realization of this benefit relies on extensive equipage adoption among airlines (i.e., strong benefit network effects) but few airlines in the United States are ADS-B equipped at present. ADS-B therefore offers little value except in cases where an airline is a heavy user of an ADS-B equipped hub and can gain value from reduced separation between its own aircraft and improved management of surface traffic. ADS-B is viewed more favorably in areas where radar coverage is not available. For example, Australia is implementing ADS-B coverage across the vast interior where there is currently no radar coverage. In cases like this airlines have a clear incentive to invest.

As discussed in section 3.2, airlines are less likely to invest when benefits or costs are uncertain. Currently available data on the costs and benefits of ADS-B in United States airspace to commercial airlines is ambiguous and does not make a clear business case for investing. While the benefit to the FAA is clear, the benefit to airlines is much less certain. Obtaining commercial aviation cooperation in the transition effort requires first that clear data on the costs and benefits of ADS-B be provided. In particular, the problem of 1090 MHz Mode-S datalink congestion within the next ten to fifteen years must be studied and potential solutions must be developed. Datalink congestion will limit the benefit lifetime and therefore shift the value of investing down.

Aviation agencies across the world have performed extensive analyses of the costs to aircraft operators of equipping. See, for example, [Mitre, 2005] and [Fontaine, 2005]. Determining future costs is part art, part science. Many assumptions must be made to work around uncertainties. For example, the future costs of equipage may drop dramatically as economies of scale are realized. Labor and downtime costs are also volatile. Cost estimates from different agencies and groups therefore tend to differ. For example, the FAA and Eurocontrol cost studies provide different figures; Yablonski Rurup et al. [2002] provide a useful discussion of these different approaches and the different underlying assumptions.

There is little quantified data publicly available on the value of ADS-B benefits to individual airlines, or on the value of equipping a single aircraft. Publicly available FAA studies indicate substantial benefits to the US airline industry as a whole [Fontaine, 2005]. While these kinds of studies do seem to indicate that there is a strong case for airlines to invest, they do not provide sufficient resolution for individual airlines to make adoption decisions. The paucity of clearly derived and publicly available data on the monetary value of benefits to airlines illustrates the uncertainty surrounding ADS-B.

In summary, though we do not have access to sufficient data on ADS-B, it is clear that for commercial airlines ADS-B shows strong benefit network effects relative to adoptions because substantial adoption is required for delay reductions to become financially significant. Benefit network effects relative to ground infrastructure are also quite significant because commercial airlines tend to have large operating areas and benefits are therefore dependent on multiple ground station deployments. In addition, because of the strong benefit network effects and because current adoption rates are slow, airlines face a long delay between costs and benefits. For the FAA, the primary benefit derives from cost reduction from operating fewer radars. In the next section we discuss the appropriate leverage strategies for this situation.

4.2.4 ADS-B Value to General Aviation

In contrast to commercial aviation, the primary benefit of ADS-B to general aviation users is improved safety through weather and traffic information services provided to equipped aircraft. While the general aviation community views this benefit positively, it is concerned about the costs of equipping and about the possibility of equipage mandates in the short term[3]. Another concern is the possibility that business jets may have to equip with both 1090 and UAT equipage because they fly at high altitudes with commercial airlines and also into non-radar airfields with general aviation. They may therefore have to expend double the equipage cost.

General aviation equipage costs per aircraft are substantially lower than those for commercial aviation. See, for example [Mitre, 2005] and [Fontaine, 2005]. Nevertheless, the costs may still be prohibitively high for many general aviation operators. To address this problem, the Australian air traffic operator has convinced commercial airlines to pay the cost of equipping the general aviation fleet in Australia [Evans, 2004].

The safety benefits to general aviation are clear and recognized by the general aviation community. Because the safety benefits are immediately realized on individual adoptions, they have negligible network effects relative to the number of adoptions and there is little delay between costs and benefit realization. Benefit network effects relative to ground infrastructure deployment are also weak because general aviation operators tend to have small ranges centered about one or two airports. Benefits can therefore be immediately realized on equipage provided there is at least one ground station in a particular operator's operating area. The primary challenge with general aviation is overcoming the equipage cost obstacle. In the next section we discuss the appropriate leverage strategies for this situation.

4.2.5 ADS-B Value Distribution Summary

Figure 13 illustrates the notional value distribution of ADS-B benefits across key stakeholders. Benefits are not mutually exclusive. For example, increased capacity can be seen as a result of delay reduction, or vice versa. Aviation agencies stand to reap significant benefits from ADS-B, as indicated by the dashed oval in the figure. Both commercial airlines and general aviation can also reap significant benefits from ADS-B. However, the costs and uncertainties associated with these benefits, and, in the case of commercial aviation, the delay to full benefit realization, make ADS-B a less attractive investment opportunity.

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[3] See, for example, AOPA's stand on ADS-B.

[http://avweb.com/cgi-bin/udt/im.display.printable?client.id=avflash&story.id=191022]

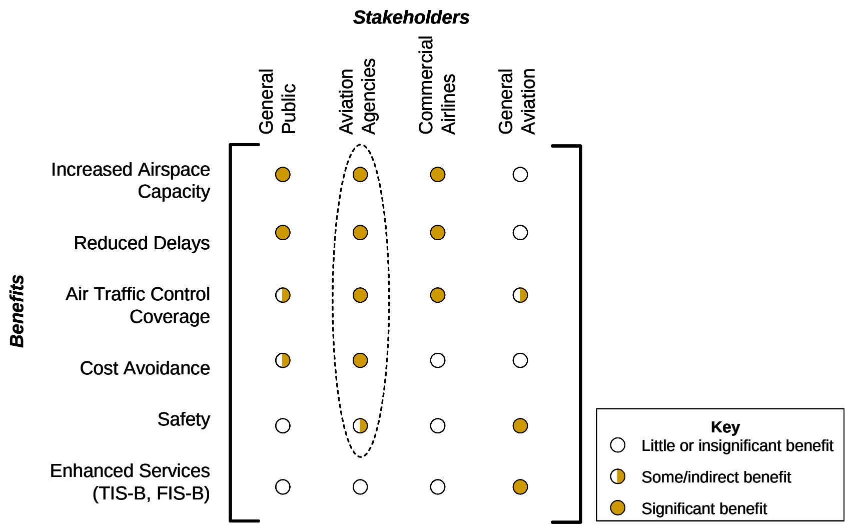

Figure 13: ADS-B benefit distribution across key stakeholders

Figure 14 illustrates the notional distribution of costs across key stakeholders. Costs are relative to each stakeholder. For example, $5000 for equipage may be relatively cheap for a commercial airliner but prohibitively expensive for a general aviation operator. The cost to the public is indirectly realized through airline fares to recover general and federal taxes on airline tickets. Both commercial airlines and general aviation operators must make relatively significant investments in order to use ADS-B, as indicated by the dashed oval in the figure. In contrast, the investment required from aviation agencies, and by extension the public, is much smaller.

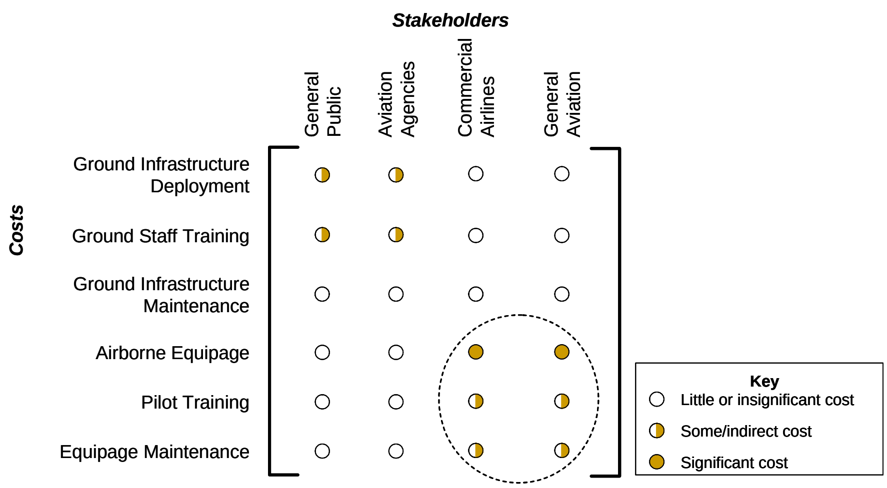

Figure 14: ADS-B cost distribution across key stakeholders

Figure 15 illustrates some of the notional benefits over time for key stakeholders. Benefits are not to scale in the figure—our intent is to show the relative timing of benefits and costs (see Figure 16). For aviation agencies and the public, the first benefit to be realized is cost avoidance arising from deferred or cancelled radar station replacements. The benefits associated with increased capacity, reduced delays, and improved air traffic control coverage accrue to the public, aviation agencies, and commercial airlines, but take longer to realize. General aviation operators reap near immediate safety and improved services (TIS-B and FIS-B) benefits.

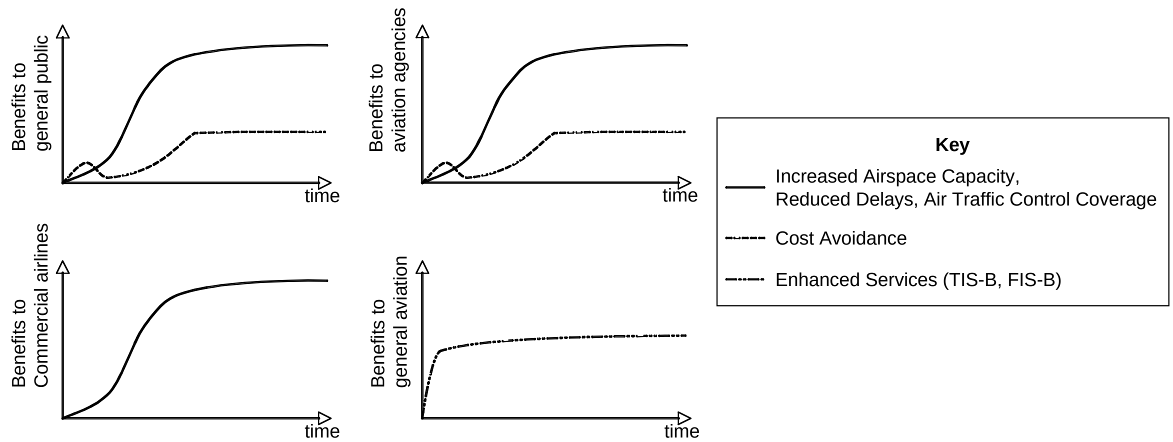

Figure 15: ADS-B benefits over time

Figure 16 illustrates the notional costs over time for key stakeholders. Again, costs are notional and not to scale. Aviation agencies and the public by extension must make initial investment in ADS-B ground infrastructure deployment and training. These costs are more than subsumed by the cost savings resulting from deferred or cancelled radar installations. The public may also bear some of the cost of ADS-B through increased air fares. As mentioned previously, commercial airlines and general aviation operators must make significant upfront investments in equipage. For both ground and airborne equipment, maintenance costs will persist throughout the lifetime of the system. Maintenance costs for ADS-B ground stations are however expected to be significantly lower than those for the FAA's radar systems.

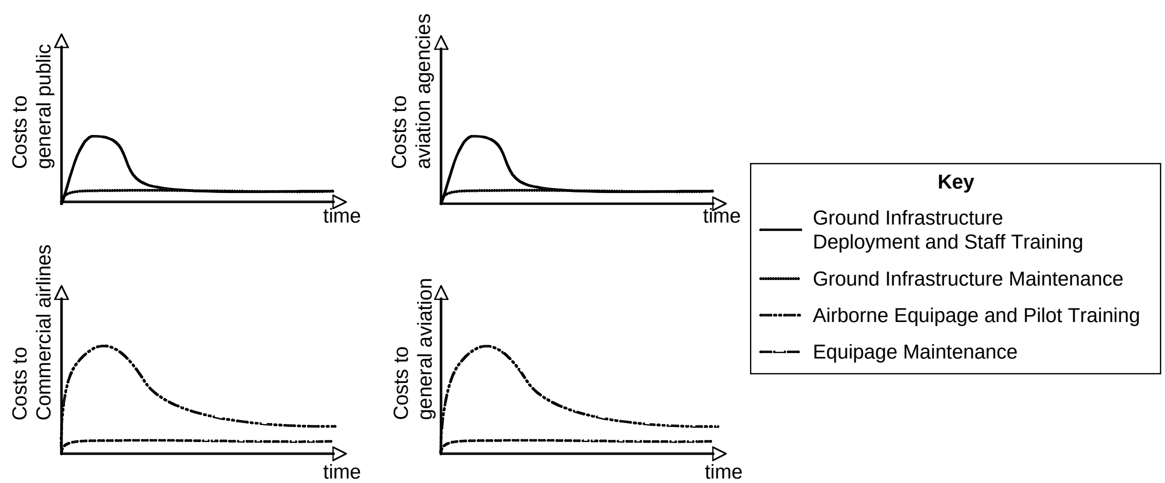

Figure 16: ADS-B relative costs over time

4.3 ADS-B Leverage Strategy Selection

Internationally ADS-B appears to be moving forward. Commercial airlines are equipping to make use of ADS-B stations in European and Australian airspace. General aviation stakeholders are enthusiastic about the safety benefits of ADS-B but are reluctant to endorse ADS-B strongly because of fear of user fees or exclusion from certain airports or airspace regions and the cost of equipping. Commercial airlines are reluctant because a lack of data means there is still no clear business case. The value analysis in the preceding section has shown that there are significant imbalances in the distribution of costs and benefits across stakeholders and over time. In particular, there is uncertainty about the value of adopting ADS-B and the potential for the 1090 Mode-S datalink to become congested and unusable in the near future. This section shows how these imbalances can be reduced or circumvented by means of appropriate strategies.

4.3.1 Commercial Aviation

Commercial airlines derive ADS-B benefits primarily from the increase in airspace and airport capacity. To derive these benefits a threshold level of ground infrastructure deployment and equipage adoption is required. The appropriate strategies in this case include proactive ground infrastructure deployment, pioneer schemes to obtain an initial foothold, financing schemes to offset and delay initial costs and eventually mandates reap maximum benefit from benefit network effects.

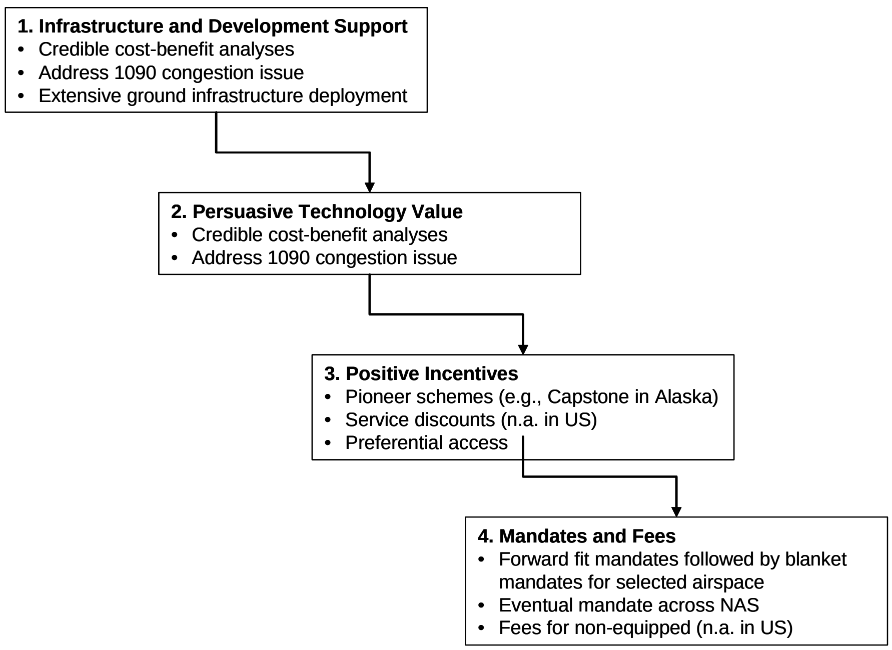

Figure 17: Commercial aviation ADS-B Strategy

Figure 17 illustrates the derived strategy for encouraging ADS-B adoption by commercial airlines. The first step is to provide development support and ground infrastructure deployment. Aviation agencies can increase airline certainty of benefits by installing ground stations at major airports. In particular, it is necessary to address the uncertainty surrounding benefits of ADS-B and in particular the potential 1090 MHz Mode-S congestion problem.

The second step is to determine whether ADS-B offers persuasive value to airlines. Credible cost-benefit analyses that are linked to specific aircraft types, routes, equipage options (ADS-B out vs. ADS-B in), and that take the potential for datalink congestion into account are required for considering investment decisions. The benefits of ADS-B can be increased by adding additional applications. For example, runway incursions (RIs) are a significant and growing problem at airports. ADS-B can be used to address this problem if ground vehicles are also equipped with ADS-B.

The third step involves developing positive incentives for equipping. Pioneer schemes such as the Capstone program in Alaska have shown initial success. While the FAA financing structure makes discounts for equipped aircraft impossible, other positive incentives such as preferential access to airports and airspace for equipped aircraft can be considered. Such incentives may be controversial however.

Finally, mandates must be implemented to ensure that the transition is complete and that operators who have equipped realize the full benefits of ADS-B. Because forward fit costs are significantly lower, the least contentious approach is to begin with forward fit mandates. Next, regional and airport specific mandates should be implemented. Retrofit mandates are the final step in the transition. In each appropriate deployment of ground infrastructure is essential to ensure airlines can derive benefit from their equipage. The optimal timing of mandates depends on a number of factors including current fleet age mixes, ground equipment time to obsolescence, and the scaling of benefits with adoption levels. We leave the determination of optimal mandate timing for future work.

4.3.2 General Aviation

General aviation operators and private pilots derive benefits primarily from the safety aspects of ADS-B. Unlike commercial aviation, general aviation operators should have an immediate incentive to invest because significant safety benefits which are relatively independent of benefit network effects are realized immediately upon installation. However, the high cost of equipping relative to average aircraft value is a limiting factor. In addition, fears about user fees (which are easier to impose on ADS-B equipped aircraft) and exclusion from certain airports or airspace regions make general aviation operators cautious about supporting ADS-B.

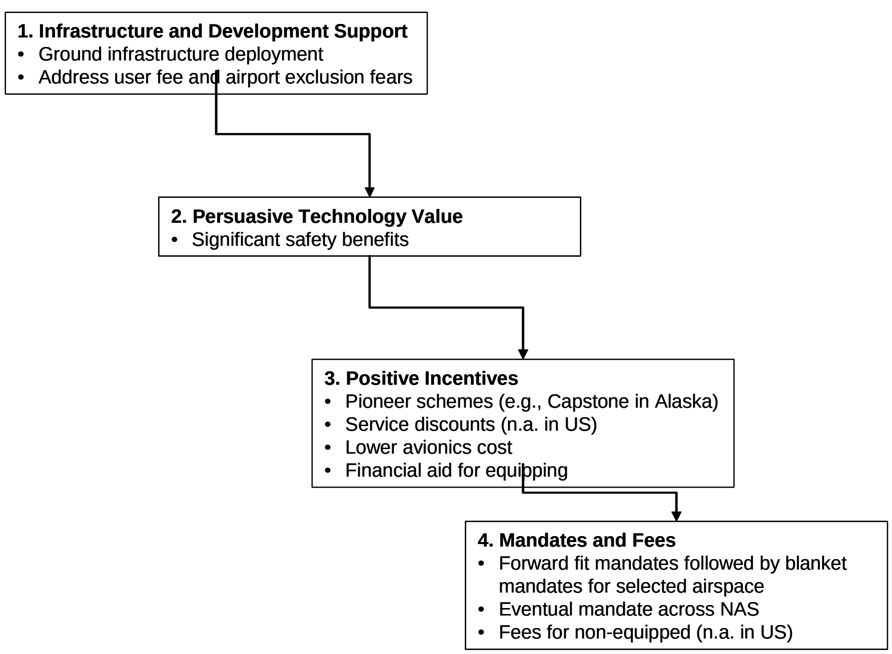

Figure 18: General aviation ADS-B Strategy

Figure 17 illustrates the derived strategy for encouraging ADS-B adoption by general aviation operators. As with commercial airlines, the first step is to provide development support and ground infrastructure deployment. General aviation fears of user fees and of exclusion from airports must be addressed explicitly. While these questions remain unanswered general aviation stakeholder groups such as AOPA may be expected to dissuade their members from equipping. The second step, demonstrating persuasive technology values, is satisfied by the safety benefits offered by ADS-B.

The high relative cost of equipping can be addressed in several ways. First, progress in the technology and competition between manufacturers have already decreased the cost of equipage to about $7800 today [Wood, 2005]. Economies of scale may also result in a further decrease in cost. Second, the FAA could partially or completely subsidies the cost of equipage. This approach is being advocated in Australia where commercial airlines have been persuaded to subsidies general aviation operators' equipage through service fees [Evans, 2004]. Partial subsidies should also be considered.

The final step, mandates, must be carefully managed. As discussed above, general aviation fears of exclusion from airports must be addressed. For example, mandating ADS-B at a given airport may be less contentious if a nearby airport does not have such a mandate. It may be necessary to maintain some radar coverage at selected airports and as a safety backup.

5 Conclusions

We have proposed an approach to developing appropriate strategies to persuade stakeholders to participate in technology transitions. By analyzing stakeholder values, the distribution of equipage value (costs and benefits) across stakeholders, and the distribution of value over time, appropriate strategies can be determined. Technologies that may show an overall positive value can nevertheless not provide value to individual stakeholders. Such imbalances in value distribution lead to stakeholder intransigence and can stymie efforts to transform systems. Leverage strategies that correct these imbalances and accelerate the realization of value for all stakeholders can enhance cooperation and increase the likelihood of a successful transition to the new technology. We showed how value distribution across stakeholders and over time can be used to determine appropriate policy strategies. We illustrated the use of the approach in the case of ADS-B adoption. The approach is also applicable to a wide range of industries beyond aviation, such as the energy sector and telecommunications.

6 Acknowledgements

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